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# Word knowledge and lexical access in monolingual and bilingual migrant children: Impact of word properties

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## ABSTRACT

Word knowledge and the speed of word processing in monolingual children and adults are influenced by word properties, such as the age of acquisition (AoA), imageability, and frequency. Understanding how different properties of words contribute to the ease of processing by bilingual children is a critical step for establishing models of childhood bilingualism. However, a joint impact of these properties has not been so far assessed in bilingual children. Here, we compared the impact of AoA, imageability, and frequency on accuracy and response times in picture naming and picture recognition tasks in monolingual and bilingual children. We used Cross-Linguistic Lexical Tasks to test 45 monolingual children (aged 4 to 7 years) and 45 migrant bilingual children in their L1 (Polish). Word AoA, imageability, and frequency independently affected the accuracy and response times in both picture naming and picture recognition tasks. Crucially, bilingual children were more sensitive to word characteristics than their monolingual peers: Bilingual children's accuracy was particularly low for words of high AoA (in the picture recognition task) and for words of low frequency (in the picture naming task). Also, the increase in response times for low-imageable and low-frequent words was particularly salient in bilingual children. The results suggest a new area of interest for further studies: the question of whether bilinguals and monolinguals show different sensitivity to psycholinguistic factors, and if so, does that sensitivity change with age or language exposure?

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## 1. Introduction

At the age of 5, children from various language backgrounds are more likely to know the word for a ball than they are to know the word for a nutcracker. Some words are easier to learn than others, and the easiness or difficulty of processing a word largely depends on its properties, such as the age at which the word is typically learned (age of acquisition, AoA; Carroll & White 1973a), its ability to evoke a mental image in the speaker's mind (imageability; McDonough et al. 2011), or its frequency in linguistic input (Groot & Keijzer 2000). The present study focuses on processing rather than learning of words and examines how these properties impact the word knowledge (measured by accuracy in picture naming and picture recognition tasks) and the speed of word processing (measured by response times in the same tasks) in bilingual and monolingual children 4–7 years old.

Our goal was to examine whether bilingual and monolingual children are equally sensitive to the word properties and if not, which aspects of word knowledge are more vulnerable in bilinguals compared to monolinguals. Understanding whether, and if, how exactly bilingual children differ

from their monolingual peers in word knowledge and processing is critical for developing accurate models of childhood bilingualism. Still, the majority of studies on the impact of word properties on word knowledge or speed of word processing were run on monolingual adults. It is an open question to what extent the results found in adults can be extended to children. Similarly, given how bilingualism affects the mind and brain from early infancy (e.g., bilingual infants and adults have shown inhibitory control advantage; see Kroll et al. 2012), it is highly probable that any effects found in monolingual populations cannot be readily extended to bilinguals (Faroqi-Shah, Kevas & Li 2021). Moreover, studies typically focus on word production, leaving word comprehension largely unexplored. What is more, most studies focused on one or two properties, even though factors such as AoA, imageability, or frequency may be intertwined and their unique contribution to word knowledge and word processing may depend on whether other factors are controlled for or not (e.g., Brysbaert & Ghyselinck 2006). Finally, understanding the differences in word processing by bilingual and monolingual children should lead to informed decisions on the optimal language support for bilingual children.

### **1.1. Word properties influencing word knowledge and speed of word processing**

The effects of word AoA, imageability, and frequency on word knowledge and speed of word processing were thoroughly examined in many languages. However, most evidence comes from studies on adults (see Souza, Garrido & Carmo 2020 for a systematic review). In the following pages we present a review of the few studies conducted on children. Importantly, those studies typically involved monolinguals and focused on only one property of words.

#### **1.1.1. Age of acquisition**

By definition, words with higher AoA are acquired later than words with lower AoA. Therefore, AoA may be indicative of a word's difficulty. Haman, Łuniewska et al. (2017) did a cross-linguistic investigation of lexical development of monolingual children in 17 languages. They found that words with higher AoA were more difficult in picture naming and picture recognition tasks across languages, perhaps because AoA is correlated across languages (Łuniewska et al. 2016, 2019; Tjuka, Forkel & List 2021). Moreover, AoA was more strongly correlated with accuracy than the morphological or phonological complexity of the words (Haman, Łuniewska et al. 2017; van Wonderen & Unsworth 2020). It remains to be seen whether AoA would have the same impact on bilinguals. Perhaps, as the order of early word acquisition is relatively similar across languages (Łuniewska et al. 2016, 2019; Tjuka, Forkel & List 2021), the number of languages being acquired has no additional impact on the order (or the difficulty) of word acquisition. However, AoA is not the only factor affecting accuracy in picture naming tasks. It is not clear whether and how it interacts with other potential factors such as imageability and frequency—which, being connected with word complexity (Dye et al. 2013), influence accuracy in picture naming in monolingual children and adults (see subsequent sections).

Regarding the speed of word processing, words with earlier AoA are faster to process than words acquired later (Carroll & White 1973b; Chalard & Bonin 2006; Johnston & Barry 2006; Juhasz 2005). D'Amico, Devescovi & Bates (2001) confirmed the AoA effect in children: The AoA ratings gathered from adults predicted the children's speed of picture naming, together with frequency.

A largely debated issue is the connection between AoA and frequency. There are some conflicting results related to the dependent and independent roles of the AoA and frequency in word processing. On the one hand, words that occur more frequently in language input tend to be acquired earlier. Moreover, there is a very strong correlation between the magnitude of the effects of AoA and frequency across tasks (Brysbaert & Ghyselinck 2006). This has led some researchers to suggest (e.g., Morrison & Ellis 1995) that there are in fact no unique effects of frequency visible after controlling for AoA. On the other hand, Brysbaert & Ghyselinck (2006) propose that the AoA effect is partly frequency related and partly frequency independent. They follow Ellis and Ralph's (2000) idea

based on neural-network accounts that words acquired earlier and continually represented throughout life (i.e., not replaced by later words) show an advantage over words acquired later (the frequency-related AoA effect). Yet the authors also identified a frequency-independent effect in tasks that required a specific word to be produced based on the semantic analysis of input, i.e., picture naming instead of word naming (Brysbaert & Ghyselinck 2006). Thus, AoA and frequency may show distinct effects, especially if pictures rather than words are presented as stimuli. To provide insights into the unique contribution of each of the factors, both should be taken into account.

### 1.1.2. *Imageability*

Perceptual characteristics of words have an important role in early vocabulary development. There is evidence (Bergelson & Aslin 2017; Willits et al. 2013) that infants and toddlers evoke mental images of words they hear and that these images may affect the way they process the words. Gentner & Boroditsky (2001) proposed a partition hypothesis that states that concrete objects (represented by words of high imageability) are easier to identify in the world, and thus their names are easier to learn. Thus, imageability may also be related to the AoA. Peters & Borovsky (2019) examined perceptual characteristics of words (e.g., smell, sound, tactile, taste, visual color, etc.) included in the Words & Sentences version of the MacArthur-Bates Communicative Development Inventory (CDI) and used Wordbank data to calculate objective AoA measures for the words from the CDI. They found that the number of perceptual characteristics was the best predictor of the order of word acquisition: The more perceptual features a word has, the earlier it is acquired.

McDonough et al. (2011), using imageability ratings gathered from adults (not based on perceptual features of the words), found that imageability contributed to the variance of the AoA of CDI words above and beyond the frequency of words and the form class (nouns or verbs). Similar results showing predictive power of imageability on the AoA of CDI words were found for Chinese (Ma et al. 2009), Czech (Smolík 2019), Norwegian (Hansen 2017), and Portuguese (Marques et al. 2007).

In a study with preschool children, Masterson, Druks & Gallienne (2008) found that imageability was a significant predictor of object naming accuracy for both 3-year-olds and 5-year-olds and a significant predictor of action naming accuracy for the younger group. Imageability also influenced the response times: Pictures of highly imageable object words were named faster in both age groups; pictures of highly imageable action words were named faster in the younger group. Masterson, Druks & Gallienne (2008) suggest that imageability may have a more profound effect on the acquisition of nouns than verbs, and the magnitude of the effect on verbs might change with age. Specifically, the effect of imageability on verbs decreased with participants' age (or their growing language skills). However, it is possible that in older bilingual speakers—who present limited vocabulary as compared to their monolingual peers—the effects of imageability would still be present or would be even stronger. Therefore, in addition to the AoA (described previously) and word frequency (described in the subsequent section), we decided to include imageability of the words in our analyses as well.

### 1.1.3. *Frequency*

The role of frequency in language acquisition is proposed by the usage-based theory of language acquisition, which shows input frequency as predictor of the language acquisition rates (Ambridge et al. 2015; Cameron-Faulkner, Lieven & Tomasello 2003; Engelmann et al. 2019; Granlund et al. 2019). Empirical research confirms that high-frequency words, i.e., those that appear often in the immediate linguistic environment, are generally learned earlier than low-frequency words. In a seminal paper on the role of frequency in the acquisition of vocabulary, Goodman, Dale & Li (2008) contrasted normed AoA ratings for CDI words and the frequency ratings based on parental input (obtained from CHILDES) and found that for each word class (nouns, verbs, adjectives, function words, etc.), the higher the frequency of a word in parental input, the earlier the word was produced by children. For comprehension, on the other hand, parental frequency correlated only with the age of acquisition of common nouns. The authors concluded that the frequency effect on vocabulary acquisition interacts with word category and modality. Similarly, Hansen (2017) found that word

frequency in child-directed speech and imageability predicted the order of the acquisition of words in Norwegian toddlers, as estimated on the CDI data. Some previous research compared the effects of frequency with other word properties (although none included AoA, imageability, and frequency). Stokes (2010) noticed that word frequency and neighborhood density (the number of phonologically close words) predicted vocabulary size in monolingual toddlers. Newman & German (2002) examined the impact of AoA, neighborhood density, and frequency on word retrieval in school-age children (measured via picture naming). Children were better at naming high-frequency words than low-frequency words, and the effect of frequency was constant across the children's age (7–12 years).

Regarding the effect of frequency on the speed of word processing, few studies considered child participants, as most focused on adults. For adults, the higher the frequency, the faster the word processing in monolinguals (Janssen, Bi & Caramazza 2008). Similar results were obtained for children and adults speaking Dutch (Brysbaert 1996; Brysbaert, Lange & Wijnendaele 2000), where despite the strong effects of AoA on naming latencies, the authors observed the effect of word frequency when AoA was controlled for. This was in contrast to some earlier studies on adults, where the frequency effects were not significant when AoA was controlled for (Morrison & Ellis 1995). Therefore Brysbaert (1996) explained that children tend to be more sensitive to linguistic factors in word processing than adults.

To summarize this section, in toddlers and preschool children, AoA may influence word's difficulty in picture naming (Haman, Łuniewska et al. 2017) and picture recognition (Haman, Łuniewska et al. 2017, Walley & Metsala 1992). Subjective AoA and word frequency may together influence the speed of picture naming in both adults and children (D'Amico, Devescovi & Bates 2001). Imageability is found to influence the accuracy and the speed of picture naming in 3- and 5-year-olds, but the effects may be stronger in younger children (Masterson, Druks & Gallienne 2008). School children are better at naming high-frequency words than low-frequency words, and the effect of frequency seems constant across age (7–12 years; Newman & German 2002). However, these effects were found in monolingual children only, and the three factors were never studied together. Therefore, in the current study we included AoA, imageability, and frequency to verify whether the sensitivity to these word properties is the same in monolingual and bilingual children, across the modes (picture naming vs. picture recognition), and whether the three factors considered together show independent effects.

## 1.2. *Distinction between word comprehension and production*

Most of the studies that examined the influence of psycholinguistic factors on accuracy and the speed of word processing focused on word production, measured with picture naming tasks (D'Amico, Devescovi & Bates 2001; Masterson, Druks & Gallienne 2008). However, accuracy and response times may show different patterns for picture naming (word production) and picture recognition (word comprehension). Therefore, in the current study we included both picture naming and picture recognition.

An often-reported phenomenon in relation to accuracy is the comprehension-production asymmetry. It is clearly visible in children who—at different ages—understand more words than they produce (Benedict 1979; Dale & Fenson 1996; Goldfield 2000). The gap is also visible in adults; for example Gershkoff-Stowe & Hahn (2013) taught children and adults novel words for novel objects and found a comprehension advantage for both age groups.

In reference to the speed of word processing, the need to include both picture naming (word production) and picture recognition (word comprehension) comes from the argument of Levelt (2002). In his response to Alario, Costa & Caramazza (2002), who reported frequency effects in noun phrase production, Levelt suggested that if the response times are measured only in picture naming, it is difficult to assess whether the psycholinguistic properties (here: frequency) influence the

time needed to name the picture or the time needed to recognize the picture (Levelt 2002). In the current study, we aim to verify whether the word characteristics affect only the time needed to recognize a picture and the time needed to name the picture.

Are the effects of word properties similar on the speed of processing in picture naming and picture recognition tasks? There is evidence of both AoA and frequency effects on the speed of object categorization (Moore, Smith-Spark & Valentine 2004). However, the size of these effects is not nearly as large as those reported in picture naming (Juhasz 2005). In lexical decision tasks, where participants decide whether the presented stimulus is a word or not, Fiebach et al. (2003) found frequency and AoA effects on recognition for visually presented items and an AoA effect on performance on the auditory presented items. However, to the best of our knowledge, no previous studies investigated the effects of word properties on response time in picture recognition tasks in which children hear a target word and choose a picture that represents the word from a multipicture board. Moreover, we explore the differences between picture recognition and picture naming tasks and the differences in speed of word processing in monolinguals versus bilinguals.

### 1.3. *Vocabulary size in bilingual and monolingual children*

Most research shows that bilingual children have smaller vocabulary size in each of their languages when compared to monolinguals. For example, Bialystok et al. (2010) tested receptive word knowledge in a sample of over 1,700 children (over half of them bilingual) between 3 and 10 years old. The bilingual children were of immigrant background, speaking different languages at home (L1) and English, the majority language, at school. The authors found that bilinguals of all age groups scored significantly below their monolingual peers on the receptive vocabulary test in English. Limited vocabulary size either in L1 or L2 (second language) of migrant children has also been reported by other researchers investigating both receptive and productive vocabulary in bilinguals at early school age: Haman, Wodniecka et al. (2017) in Polish-English bilinguals; Hansen et al. (2019) in Polish-English and Polish-Norwegian bilinguals and in the area of productive vocabulary; Bohnacker, Lindgren & Öztekin (2016) in Turkish-German bilinguals; and Klassert, Gagarina & Kauschke (2014) in Russian-German bilinguals.

The difference in vocabulary size between bilinguals and monolinguals appears to be a natural consequence of developing two or more lexical systems (Haman, Wodniecka et al. 2017; Hoff & Ribot 2017; Klassert, Gagarina & Kauschke 2014; Pino Escobar, Kalashnikova & Escudero 2018). The linguistic environment of a bilingual child is by definition more diverse than that of a monolingual child: A bilingual child hears less of each language when compared to the input received by a monolingual child (Hoff 2017; Hoff et al. 2012). However, when bilingual children are exposed to two languages equally often, they might show similar vocabulary outcomes as monolingual peers (Thordardottir 2011). In a migrant context, children who heard English (the majority language) at least 60% of the time performed equivalently to their English monolingual peers in standardized vocabulary tests (Cattani et al. 2014).

Interestingly for the context of our study, monolinguals and bilinguals show some differences with regard to processing abstract and concrete words. Kaushanskaya & Rechtzigel (2012) found that bilingual adults performed better than monolingual adults on learning novel concrete words. The authors concluded that concrete words may cause a wider activation of the bilingual lexical-semantic system (vs. the monolingual system), thus yielding a stronger concreteness effect in bilinguals than in monolinguals. Importantly, this shows that some word properties (e.g., imageability) may in fact enhance bilinguals' word learning. If so, bilinguals may be more sensitive to some of the word properties.

There is little research on the impact of word properties on accuracy in picture naming and word recognition in bilinguals versus monolinguals. To the best of our knowledge, only four studies investigated the issue in bilingual children of immigrant origin who spoke one language at home and used a different language at school. This is a particularly interesting issue since vocabulary learned



at home can differ considerably from that acquired at school due to the environmental characteristics (i.e., names for home objects such as *oven* may be known only in the language used at home; McMillen et al. 2020). Hansen et al. (2017) examined AoA, imageability, frequency (in child-directed speech), and word complexity as predictors of word knowledge (receptive and productive) in Polish-Norwegian bilingual and monolingual preschool children. They found that AoA was a robust and significant predictor of word knowledge in both groups, but frequency was a stronger predictor in Norwegian production than in Polish production in the bilingual group (possibly due to a larger variation in Norwegian results). The validity of AoA as a predictor of monolingual and bilingual accuracy in picture naming and picture recognition was recently confirmed in Dutch and Spanish monolinguals, as well as Dutch-Spanish bilinguals (van Wonderen & Unsworth 2020). Also recently, McMillen et al. (2020) showed that AoA was the most important contributor to accuracy in picture naming in both languages (Spanish and English) of typically developing bilingual children. Vermeer (2001), on the other hand, investigated the effect of word frequency on the receptive word knowledge of Dutch monolingual and bilingual children and found a significant relation between the probability of knowing a word and its frequency in oral and written language input in primary education. Overall, the limited available evidence suggests that bilinguals and monolinguals might be equally sensitive to word properties. However, those studies used only accuracy as the measure of word knowledge, and we include the speed of word processing as an additional measure. Moreover, few studies examined both receptive and productive word knowledge and more than one word property (Hansen et al. 2017; van Wonderen & Unsworth 2020). Therefore, more research is needed to ensure these results are persistent across languages and across bilinguals and monolinguals.

To sum up, bilingual children are generally reported to have smaller vocabularies in a single language than monolingual peers (e.g., Bialystok et al. 2010), and this gap may depend on the balance of the language input in children's environment (see Cattani et al. 2014; Thordardottir 2011). Available evidence on different effects of word properties on children's vocabularies in monolinguals versus bilinguals is scarce but suggests that the groups' accuracy in lexical tasks may be similarly affected by word properties (Hansen et al. 2017; van Wonderen & Unsworth 2020; Vermeer 2001). This issue, however, has not been addressed with regard to both accuracy and the speed of word naming but only with regard to accuracy. In the current study, we attempt to fill this gap by analyzing both accuracy and the speed of word processing in picture naming and picture recognition tasks.

#### **1.4. Speed of lexical processing in bilingual and monolingual children**

Legacy et al. (2016) were first to compare response times in picture recognition across bilingual and monolingual children. They used a computerized vocabulary comprehension task in which toddlers are shown pairs of pictures and asked to touch the target image related to the word heard. They found that bilinguals showed comparable speed of processing for words in both of their languages, as well as comparable speed of processing relative to their monolingual peers. However, in line with research on vocabulary size, bilinguals were outperformed by monolinguals on accuracy in both languages separately. DeAnda et al. (2018) used a similar computerized comprehension task to investigate the speed of word processing and vocabulary size in toddlers. Similarly to Legacy et al. (2016), they found no differences between bilinguals and monolinguals in the speed of word processing. Though within the bilingual group, they found that the vocabulary size in the dominant language predicted the speed of word processing in the dominant language (i.e., the larger the vocabulary size, the faster the response). Conversely, vocabulary size and speed of word processing were not related in the non-dominant language.

Early processing efficiency may lead to better language outcomes at early school age both within a language and across languages. Marchman et al. (2020) measured processing efficiency, based on accuracy and response times, in a looking-while-listening task (a task in which children are shown pairs of pictures, hear a target word, and their looking time at the target picture is measured). They

tested children longitudinally, at the age of 2 years and at the age of 4.5 years. The results show that bilingual children who knew more words and showed better processing efficiency in L1 (Spanish) as toddlers demonstrated better L1 skills at preschool age, after controlling for socioeconomic status (SES) and language exposure. Moreover, these children presented higher L2 (English) skills at preschool age, compared to children with weaker L1 processing skills at the age of 2. These results indicate that bilingual children's level of proficiency in their home language is associated with that in the L2.

However, there is evidence that bilingual adults tend to be slower (than monolinguals) in word processing, e.g., lexical decision tasks (Soares & Grosjean 1984) and in picture naming, even in their L1 (Ivanova & Costa 2008). This gap is especially visible in low-frequency words (Gollan et al. 2008). This suggests that bilingual and monolingual speakers might be differently influenced by word frequency when processing or producing words. However, this effect has not been investigated in children before.

To sum up, research from bilingual toddlers (DeAnda et al. 2018; Legacy et al. 2016) on word recognition suggests that bilinguals and monolinguals show comparable speed of processing for words, even though bilinguals may be disadvantaged in accuracy. Also, bilinguals' processing efficiency in toddlerhood may lead to better language outcomes at early school age both within a language and across languages (Marchman et al. 2020). Interestingly, in adults, the pattern seems to be different: Bilinguals tend to be slower both in word processing (Soares & Grosjean 1984) and in picture naming than monolinguals (Ivanova & Costa 2008). Therefore, bilinguals and monolinguals may be differently influenced by word frequency. However, this finding was established for adult speakers only, and the issue has not been yet investigated in children. In the study reported here, our aim was to address some of the limitations of previous research by analyzing the effects of AoA, imageability, and frequency on word knowledge and word processing in monolingual and bilingual children.

### 1.5. *The current study*

We tested bilingual children of migrant background, who spoke a minority language at home (L1), and a majority language (L2) at school, and we focused on their L1 only. The primary interest of the present study was whether the AoA, imageability, and frequency affect the bilingual and monolingual children's accuracy and the speed of word processing in the same way. To the best of our knowledge, this is the first study to include all these three psycholinguistic factors and to assess their unique contribution in both word knowledge and the speed of word processing in bilingual children. It is also the first study to compare the impact of the three factors on word comprehension and production.

We expected bilinguals to perform worse than monolinguals in both word production and comprehension accuracy in Polish (bilinguals' L1). The expected bilingual disadvantage in accuracy would replicate the earlier findings with a similar population (but a different sample) of Polish-English migrant children in the UK (Abbot-Smith et al. 2018; Haman, Wodniecka et al. 2017), as well as the previous findings from other studies that used the same method—Cross-Linguistic Lexical Tasks (Bohnacker, Lindgren & Öztekin 2016; Gatt et al. 2017; Khoury Aouad Saliby et al., 2017; Lindgren & Bohnacker 2019)—and the patterns observed in the L1 of bilingual migrant children (see the previous section on bilingual and monolingual vocabulary size).

Although previous studies on toddlers have not reported any differences in the speed of word processing between monolingual and bilingual children, we expected to see such differences. These differences have been previously observed in adults (Gollan et al. 2008; Sullivan, Poarch & Bialystok 2018) who had limited exposure to each of the languages. Our question was whether limited exposure to each of the languages also impacts the speed of word processing in bilingual preschool children. In particular, the migrant status of the tested bilingual children may affect (limit) their exposure to L1 and therefore lead to reduced speed of word processing (Haman, Wodniecka et al. 2017). Also, it is worth noticing that toddlers in the previous studies took part only in the comprehension tasks, while here we investigate both comprehension and production. Taking that into account, we expected bilinguals to fall behind monolinguals in the speed of word processing.



Based on the previous literature, we also predicted that the three psycholinguistic factors—AoA, imageability, and frequency—would contribute to both word comprehension and production in both groups. In particular, we expected that accuracy would be higher for words of low AoA (Haman, Łuniewska et al. 2017; McMillen et al. 2020; van Wonderen & Unsworth 2020; Walley & Metsala 1992), high imageability (Hansen 2017; Ma et al. 2009; Marques et al. 2007; Smolik 2019), and high frequency (Hansen 2017; Newman & German 2002; Stokes 2010). Similarly, we predicted that the word processing would be slower for words of higher AoA (D’Amico, Devescovi & Bates 2001) and faster for words of higher imageability (e.g., Masterson, Druks & Gallienne 2008) and higher frequency (e.g., D’Amico, Devescovi & Bates 2001).

Since AoA and imageability of words are relatively similar across languages (e.g., Hansen 2017; Łuniewska et al. 2016, 2019), we expected the effects of both factors to be similar in monolinguals and bilinguals. As for the word frequency, we predicted that it would contribute more to the responses of bilinguals due to a larger variability in the amount of input they receive in both languages (e.g., Gollan et al. 2008; Ivanova & Costa 2008; Soares & Grosjean 1984).

## 2. Materials and methods

### 2.1. Participants

In the current analyses, we included data from 45 Polish-English bilingual children (16 girls, 29 boys) living in the UK, aged 4;03–7;08, and a group of 45 Polish monolinguals (21 girls, 24 boys) of the same age range, living in Poland.<sup>1</sup>

All the bilingual children had a Polish mother, 38 had a Polish father, five had a British father, and two children had fathers from another country who used only English at home. The bilingual children were born in the UK ( $n = 34$ ) or were born in Poland ( $n = 9$ ) and moved to the UK before the age of 2.5 years (mean age of moving to the UK:  $M = 16.78$  months,  $SD = 10.36$ ). For two children no information about the place of birth was available. The current exposure to English and Polish in the bilingual group was calculated via a parental questionnaire (Polish adaptation of PABIQ for preschool and early-school bilingual children entitled “Kwestionariusz Rozwoju Językowego,” Kuś et al. 2012; Tuller 2015) with the use of formulas applied in previous research (Hansen et al. 2019; Mieszkowska et al. 2017). The exposure was divided into two parts: at-home exposure and outside-of-home exposure (as in Mieszkowska et al. 2017). The bilinguals’ current at-home exposure to Polish varied between 12% (for a child whose father was a native English speaker and who spoke only English with the father and with siblings) and 100% (for a child whose whole family spoke only Polish at home;  $M = 69\%$ ,  $SD = 20\%$ , 95% CI = [63%; 75%]). The bilinguals’ current outside-of-home exposure to Polish varied between 7% (for a child who attended English primary school for 36 hours per week, participated in various additional classes run in English, and heard only English while playing with friends at playgrounds) and 69% (for a child who attended a Polish Saturday school, played mostly with Polish-speaking peers, and whose family was often visited by Polish-speaking guests;  $M = 41\%$ ,  $SD = 12\%$ , 95% CI = [38%; 45%]).

<sup>1</sup>The Polish-English bilinguals were participants in one of two projects: a longitudinal project on vocabulary development ( $n = 26$ ; total sample size in the project was 28, data from two children were excluded from the current analyses because of the low quality of naming recordings) or a project assessing factors influencing vocabulary with the use of tools selected from the Language Impairment Testing in Multilingual Settings (LITMUS) battery (Armon-Lotem, de Jong & Meir 2015;  $n = 19$ ; total sample size was 32, data from six children were excluded from the analyses because of the loss of the recordings, and data from seven children were excluded due to low quality of the recordings). Part of the current bilingual sample—18 participants (three participants from the first project and 15 participants from the second one)—were already included in a publication reporting results from different LITMUS tools (CLT and parental questionnaires; Hansen et al. 2019).

The Polish monolingual children (21 girls, 24 boys) participated in a project on the risk factors for developmental language disorder and constituted a control group in that study.<sup>2</sup> The bilingual and monolingual groups did not differ in the gender distribution, age in years, or maternal or paternal years of education as reported by the parents in PABIQ (see Table 1).

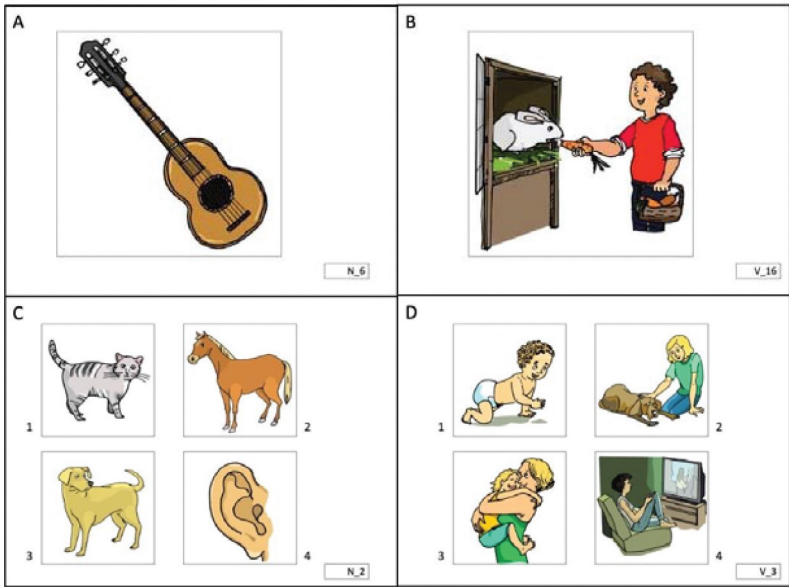
## 2.2. Materials and procedures

### 2.2.1. Cross-linguistic Lexical Tasks

To assess the children’s word knowledge and their speed of word processing, we applied a computerized Polish version of *Cross-Linguistic Lexical Tasks* (Haman et al. 2012; see Supplementary material 1 for the exact list of items in Polish CLT; available from OSF archive: <https://osf.io/dy62v/>). The CLT measures noun and verb production (in a picture naming task; Figure 1a and 1b) and comprehension (in a picture recognition task; Figure 1c and 1d). CLT is divided into four subtasks: noun comprehension, verb comprehension, noun production, and verb production (Haman, Łuniewska & Pomiechowska 2015). In

**Table 1.** The demographic characteristics of the monolingual and bilingual children: Number of participants (*N*) and means (*SD*) [95% CI].

	Monolinguals	Bilinguals	
Gender ( <i>N</i> )	21 girls 24 boys	16 girls 29 boys	$\chi^2(1) = 1.15, p = .28$
Age (in years)	6.03 (0.50) [5.88; 6.18]	6.24 (0.74) [6.02; 6.46]	$t(88) = 1.59, p = .11$
Maternal education (in years)	15.73 (2.56) [14.88; 16.58]	16.42 (3.18) [15.43; 17.41]	$t(73) = 1.03, p = .30$
Paternal education (in years)	14.17 (3.51) [12.97; 15.37]	14.68 (2.73) [13.81; 15.55]	$t(69) = 0.70, p = .49$



**Figure 1.** Examples of picture boards in Polish version of *Cross-Linguistic Lexical Tasks* (A: noun production, B: verb production, C: noun comprehension, D: verb comprehension).

<sup>2</sup>From the total sample of monolingual children without language disorder ( $N = 73$ ), we first excluded two children whose recordings were of low quality and four children who refused to complete one of the four CLT subtasks. From the 67 children, we selected 45 children who matched the bilingual sample as accurately as possible in terms of age and gender.

the comprehension subtasks, children hear a prerecorded question (e.g., “Where is a flag?” in the noun comprehension task, and “Who is kissing?” in the verb comprehension task) and are supposed to point to one of the four pictures presented on a touchscreen (the target picture and three distracting pictures). In the production subtasks, children see one picture and are asked to respond to a prerecorded question (e.g., “What is this?” in the noun production task, and “What is she doing?” in the verb production task).

Each of the CLT subtasks includes 32 items (Haman, Łuniewska & Pomiechowska 2015). The items were selected in a language-universal procedure applied in all language versions of CLT (Haman, Łuniewska et al. 2017; Simonsen & Haman 2017; <https://multilada.pl/en/projects/clt/>) on the basis of AoA and complexity index of the words. The AoA ratings were posed as described in the subsequent section. The complexity index was calculated for each word on the basis of a set of linguistic features: the number of phonemes in the word, morphological features (the number of roots for compound words, whether it is a derived word, plus the number of suffixes and prefixes), phonological features (the presence of initial fricatives, an initial consonant cluster or an internal consonant cluster), whether it is a recent loanword, and the subjective frequency of exposure to the word. All criteria included in the complexity index, which is a composite score, were judged by an expert linguist. The exact formula for calculating the complexity index was described by Haman, Łuniewska & Pomiechowska (2015) and also explained in detail by Hansen et al. (2019). Each of the four subtasks included a balanced number of target words from the following categories: early and easy (low AoA and low complexity), early and complex (low AoA and high complexity), late and easy (high AoA and low complexity), and late and complex (high AoA and high complexity). In the comprehension tasks, the distracting words were selected to match the target words in terms of AoA and complexity. Items for comprehension and production parts were controlled for similar AoA and complexity. Frequency and imageability of the target words were not considered in the CLT design and were not controlled for when selecting the items. The information on AoA, level of AoA, complexity index, level of complexity, imageability, and frequency for all target words of the Polish CLT is available in Supplementary material 2 (available from OSF archive: <https://osf.io/dy62v>).

In each CLT task (comprehension and production), the first two items—the training items—were selected in such a way that they would be the easiest ones in the task (based on the exact values of AoA and the complexity index). The remaining 30 items were arranged randomly within the task (i.e., not according to difficulty) and were presented to each participant in the same (previously arranged) order. Thus, the order of all the items in the comprehension and production task was inherently random but presented in the exact same way to each participant in the present study. The exact location of a target picture on the picture board in a comprehension part was controlled so that each of the four locations had a similar number of target pictures across the whole set of 32 items.

So far, there are no published data on the reliability of the CLT (see the subsection on validity and reliability in the Results section). The previous studies, however, confirmed the validity of CLT by showing that the accuracy in CLT is highly correlated to parental estimates of child language skills (Abbot-Smith et al. 2018; Hansen et al. 2019; Kołak 2020), and its overall score is positively correlated with children’s age (Haman, Łuniewska et al., 2017).

The current study used a computerized version of the CLT that enabled the measurement of response times during comprehension and production (Haman, Łuniewska & Pomiechowska 2015). In the computerized version of the tasks, pictures were presented on a touch screen. In the comprehension part, children first heard the prerecorded question. After the question a blank screen was presented for 100 ms. Then children saw the four pictures and touched one of them. The response times were defined as the difference (measured in ms) between the presentation of the four pictures and the moment when the child touched the picture on the touch screen. In the production part, pictures were presented one by one on the screen, and the experimenter pressed a mouse button to move to the next item. The testing was recorded and the response times in the production part were calculated on the basis of the spectrograms of the recordings (see the section on Data Coding for details).

### 2.2.2. Procedure

The CLTs testing procedure was the same for all tested children. The children were tested individually by a native speaker of Polish in a quiet room: the monolingual children in their preschools, and the bilingual children in their day care centers, Saturday schools, or in their homes in the UK. The order of the CLT subtasks was fully counterbalanced across the participants. The approximate total time of testing with the CLT in Polish was 15 minutes. During the testing procedure children's responses were recorded.

Apart from the CLT, the monolingual group completed a battery of language and cognitive tests. The other tests in the monolingual group were applied after the Polish CLT. The bilingual group was also tested with the British English computerized version of the CLT, which includes different items than the Polish version, as each CLT version is prepared individually for a particular language based on a cross-linguistic procedure (Haman, Łuniewska & Pomiechowska 2015).

### 2.2.3. Data coding

We coded both the accuracy (a measure of word knowledge) and the response times (a measure of the speed of word processing) for the Polish picture recognition and picture naming tasks. In the picture recognition tasks, the accuracy and the response times were coded automatically with the software used for the testing. The children obtained 1 point if they touched the correct picture and 0 points if they touched one of the three distractors. The response times were defined as described in the previous section on CLT. In the current analyses, we used the response times of the correct responses only.

In the picture naming tasks, we applied strict accuracy scoring rules, similarly as in the previous papers that used CLTs (e.g., Abbot-Smith et al. 2018; Gatt et al. 2017; Haman, Łuniewska et al. 2017; Hansen et al. 2019; Kapalková & Slančová 2017), which means that only responses that contained a form of the target word were assessed as correct. The list of correct responses included: exact target words and mispronounced, inflected, and derived forms of the target words. All other answers, such as synonyms, regional variants, definitions, and the instances of code-switching, were coded as incorrect (for information about classification of each response see Supplementary material 4; available from OSF archive: <https://osf.io/dy62v>). We adopted such strict rules because the psycholinguistic properties (AoA, imageability, frequency) were calculated for these specific target words and not their regional variants or synonyms. The response times in the picture naming tasks were coded from the spectrogram analyses of the audio recordings with the use of Audacity (Audacity Team 2019). The response times were defined as the time between the end of the prerecorded question and the first phoneme of the target word in the child's response (e.g., *d* in "dog" or *d* in "That's a dog!"). In the analyses, we included only the response times for the correctly named pictures. All the raw data including the participants' responses, accuracy, response times, as well as the values of the psycholinguistic variables for each item, are available in Supplementary material 4 (available from OSF archive: <https://osf.io/dy62v>).

### 2.2.4. Psycholinguistic variables

**2.2.4.1. Subjective age of acquisition.** We used subjective AoA ratings collected for the Polish words from the CLT word base (Łuniewska et al., 2016). These estimations were based on the responses from 32 adult participants to the question "When did you learn the word X?" The ratings, expressed in years, were highly correlated ( $\rho = .93$ ) with the estimations provided by another group of participants in response to the question "When do children acquiring Polish learn the word X?" (Łuniewska et al. 2016). All the words used in the Polish CLT were assessed as rather early acquired; the estimated AoA varied between 2.31 and 6.10 years ( $M = 3.79$ ;  $SD = 0.84$ , 95% CI = [3.66; 3.91]). The exact values are given in Supplementary material 2 (available from OSF archive: <https://osf.io/dy62v>).

**2.2.4.2. Imageability.** Word imageability was assessed in a separate study run for the purpose of the current analyses. Eighty-four native Polish speakers (52 females, 32 males, aged 18–57,  $M = 25.03$ ,  $SD = 8.37$ ) assessed 150 words randomly selected from the CLT list of 299 words. Similarly to the previous studies (Lind et al. 2015; Rofes et al. 2018; Simonsen et al. 2013; Stadthagen-Gonzalez & Davis 2006; Võ et al. 2009), the participants rated the words on a 7-point scale from 1 (*very difficult to imagine*) to 7 (*very easy to imagine*). Due to random word selection for each participant of the word imageability study, we collected from 31 to 65 responses for each word ( $M = 42.34$ ,  $SD = 4.93$ ). Then we calculated the average rating for each word. The ratings for all the 299 words are presented in Supplementary material 3, and the ratings for the words used in the Polish CLTs are presented in Supplementary material 2 (OSF archive: <https://osf.io/dy62v>). For the whole list of 299 words, the imageability ratings varied from 4.09 to 6.98 ( $M = 6.29$ ,  $SD = 0.51$ , 95% CI = [6.23; 6.34]). For the 128 target words included in the Polish CLT the imageability ratings varied between 4.70 and 6.98 ( $M = 6.26$ ,  $SD = 0.51$ , 95% CI = [6.17; 6.35]).

**2.2.4.3. Frequency in child-directed speech.** We used word frequencies in child-directed speech gathered in the Polish Frequency List of Child-Directed Speech (Haman et al. 2011). These frequencies were based on the corpus data available from CHILDES and some additional unpublished data sets and included utterances spoken by Polish adults and older children to (or in the presence of) Polish monolingual children between 0;10 and 6;11. The list incorporates data from seven corpora and includes more than 794,000 word tokens in CDS. The exact values of the frequencies in CDS for the words in the Polish CLT are presented in Supplementary material 2 (OSF archive: <https://osf.io/dy62v>).

## 2.3. Statistical analyses

To investigate whether the children's word knowledge and their speed of word processing is predicted by group (monolingual, bilingual), AoA, imageability, and frequency, we ran a series of linear mixed-effects regression models (Baayen, Davidson & Bates 2008) with the lme4 package (Bates et al. 2015) in R (R Core Team 2019). The scripts used for the analyses are available from the OSF archive (<https://osf.io/dy62v/>). We ran four separate models: accuracy in production, accuracy in comprehension, speed of word processing in production, and speed of word processing in comprehension. In the analyses of accuracy, we fitted a generalized mixed effects model with a binomial link function with response accuracy as a binary dependent variable (0,1). In the speed of word processing analysis, we fitted a generalized mixed effects model with an inverse Gaussian link function, with the response times (ms) as a continuous dependent variable. In both models we included the fixed effects of the group and AoA, imageability, and frequency of words. In the group variable, bilinguals were coded as 0, and monolinguals were coded as 1. AoA and imageability were centered to the mean, and frequency was log transformed, scaled, and centered at 0. In all four models, we included three interactions with the group (group x AoA, group x imageability, group x frequency).

Though power analysis was not conducted prior to the analyses, the models were justified by inclusion of items as units of analyses. Each participant contributed 64 items to each model, which resulted in 5,760 items (90 participants x 64 items) in the word knowledge production and word knowledge comprehension model. The models for speed of processing included fewer items because response times were only calculated for the correctly answered items. The models can also be justified by the fact that they converged with at least the simplest random structure (and some of them with almost full random structure), all the main effects, and all the interactions. The three- and four-way interactions were not included due to the lack of power (i.e., the models with those interactions did not converge). Random intercepts for participants and words were specified. Additionally, random slopes for AoA, imageability,

frequency, and group were included by participant. In the case of convergence problems, the random structure was simplified according to the procedure outlined by Barr et al. (2013). *P* values were derived using ANOVA model comparison.

### 3. Results

#### 3.1. Correlations between the psycholinguistic variables

Before proceeding with the analyses, we investigated whether the three psycholinguistic variables were correlated with each other. Using Spearman's rank correlation, we observed that AoA and frequency were moderately negatively correlated,  $\rho(128) = -0.34$ ,  $p < .001$ , meaning that the later the word was acquired, the less frequent it was. Frequency and imageability were not correlated,  $\rho(128) = 0.01$ ,  $p = .837$ . AoA and imageability were also not correlated,  $\rho(128) = -0.14$ ,  $p = .099$ .

#### 3.2. Validity and reliability of the tasks

To assess the internal reliability of the accuracy and the response times in the sample, we calculated split-half (odd versus even items) reliabilities with a Spearman-Brown correction,  $\rho = 2 * r / (1 + r)$ . The obtained coefficients were high for both accuracy (Comprehension:  $\rho = .90$ , Production:  $\rho = .87$ ;  $n = 90$ ) and the response times (Comprehension:  $\rho = .92$ , Production:  $\rho = .86$ ;  $n = 90$ ).

We assessed the validity of the accuracy and the response times with the use of Pearson correlation. First, we calculated the correlations between accuracy scores and the response times in Comprehension and Production in the whole sample. The accuracy in Comprehension and Production was strongly correlated,  $r(90) = .69$ ,  $p < .001$ . The response times in Comprehension and Production were moderately correlated,  $r(90) = .37$ ,  $p < .001$ . The accuracy in Comprehension was weakly negatively related to the response times in Comprehension,  $r(90) = -.25$ ,  $p = .017$ , and moderately negatively related to the response times in Production,  $r(90) = -.36$ ,  $p = .001$ . The accuracy in Production was moderately negatively related to the response times in Comprehension,  $r(90) = -.37$ ,  $p < .001$ , and Production,  $r(90) = -.56$ ,  $p < .001$ .

The validity of accuracy was further confirmed by moderate correlations with age in the monolingual sample—accuracy in Comprehension:  $r(45) = .36$ ,  $p = .015$ ; accuracy in Production:  $r(45) = .33$ ,  $p = .029$ —and moderate correlations with cumulative exposure to Polish in the bilingual sample—accuracy in Comprehension:  $r(42) = .38$ ,  $p = .012$ ; accuracy in Production:  $r(42) = .52$ ,  $p < .001$ ; response times in Comprehension:  $r(42) = -.46$ ,  $p = .002$ ; response times in Production:  $r(42) = -.40$ ,  $p = .009$ . The accuracy in the bilingual sample was not correlated with age—Comprehension:  $r(45) = .21$ ,  $p = .176$ ; Production:  $r(45) = .02$ ,  $p = .922$ ; neither were the response times in bilinguals—Comprehension:  $r(45) = -.20$ ,  $p = .189$ , Production:  $r(45) = .19$ ,  $p = .210$ —and monolinguals—Comprehension:  $r(45) = -.03$ ,  $p = .845$ ; Production:  $r(45) = -.04$ ,  $p = .808$ .

#### 3.3. Overall task performance

The overall accuracy and the response times (for the correct responses) in the comprehension and production tasks are presented in Table 2 for each group separately. The significant differences between the groups are marked in the table, and statistical details on those differences are reported in the next section, based on the mixed models results. Monolinguals knew more words than bilinguals in both the production and comprehension tasks. In the comprehension tasks, monolinguals achieved close-to-ceiling scores (correctly recognizing on average 97% of the words), but they were slower in their responses than bilinguals. This suggests a speed-accuracy trade-off for the comprehension in both groups: Bilinguals showed faster word processing and lower scores in word knowledge (on average, 90%); monolinguals were slower to respond but knew more words. In the production tasks, the scores were relatively lower than in the comprehension: The monolingual children correctly



**Table 2.** The overall accuracy (%) and the speed of word processing (ms) in monolingual and bilingual children in comprehension and production: Means (SD) [95% CI].

	Monolinguals	Bilinguals	
Comprehension:	0.97 (0.04)	0.90 (0.10)	$p < .001^{***}$
Accuracy	[0.96; 0.98]	[0.87; 0.93]	
Comprehension:	2604 (481)	2480 (532)	$p < .001^{***}$
Speed of word processing	[2463; 2744]	[2324; 2635]	
Production:	0.79 (0.07)	0.68 (0.16)	$p < .001^{***}$
Accuracy	[0.77; 0.81]	[0.63; 0.72]	
Production:	1996 (393)	2532 (591)	$p < .001^{***}$
Speed of word processing	[1881; 2111]	[2359; 2704]	

Note. The significance of the difference between monolingual and bilingual children is reported on the basis of the mixed models (see Tables 3–6).

\*\*\* -  $p < .001$

\*\* -  $p < .01$

\* -  $p < .05$

named, on average, 79% of the words, and the bilingual children correctly named, on average, 68% of the words. In the production tasks, monolinguals were faster in their responses than bilinguals, an effect opposite to that obtained in comprehension tasks.

### 3.4. Mixed models results

In this section we present the results from the series of mixed models, first for the comprehension, then for the production task. For both tasks, we first present the results from accuracy and then the findings regarding the response times.

#### 3.4.1. Comprehension

**3.4.1.1. Accuracy.** The model converged with the full random structure. The results of the analysis of accuracy in the comprehension part are presented in Table 3. The analysis showed significant main effects of group, AoA, imageability, and frequency. Monolinguals outperformed bilinguals. As expected, all participants showed better knowledge of words with lower AoA, higher imageability, and higher frequency. The results also point to an interaction between the group and AoA. The positive value of this interaction suggests that the gap between the monolingual and bilingual scores was larger for the words acquired later in life; for the words acquired early in life, the performance of the two groups was similar (see Figure 2). None of the other interactions was significant.

**3.4.1.2. Response times.** The final model converged with the simplest random structure (random intercepts for participant and word). The results of the response times analysis for comprehension are presented in Table 4. The analysis showed significant main effects of group, AoA, imageability, and

**Table 3.** Mixed models: Accuracy results for comprehension.

Comparison	Est.	SE	Z	p
Intercept	2.85	1.05	–	–
Group	2.26	0.53	4.24	$< .001^{***}$
AoA	–0.64	0.15	–4.39	$< .001^{***}$
Imageability	0.51	0.13	3.87	$< .001^{***}$
Frequency	0.37	0.15	2.56	.01*
Group: AoA	0.20	0.08	2.45	.01*
Group: Imageability	0.09	0.07	1.38	.17
Group: Frequency	–0.10	0.08	–1.34	.18

Note. \*\*\* -  $p < .001$

\*\* -  $p < .01$

\* -  $p < .05$

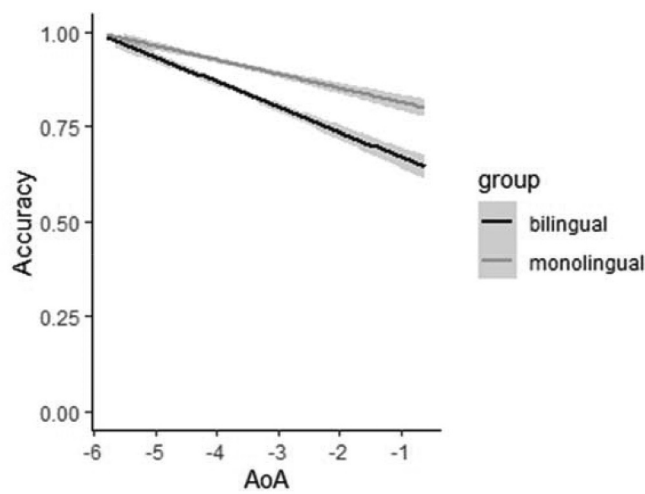


Figure 2. Accuracy in the comprehension task: Interaction between AoA and group.

Table 4. Mixed models: Response times results for comprehension.

Comparison	Est.	SE	Z	p
Intercept	2123.73	20.94	–	–
Group	504.41	14.07	35.86	<.001***
AoA	141.90	12.73	11.14	<.001***
Imageability	–233.67	14.38	–16.25	<.001***
Frequency	–55.70	18.13	–3.07	<.001***
Group: AoA	–14.65	13.05	–1.12	0.42
Group: Imageability	133.85	11.15	12.00	<.001***
Group: Frequency	91.94	21.62	4.25	<.001***

Note. \*\*\* -  $p < .001$   
\*\* -  $p < .01$   
\* -  $p < .05$

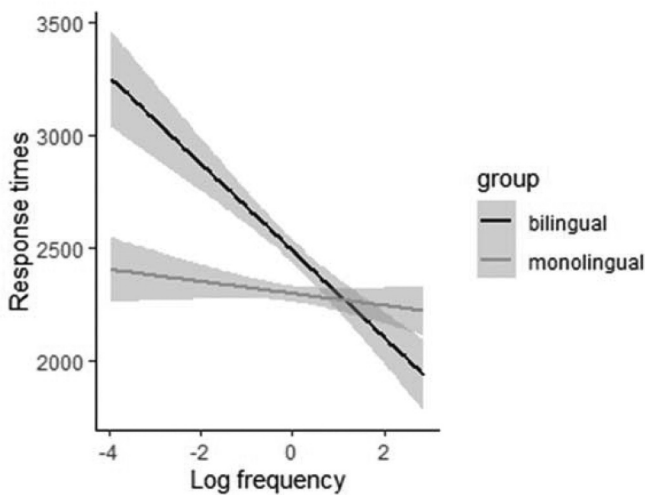
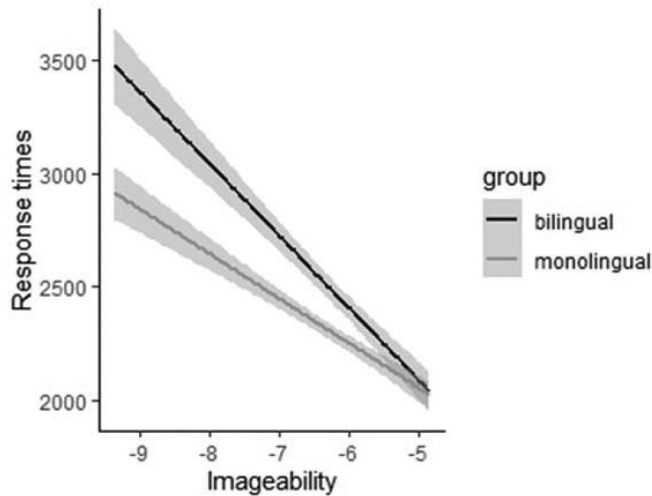


Figure 3. Response times (ms) in the comprehension task: Interaction between log frequency and group.



**Figure 4.** Response times (ms) in the comprehension task: Interaction between imageability (z-scores) and group.

**Table 5.** Mixed models: Accuracy results for production.

Comparison	Est.	SE	z	p
Intercept	1.21	0.21	–	–
Group	0.66	0.18	3.60	.0003***
AoA	–1.02	0.19	–5.18	<.0001***
Imageability	0.73	0.26	2.75	.006**
Frequency	0.38	0.16	2.38	.017*
Group: AoA	0.22	0.12	1.82	.07
Group: Imageability	0.07	0.15	0.50	.63
Group: Frequency	–0.20	0.09	–2.21	.03*

Note. \*\*\* -  $p < .001$

\*\* -  $p < .01$

\* -  $p < .05$

frequency. Bilinguals were generally faster than monolinguals (though less accurate; see the previous section on Accuracy). Overall, the children were faster to recognize words of lower AoA, higher imageability, and higher frequency. The results also point to two interactions. First, an interaction between group and frequency indicates that bilinguals were slower than monolinguals in recognizing low-frequency words, but the two groups did not differ in recognizing words of high frequency (see Figure 3). Second, the other significant interaction was between group and imageability (see Figure 4). Again, bilinguals were slower when recognizing pictures of low imageability, but their response times did not differ from monolinguals in the area of highly imageable words. The interaction between AoA and the group was not significant.

### 3.4.2. Production

**3.4.2.1. Accuracy.** The final model converged with the full random structure. The results of the accuracy analysis for production are presented in Table 5. As expected, the analysis showed significant main effects of group, AoA, imageability, and frequency. Monolinguals outperformed bilinguals. The higher the frequency of words, the higher was the participants' accuracy. Higher accuracy was also related to higher imageability and lower AoA. The results also point to an interaction between group and frequency. The negative value of this interaction suggests that the gap between the monolingual and bilingual scores was larger for the lower-frequency words, while the performance of the two groups was similar for the high-frequency words (see Figure 5). None of the other interactions was significant.

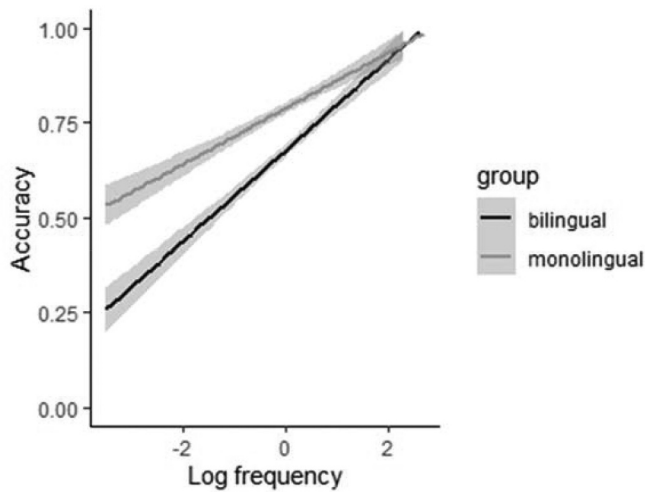


Figure 5. Accuracy in the production task: Interaction between log frequency and group.

Table 6. Mixed models: Response times results for production.

Comparison	Est.	SE	Z	p
Intercept	2823.70	26.60	–	–
Group	–385.44	16.56	–23.27	<.0001***
AoA	270.16	18.80	14.36	<.0001***
Imageability	–256.32	47.24	–5.47	<.0001***
Frequency	–189.82	20.74	–9.15	<.0001***
Group: AoA	1.91	25.42	0.07	.95
Group: Imageability	219.02	21.11	10.37	<.0001***
Group: Frequency	134.81	19.11	7.06	<.0001***

Note. \*\*\* -  $p < .001$   
\*\* -  $p < .01$   
\* -  $p < .05$

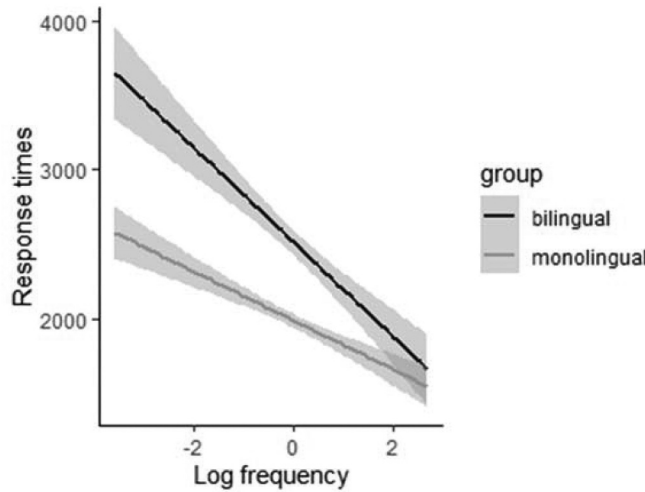
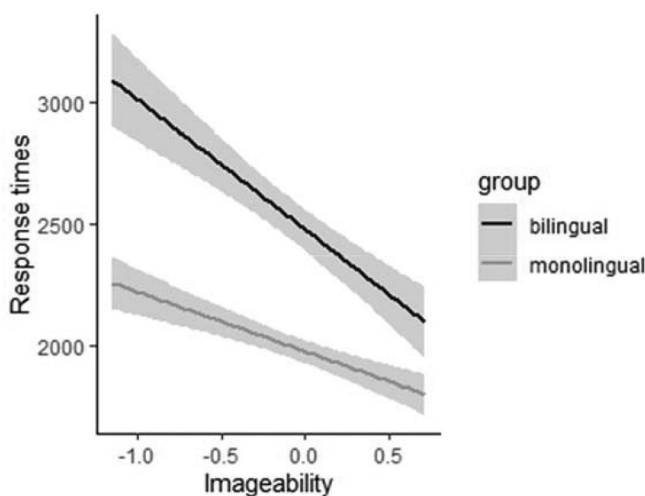


Figure 6. Response times (ms) in production: Interaction between log frequency and group.



**Figure 7.** Response times (ms) in production: Interaction between imageability (z-scores) and group.

**3.4.2.2. Response times.** The final model converged with the simplest random structure (random intercepts for participant and word). The results of the response times analysis for production are presented in Table 6. The analysis showed significant main effects of group, AoA, frequency, and imageability. Monolinguals were generally faster than bilinguals. As expected, all children were faster in naming words of lower AoA, higher frequency, and higher imageability. The results also point to two interactions. First, an interaction between group and frequency indicates that although monolinguals were slightly faster in naming higher-frequency words, bilinguals benefited more from high-frequency than monolinguals did (see Figure 6). In other words, in naming the low-frequency words, bilinguals were slower than monolinguals, but the higher the word frequency, the shorter picture naming latencies in bilinguals.

Second, the other significant interaction was between group and imageability. The positive value of this interaction suggests that monolinguals were responding faster than bilinguals on items with low imageability; for the words with high imageability, the performance of the two groups was similar (see Figure 7). The interaction between AoA and the group was not significant.

## 4. Discussion

In the current study we employed picture recognition and picture naming tasks to explore the impact of three psycholinguistic factors (AoA, imageability, frequency of words) on word knowledge (accuracy) and the speed of word processing (response times) in monolingual and bilingual children. We used cross-linguistic lexical tasks and confirmed their high internal reliability and validity: Accuracy increased, and the response times decreased with greater language experience (i.e., the older the monolingual children were the larger the cumulative exposure to L1 in bilingual children was). Before proceeding with the discussion about the most critical results, we comment on the differences between the groups' overall performance on the tasks.

### 4.1. Bilingual and monolingual accuracy and response times

#### 4.1.1. Accuracy

The Polish-English migrant children in the UK generally knew fewer words in their L1 than their Polish monolingual peers. The difference between the monolingual and bilingual scores was found both in receptive vocabulary, assessed with a picture recognition task, and expressive vocabulary, measured with a picture naming task. A similar gap in the size of bilinguals' lexicon in their L1

compared to their monolingual peers has been previously found across different languages and with the use of different picture tasks (e.g., Bialystok et al. 2010; Klassert, Gagarina & Kauschke 2014), as well as in previous studies using CLTs with various bilingual populations (Altma, Goldstein & Armon-Lotem 2017; Bohnacker, Lindgren & Öztekin 2016; Gatt et al. 2017; Hansen et al. 2017; Khoury Aouad Saliby et al. 2017; Lindgren & Bohnacker 2019) and previous studies on Polish-English bilingual children living in the UK using CLTs (Abbot-Smith et al. 2018) or other tools for assessing word knowledge in children of similar age to the current sample (Haman, Wodniecka et al. 2017; Mieszkowska et al. 2017) or younger ones (Miękisz et al. 2017).

Previous research has demonstrated that when migrant children enter school, their language dominance often shifts from the home language toward the majority language (Brown 2011; Jia et al. 2014; Lee 2013; Nesteruk 2010; Pham & Kohnert 2014; Pham & Tipton 2018; Sun et al. 2018). This language shift upon school entrance can be explained by extensive support for the majority language from the school and community and from relatively limited social support and fewer opportunities for the home language use outside of home (e.g., Pearson 2007; Pham & Tipton 2018; Sun et al. 2018). Limited vocabulary size in migrant children's L1 is observed especially when the majority language is English: a culturally powerful language present in the popular culture, e.g., children's media, popular songs, and films (see Brown 2011; Kang 2013; Lee 2013; Nesteruk 2010; Welsh & Hoff 2020). Perhaps the bilingual children in the current study, aged 4 to 7 years, were already in the process of shifting their language dominance to English. However, here we did not examine the bilinguals' L2; therefore we cannot draw any conclusions either about their knowledge of English, the majority language, or about their total vocabulary (Hoff et al. 2012).

#### 4.1.2. *Speed of word processing*

Surprisingly, the bilingual group was faster than monolinguals in the comprehension task (picture recognition). Note, however, that while bilinguals may have been faster than monolinguals in picture recognition, they were not as accurate as monolinguals. This demonstrates a group-specific speed/accuracy trade-off in children: Bilinguals were faster to respond, but they gave more incorrect responses than monolinguals, who took their time before providing the answers. Perhaps the bilingual children sacrificed accuracy to gain speed, as was previously shown in bilingual children at the same age (in a picture naming task; Kohnert, Bates & Hernandez 1999).

We also considered another explanation: Since the response times were calculated for the correctly answered items only, it is possible that bilingual children knew a different set of words than monolinguals, i.e., words that were easier in regards to their properties. However, additional analyses did not confirm this hypothesis: The words known by at least 95% of the bilinguals ( $n = 34$ ) and 95% of the monolinguals ( $n = 54$ ) did not differ in terms of any of the psycholinguistic variables—AoA:  $M_{bi} = 3.58$ ,  $SD_{bi} = 0.62$ , 95% CI = [3.37; 3.79],  $M_{mo} = 3.81$ ,  $SD_{mo} = 0.69$ , 95% CI = [3.62; 3.99],  $t(86) = 1.55$ ,  $p = .06$ ; imageability:  $M_{bi} = 6.42$ ,  $SD_{bi} = 0.38$ , 95% CI = [6.29; 6.54],  $M_{mo} = 6.41$ ,  $SD_{mo} = 0.38$ , 95% CI = [6.31; 6.51],  $t(86) = 0.12$ ,  $p = .45$ ; frequency:  $M_{bi} = 5764$ ,  $SD_{bi} = 11069$ , 95% CI = [2043; 9484],  $M_{mo} = 5902$ ,  $SD_{mo} = 10970$ , 95% CI = [2977; 8828],  $t(86) = 0.06$ ,  $p = .48$ ; see Supplementary material 4, OSF archive: <https://osf.io/dy62v/>). Perhaps there are some other variables that could differentiate the words known by the monolingual and bilingual children, such as semantic categories (Bialystok et al. 2010), word class, or phonological neighborhood density (Storkel 2004). If so, the difference in the response times could be partially explained by these item characteristics. However, we do not possess sufficient data to explore this issue in detail.

Finally, it is plausible that bilingual and monolingual children differed in their strategy of solving the task, i.e., the amount of guessing in the comprehension task. We cannot assess to what extent the accuracy in picture recognition was driven by guessing and whether the two groups differed in their tendency to guess. However, knowing that the comprehension task was relatively easy for monolinguals and more demanding for bilingual children, perhaps monolinguals focused more easily on the



task, and the bilingual children might have been less motivated to finish the task and might have wanted to hasten the procedure by guessing (which was possible in the case of comprehension but not in the case of production tasks).

In the production task, we found a main effect of group in the response times, with bilinguals being slower than monolinguals. This is in line with a number of studies on adults reporting that adult bilingual participants show slower naming latencies than monolinguals in picture naming tasks (Ivanova & Costa 2008; Gollan et al. 2008; Sullivan, Poarch & Bialystok 2018). Notably, these effects were shown to be particularly visible in balanced bilinguals (Legacy et al. 2016) with good knowledge of L2. This may suggest that the studied Polish-English bilingual children, although assessed at the earliest stages of school education, were already well experienced with English, which affected their lexical access in Polish, their L1.

## **4.2. Independent impact of psycholinguistic variables**

The psycholinguistic variables under investigation affected both accuracy and the speed of word processing, and the effects were consistently found across all tasks included in the study: Words of lower AoA, higher imageability, and higher frequency were recognized faster and more accurately in the comprehension task and named faster and with a higher accuracy in the production task. These results were expected. For accuracy, similar findings were previously reported for word AoA in both monolingual (Haman, Łuniewska et al. 2017) and bilingual children (Hansen et al. 2017; McMillen et al. 2020), for word imageability in monolingual children (Ma et al. 2009; McDonough et al. 2011) and bilingual children with developmental language disorder (McMillen et al. 2020), and for word frequency in both monolingual (Goodman, Dale Li 2008; Stokes 2010) and bilingual children (Hansen et al. 2017; Vermeer 2001). Similarly for naming latencies, in the studies to date, pictures of words of lower AoA (D'Amico, Devescovi & Bates 2001), higher imageability (e.g., Masterson, Druks & Gallienne 2008), and higher frequency (e.g., Alario, Costa & Caramazza 2002; D'Amico, Devescovi & Bates 2001) were named faster. Here we demonstrate that the same pattern of results can be observed in the picture recognition task. Crucially, our study is the first one to show the independent effects of AoA, imageability, and frequency on both accuracy and lexical access in monolingual and bilingual children and in both word comprehension and production. Thus we provide evidence that all three factors should be considered when assessing the impact of word properties on performance in lexical tasks, as each provides a unique contribution to the outcomes.

### **4.2.1. AoA**

The effects observed for AoA confirm again the validity of subjective AoA ratings: The lower the subjective AoA of a word, the earlier it is acquired by children. These effects concur with the idea that words of lower AoA enter the mental lexicon earlier, are consolidated better, and are represented more stably (Catling & Elsherif 2020); as a result they are easier to evoke. The AoA effects were observed not only in picture naming but also in the picture recognition task. Previous studies (e.g., Chalard & Bonin 2006; Morrison, Ellis & Quinlan 1992) suggested that AoA effects were not observable in tasks that required access to word meaning (such as semantic categorization or name-object verification). Our results are, however, in line with the hypothesis proposed by Brysbaert, Lange & Wijnendaele (2000), who suggested that AoA may be involved in semantic tasks.

### **4.2.2. Imageability**

The impact of imageability on word knowledge may be explained by the natural partitions hypothesis, which states that concrete objects (represented by words of high imageability) are easier to identify in the world, and thus their names are easier to learn (Gentner & Boroditsky 2001). Perhaps imageability is more than a measure of word concreteness: It may also indicate the extent to which the word represents an object that is easily identified and separated from other objects and relatively stable in time. Thus, a highly imageable word is a word whose meaning is relatively independent of context and

is autonomous of other words. In this view, nouns are more imageable than verbs, as Gentner & Boroditsky (2001:220) show: In the sentence “The goose rode the horse,” the nouns *goose* and *horse* can be imagined independently of the rest of the terms, but the verb *rode* cannot. The words of higher imageability (nouns over verbs) should thus be easier to recognize or recall in tasks that require single-word responses. In our data we do find that nouns are more imaginable than verbs— $M_N = 6.66$ ,  $SD_N = 0.17$ , 95% CI = [6.62; 6.70],  $M_V = 5.86$ ,  $SD_V = 0.40$ , 95% CI = [5.76; 5.95],  $t(126) = 24.95$ ,  $p < .001$ ; see Supplementary material 2—and are easier to name and point to, which is in line with the view of Gentner & Boroditsky (2001).

#### 4.2.3. Frequency

The fact that words of higher frequency are easier to acquire (and recall) is in line with the constructivist approaches to language acquisition and in particular the usage-based theory. Such approaches point to the role of input frequency in predicting the language acquisition rates (Ambridge et al. 2015; Cameron-Faulkner, Lieven & Tomasello 2003; Engelmann et al. 2019; Granlund et al. 2019).

#### 4.2.4. Independent effects of AoA, imageability, and frequency

Crucially, in the current study we report independent significant effects of AoA, imageability, and frequency. Previous studies showed that controlling for one of the factors canceled out the influence of the other. For example, although AoA was controlled, no frequency effect was visible in the adult speed of picture naming (Morrison & Ellis 1995), and although AoA and frequency were controlled, no effect of imageability was observed (Cuetos & Alija 2003; Morrison, Ellis & Quinlan 1992). It is possible that we observed the unique effects of all three variables because our participants were children. Children were shown to be more sensitive to linguistic factors in word processing, i.e., the observed effects of the psycholinguistic variables are stronger in children than in adults (Brysbaert 1996; D’Amico, Devescovi & Bates 2001) or become reduced with age among children (Masterson, Druks & Gallienne 2008). Recently, results from a meta-analysis of picture naming studies in adults (Perret & Bonin 2019) suggested that AoA and imageability affected the process of word naming at different stages: Imageability had its main locus at prelexical stages of word production (while the picture is being recognized); AoA affected the post semantic stage (while the picture is already recognized and the exact word form is being evoked). Crucially, according to the meta-analysis, the effects of frequency were “barely worth mentioning” (Perret & Bonin 2019:2542). The clear independent effects of AoA, imageability, and frequency in our study suggest that extending the model (Perret & Bonin 2019) to children would be an overgeneralization.

Another possible explanation of the independent effects of AoA, imageability, and frequency lies in the diversity of language experiences in the tested sample and that the observed effects were driven primarily by the bilingual group, although they were present also in the monolingual group. This explanation is related to the critical hypotheses we explored in the current study. If bilingual children are more sensitive to some psycholinguistic variables than monolinguals, this allows more variability in the data overall and makes the impact of the psycholinguistic factors more salient. We elaborate on this finding in the following section.

### 4.3. Bilinguals are more sensitive to the psycholinguistic variables

The interactions between the psycholinguistic factors and group were the primary focus of the current study: We asked whether bilingual and monolingual children are equally sensitive to word properties, i.e., the relatively universal properties of AoA and word imageability and the individually varied word frequency. Having assumed that AoA and imageability are relatively similar across languages, we expected bilinguals and monolinguals to be equally affected by these variables. As for the frequency, we

predicted it would have a more pronounced effect in bilinguals than in monolinguals. Contrary to our expectations, we observed that bilinguals were more sensitive (than monolinguals) to all of the explored word properties.

In the picture recognition task, bilinguals' performance was worse (compared to monolinguals) for words of high AoA. In the picture naming task, we found an interaction of group and frequency: The gap between monolinguals and bilinguals was particularly visible in the area of low-frequency words, where monolinguals largely outperformed bilinguals. Regarding the speed of word processing, in both picture recognition and picture naming tasks, we observed interactions of the group with imageability and frequency. In both tasks, the response times of bilinguals depended more strongly on the psycholinguistic factors, i.e., bilinguals' response times were particularly long for the words of low frequency and low imageability.

Previous research by Gollan et al. (2008) showed that the gap between bilingual and monolingual adults in production (picture naming latencies) is more pronounced in the area of low-frequency words than in the area of high-frequency words. Our data confirm Gollan et al.'s results and extend them to children: We found that bilinguals were slower in naming words of low frequency, but there was no difference between bilinguals and monolinguals in the high-frequency words. We observed similar findings for picture recognition, where bilinguals were slower than monolinguals in recognizing the low-frequency words but did not differ from monolinguals in the high-frequency items. We also extend the findings of Gollan et al. (2008) to word knowledge in picture naming task: We found that the gap between monolingual and bilingual accuracy scores was larger for the low-frequency words; for the high-frequency words, the performance of the two groups was similar.

Gollan et al. (2008) suggested that this effect might be linked to the reduced language use, i.e., the fact that bilinguals' language input and language use is naturally divided between two languages. This reduction affects the low-frequency items more than the high-frequency items (Gollan et al. 2008). Our data seem to confirm this account, showing that the lexicon of bilingual children may be composed of relatively frequent words, and the gaps in their vocabulary may relate more to the low-frequency items. This indicates that although bilingual children have enough exposure to the high-frequency words, they may not hear the low-frequency words often enough to form stable, easily accessible representations.

The observed higher impact of frequency in the bilingual group may correspond to some previous work in the area of word learning. Although some studies on fast mapping showed that monolingual children are able to create lexical representations even after a single contact with a word (Carey 1978; Carey & Bartlett 1978; Spiegel & Halberda 2011), repetition is crucial to memorize new lexical items effectively (Horst & Samuelson 2008; Horst 2013). Word learning in bilinguals may be more complex because it is easier to expand the lexicon in the stronger language than in the weaker language: The greater the vocabulary size in L2, the easier the acquisition of new words in that language (Kan 2014).

In addition to the consistent (and expected) interactions with frequency, we observed an interaction between group and imageability in the response times in the picture naming and picture recognition tasks. The monolingual group was faster in naming and recognizing the less-imageable words, but the performance of the two groups was similar in the area of the high-imageable items. The only interaction between AoA and the group that we found was in accuracy in the picture recognition task: In the area of early words, bilingual and monolingual children presented comparable vocabulary size; whereas monolinguals knew more late words. It is plausible that the selectivity of the observed interactions (i.e., the fact that we did not observe the interactions between AoA and group or imageability and group across all tasks) resulted from a limited power of the conducted analyses.

The question emerges as to why the bilingual children's accuracy and response times are more affected by the psycholinguistic variables than those of their monolingual peers. We expected such an effect for frequency, following the reasoning that bilingual children have limited exposure to both languages (when compared to their monolingual peers) and therefore may be more sensitive to the frequency of the heard words. The argument of Gollan et al. (2008) applies possibly also to other

variables than just frequency: Perhaps children who speak two languages have also limited contact (especially in their L1, studied here) with words of higher AoA (e.g., school words) and lower imageability (e.g., abstract words). The words of low frequency, high AoA, and low imageability are, however, not exactly the same, as typically, AoA, frequency, and imageability are only weakly to moderately intercorrelated (e.g., Cameirao & Vicente 2010; Ferrand et al. 2008; Marques et al. 2007). Bilingual children may acquire words of higher AoA and less imageable words at school and learn these words in their L2 and not necessarily in their L1.

It is also possible that the critical factor that drives the observed effect is language (in this case L1) proficiency, which is inevitably related to the bilingual status (e.g., Haman, Wodniecka et al. 2017; Hoff & Ribot 2017; Klassert, Gagarina & Kauschke 2014; Pino Escobar, Kalashnikova & Escudero 2018). Bilinguals' limited vocabulary may cause them to be more vulnerable to various linguistic properties. In future research it would be interesting to explore this issue by studying a wider range of L1 language skills in bilingual children and adults. The impact of language skills on the sensitivity to word characteristics is supported by previous studies: The effects of frequency on the response time in lexical decision tasks were stronger for adults of lower vocabulary size (Diependaele, Lemhöfer & Brysbaert 2013; Mainz et al. 2017, Yap et al. 2012). This observation could also explain the higher sensitivity of children than adults, as children have smaller vocabularies.

Finally, it cannot be excluded that we observed the more salient impact of word properties on word knowledge and lexical processing in bilinguals due to the close-to-ceiling results and limited variance in the monolingual children. Indeed, the monolingual group showed 97% accuracy in the comprehension and 80% accuracy in the production task. The monolingual sample was also more homogenous in terms of accuracy in the two tasks than the bilingual group. If we had reported solely on accuracy, this explanation would have fitted the results. However, the most pronounced evidence for higher sensitivity of bilinguals comes from the response times to which the ceiling effects did not apply.

Our finding related to the interactions may be of practical use to bilinguals' parents and caretakers, who often look for effective ways of supporting bilingual children in language development: The results clearly indicate that the bilingual children's word knowledge is most vulnerable for high-AoA, low-imageability, and low-frequency words. Thus, different types of interventions should target these words specifically. This finding may also be of practical use to professionals (psychologists, speech and language therapists, etc.) who implement or design language tests for assessing language skills and diagnosing language delay in monolingual and bilingual children. Professionals should be aware of AoA, imageability, and frequency distributions of the test items and acknowledge that using a test with a great proportion of high-AoA, low-imageability, and low-frequency words might result in underestimated scores for the bilingual children (especially the ones with unbalanced language exposure).

#### 4.4. Limitations

Although from a theoretical point of view, it would be interesting to explore three-way interactions (e.g., group x frequency x AoA), such analyses were not possible because of the limited power of the data set (Brysbaert 2020). In particular, a study on a larger group of participants and with a longer list of items could resolve the question about a possible interaction between word frequency and word AoA. In general, the sample size of the current study, although typical (or larger than typical) for studies on bilingualism, taken together with the number of items, is too small to allow multifactorial analyses. Although recruiting more participants would be difficult but not impossible, making the tasks longer would make them much more demanding for children, and the potential effect of items' order could interfere with the results.

It needs to be noted that CLTs were not designed as an experimental tool for answering the questions regarding the impact of word characteristics on word knowledge and processing. Even though AoA was used as a criterion for target words selection for CLT (which assures a good distribution of AoA values across the items), imageability and frequency were not and were obtained for already selected items later on. What is more, CLT was developed as a tool for the assessment of lexical skills in preschool children and

therefore contains only items of relatively low AoA, i.e., words typically acquired by the age of 8 years. The fact that CLTs are picture tasks possibly reduces the range of imageability values in a given set of target words. Designing a study primarily aimed to analyze the effects of AoA, imageability, and frequency of words on children's word knowledge and processing would require (1) using an optimal procedure (e.g., not only picture tasks); (2) better control for factors related to the target words characteristics; and (3) obtaining more details on the participants (overall language skills and other potential intervening variables, e.g., nonverbal IQ or executive functions), which was not possible in the current analysis.

#### 4.5. Conclusions

The present analyses found that bilingual and monolingual children's word knowledge and their speed of word processing in their L1 may be affected differently by such psycholinguistic factors as word AoA, imageability, and frequency. Specifically, we found that AoA, imageability, and frequency have independent impact on both word knowledge and the speed of word processing. Crucially, we observed that when early AoA, high-frequency words, and high-imageable words were concerned, bilinguals and monolinguals showed similar performance; however, bilinguals performed worse than monolinguals (with respect to both response times and accuracy) when the words were of higher AoA, low imageability, and low frequency. This indicates that although bilingual children have enough exposure to early and imageable words of high frequency, they may not be exposed to low-frequency words often enough to afford easy access to them. Together, these results suggest a new area for further research: the differences in the impact of particular psycholinguistic factors on the bilingual and monolingual populations, potentially also changing with age and/or language exposure.

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#### Data availability statement

The data and the scripts that support the findings of this study are openly available in Open Science Framework at <https://osf.io/dy62v>.

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