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Introduction

Word learning starts in early childhood through an interplay between processes that enable children's in-the-moment behaviour with those creating long-term retention. To learn and retain a word correctly, one needs to map it to its referent. In any given word learning scenario, a child is exposed to many potential referents upon hearing a new label. To reduce the complexity of this task, a well-documented constraint that helps guide in-the-moment behaviour is called *disambiguation.* Disambiguation refers to children's ability to correctly assign a novel label to a new object in ambiguous word learning contexts with many other competing referents by eliminating referents that already have a name (Diesendruck & Markson, 2001; Markman, Wasow, & Hansen, 2003). By engaging in this process-of-elimination, children can resolve referential ambiguity and map a new label to a novel referent. However, mapping itself is a fast and short-lived process, and one instance of successful word-object mapping does not guarantee recall at a later stage. For the child to successfully retain a word-object link, repeated mappings of this link must have occurred (Mather & Plunkett, 2010). However, the direct impact fast mapping has on subsequent recall is not well understood (Bion, Borovsky, & Fernald, 2013; Kalashnikova, Escudero, & Kidd, 2018). Moreover, word learning and more specifically the use of disambiguation has been shown to be impacted by children's language experience, such as the size of their vocabulary or whether they are exposed to more than one language. The present study will address how multilingual children disambiguate and retain novel word-object mappings. More specifically, the contribution of the present study is the investigation of the direct impact the use of disambiguation may have on retention.

From traditional to dynamic approaches to word learning

Traditionally, the ability to map a label to its corresponding referent has been explained via various word-learning principles that children might rely on during the early stages of lexical development. Researchers have been predominantly interested in why children exhibited the use of disambiguation in the first place (Diesendruck & Markson, 2001; Golinkoff, Mervis, & Hirsh-Pasek, 1994; Markman, 1990). One of the earliest assumptions was put forward in the late 1980s (Markman, 1990; Markman & Wachtel, 1988) and became known as mutual exclusivity (ME). ME is a principle which assumes that new words tend to refer to novel objects, and that referents only have one label. In other words, if a child is already familiar with the name for an object, they would not assign another label to this object. Under the ME account, the familiar referent is rejected from the competition of potential referents, before the learner moves on to the novel object. The rejection stems from the knowledge that the familiar object already has a label and can only have one. In an early study by Merriman, Bowman, & MacWhinney (1989), ME was assessed using a preferential looking-while-listening (LWL) paradigm where children were presented with physical objects of familiar and novel referents and were asked to choose a target object in response to a new label. The idea was that if children relied on ME, they would prefer the novel over the familiar object by fixating longer on the novel object, as the latter already had a familiar label. In doing so, children exhibited the so-called *disambiguation effect* – of which the ME account offers one possible explanation. Other underlying motivations for disambiguation have been attributed to the principle of cooperation (Grice, 1975) and that speakers should use familiar terminology (Diesendruck & Markson, 2001), or to a child's motivation to map new referents to new objects from the start

(Golinkoff, Hirsh-Pasek, Bailey, & Wenger, 1992). Another more lexical motivation was found in the notion that all lexical representations contrast in meaning (Clark, 1990). Thus, a child hearing a new label upon seeing a familiar name-known and a novel name-unknown object would assign the new name onto the new object, as new object warrants enough contrast to receiving a label.

Children's ability to disambiguate has been widely studied (in various adaptations of the LWL paradigm) over the developmental trajectory, from young infants (Bion et al., 2013; Halberda, 2003; Kalashnikova, Mattock, & Monaghan, 2016), primary school children (Diesendruck & Markson, 2001; Halberda, 2006; Markman & Wachtel, 1988), to adults (Halberda, 2006; Kalashnikova, Mattock, & Monaghan, 2014; Malone, Kalashnikova, & Davis, 2016). With more research on the topic in the past decades, it has become apparent that the use of disambiguation may only be useful in some, but not in other word learning contexts, such as when children grow up in an environment where they are exposed to more than one language (Byers-Heinlein, Fennell, & Werker, 2013; Byers-Heinlein & Werker, 2009). These studies have shown that multilingual children do not exhibit the disambiguation effect compared to their monolingual peers at the same age. This finding was explained by the notion that multilingual children by their very definition will eventually acquire translational equivalents (TEs) for most words in their lexicon, and thus override the assumption of a one-to-one mapping between a referent and its label, which has been interpreted as that disambiguation is not operational in multilingual children.

The emergence of disambiguation as a mapping constraint starts early at 17-18 months in monolingual children (Halberda, 2003). Whilst previously, the focus has been on investigating the underlying motivations for disambiguation, only recent studies have explored how it initially develops (e.g. Kucker, Mcmurray, & Samuelson, 2015). At the onset of disambiguation research (e.g. Markman & Wachtel 1988), the effect was described as a language-specific constraint that is exhibited during early word learning. This view has been challenged with more recent studies (Samuelson, Kucker, & Spencer, 2017) on this topic supporting the idea that the disambiguation effect can be ascribed to more general attention biases not specific to language, as proposed by the associative network account (Horst, Samuelson, Kucker, & McMurray, 2011). For this account, disambiguation is first and foremost a mapping ‘strategy', and its use does not guarantee the actual retention and learning of that word-object mapping. Furthermore, disambiguation is not responsible for a child's first word, such as *mummy* or *daddy*, which can already occur as early as six months (Tincoff & Jusczyk, 1999). This suggests that other driving factors initiate word learning before the onset of disambiguation.

Turning to multilingual children, the question that arises is whether or not they make use of disambiguation in the same way as their monolingual peers, and if they do not, does this mean that they have not yet engaged in a sufficient number of in-the-moment learning episodes to show the disambiguation effect? After testing monolingual, bilingual, and trilingual infants aged 17 months, Byers-Heinlein and Werker (2009) concluded that their performance on disambiguation trials depended on their language background with monolinguals exhibiting the disambiguation effect, bilinguals performing at chance level, and trilinguals below chance. Also, Houston-Price, Caloghiris, & Raviglione (2010) investigated monolingual and bilingual children from 18 to 22 months, and the bilinguals did not show any use of disambiguation. These studies suggest that the emergence of disambiguation in multilingual children happens asynchronously to their monolingual peers. However, a more recent study by Byers-Heinlein et al. (2013) concluded that it is not the language exposure as such that prevents multilingual children from using disambiguation, but rather the composition of their lexicon. They tested 17- and 18-month-old bilinguals and through an analysis of individual differences were able to show that those children who knew fewer TEs did show the disambiguation effect, whilst those who knew many TEs did not. However, learning two or more languages does not preclude them from engaging in disambiguation, but that the experience of growing up with more languages impacts on the emergence of disambiguation. Studies with bilingual 2- to 4-year-olds have shown that they similarly use disambiguation as their monolingual peers (Byers-Heinlein, Chen, & Xu, 2014; Davidson & Tell, 2005; Kalashnikova, Mattock, & Monaghan, 2015). With these research findings in mind, one can say that children's multilingual experience impacts on their use of disambiguation and modulates the developmental trajectory for the disambiguation effect. However, direct predictions have yet to be made why these differences shape the associative network in the multilinguals.

Disambiguation in the associative network

With recent studies supporting the idea that the disambiguation effect is not specific to language acquisition (e.g. Kalashnikova et al., 2018; Samuelson et al., 2017), fast-mapping has been described as the consequence of more general attentional processes coupled with the growth of a child's vocabulary (McMurray, Horst, & Samuelson, 2012; Samuelson et al., 2017). A computational model by Kucker et al. (2015) suggests that the disambiguation effect could be purely derived from associative learning paired with competition, the salience of the object, attention, previous receptive vocabulary (Kalashnikova et al., 2016), and other environmental factors, such as object location or proximity. In other words, the associative network account explains successful disambiguation as the result of a sufficiently structured or pruned network which has direct implications on real-time referent selection. The authors of this account argue that lexical development in children relies on processes that differ in terms of their time course. They describe these distinct, yet interactive time scales as *situation time* and *developmental time*. Situation time encapsulates behaviours and functions that support communication at the moment, and can result in inference, constraint satisfaction, or other in-the-moment problem-solving strategies. It is during this period that fast-mapping or disambiguation takes place. Disambiguation is one way of reducing referential ambiguity; however, it is not the only way. The associative network account also takes into consideration that adults often limit the possibility for other referents by holding and naming a single object to which a child is attending and that children, due to their stature and short arms, can see fewer items during the naming of objects, which also reduces referential ambiguity (Pereira, Smith, & Yu, 2014). Fundamentally, mapping a label onto its referent is a matter of directing attention to the correct referent. Children's attention is modulated by both external (such as object salience) and internal cues (such as object novelty), which both change over time, not only as the child is ageing but also as they learn more about the task and the stimuli within a task itself (Roder, Bushnell, & Sasseville, 2000). During the developmental time, a network of mappings between words and concepts is created and updated as children encounter repeated uses of a word, and gradually over time, this learning process refines the network forming a stable vocabulary. During each situation time episode, small amounts of learning happen (Smith & Yu, 2008) which rises systematically with the repetition of mappings (Mather & Plunkett, 2010) and vocabulary development (Bion et al., 2013). Associative learning is not only forming correct word-referent links right away but also about pruning links between words and incorrect referents as the mental lexicon is faced with new evidence (Regier, 2005). With regards to the disambiguation effect, the associative network account describes its occurrence as evidence that prior learning has happened and is considered a consequence of a sufficiently structured network. This account approaches disambiguation in a top-down manner, postulating that domain-general mechanisms shape the network first, which make it then suitable for the language-specific use of disambiguation (Kucker et al., 2015). In other words, if children exhibit the disambiguation effect, they have successfully engaged in prior learning episodes.

One aspect pertinent to previous disambiguation research has not yet been addressed under the associative network account – namely how bilingual or multilingual children's trajectory of the disambiguation effect can be explained. Children who are exposed to two or more languages divide their waking hours over these languages. This means that for each language, the daily exposure time in which fast-mappings happen is also reduced, which in turn leads to fewer occasions of situation time learning episodes. In other words, the fast mappings multilingual children strengthen and prune during situation time will take longer to be solidified by slow learning processes of developmental time. Thus, the consolidation of a multilingual child's associative mental network may be at a different stage compared to their monolingual peers. If this is the case, then multilingual children will have had fewer prior learning episodes per language at the same age, which according to the associative network account, has direct implications on their use of disambiguation, and by extension also on retention.

Disambiguation and retention

Disambiguation and retention are linked insofar as they represent the two learning trajectories set out by associative network account, i.e. fast mapping in situation time, and slow learning in developmental time. If children's multilingual experience impacts on their use of disambiguation, as set out above, then the trajectory for slow learning or retention of new words is also altered, as the two processes are interactively linked and inform each other. If, as laid out in the previous section, multilingual children have fewer exposures to situation time mapping encounters, the solidification of word-object links over developmental time will take longer. Because most studies investigating disambiguation do not usually invite children for a follow-up on long-term retention, it should be noted that the term 'retention' in the subsequent studies refers to a trial type. Studies have shown that at 24 months old, relying on disambiguation to establish a novel word-object mapping did not result in successfully retaining this mapping after an only minimal delay (Bion et al., 2013; Horst & Samuelson, 2008). A study by Kalashnikova and colleagues (2018), however, found opposite results. They tested 18- and 24-month-olds and found that monolingual, as well as bilingual children, aged 18 months were already able to retain a word-object link mapped via fast mapping trials, but at 24 months old only the monolingual group was able to do the same. Moreover, this study tested the correlation between the use of disambiguation may have on retaining the object that was disambiguated, and they found no significant direct correlation between the two. Although these results are somewhat inconclusive, the age of 24 months seems to be a vital timepoint during language development. At this age children successfully retained an object-word mapping when presented in an ostensive, non-ambiguous manner (Bion et al., 2013), or if children were exposed to the target objects before the experiment as a way to familiarise them with them (but not the label) (Horst & Samuelson, 2008; Kucker & Samuelson, 2012). Even though these studies describe children's accuracy or success on retention trials as 'retention', they do not assume long-term retention of the tested items. Although long-term consolidation cannot be determined by such retention trials, unless children were to be retested in a follow-up, the success on these trials furthers our understanding of the initial steps down the *slow learning* path posited by the associative network model (Kucker et al., 2015). Despite not to be taken as synonymous with fully-fledged retention, the developmental relationship between initial retention and full consolidation of a word warrants the use of the term 'retention' for either.

In summary, the picture that is drawn from research on disambiguation still leaves some gaps. Disambiguation is not available from the get-go of language acquisition, such as when children understand their first words around six months old, and that to make use of disambiguation means to draw on prior episodes of learning (McMurray et al., 2012; Samuelson et al., 2017). This dynamic associative view of the disambiguation effect suggests that to view things as mutually exclusive in tasks of referential ambiguity, as required under the ME account, is the result of general learning or attentional biases. Moreover, only with growing vocabulary and linguistic experience can the ME assumption develop into a reliable mapping and possibly retention strategy. Nevertheless, we do not know how this trajectory unfolds for multilingual children. One possibility with increasing evidence could be that the emergence of the disambiguation is simply delayed for multilingual children as they are establishing two or more lexicons in tandem, which reduces the exposure to each language and thus the in-the-moment learning episodes within a language, and thus, requires more time for establishing an associative network. Provided this is the case, there is little consensus on what they do use in the meantime if not disambiguation. The fact that multilinguals portray the disambiguation effect in some situations, but not in others, leads to the postulation of another possibility, namely that disambiguation is kept as a "default fast-mapping heuristic" (Kalashnikova et al., 2018). However, it is not adopted as a consistent word-learning strategy. The latter makes sense in the context of learning translational equivalents, as applying disambiguation under the ME assumption for one object would be counter-productive to the creation of a multilingual semantic network.

Present study

Given the interactive nature of fast mapping and slow learning processes and the documented differences in multilingual children with regards to disambiguation, our study contributes to filling the gaps of explicitly linking fast mapping and slow learning under the associative network account and how the multilingual experience modulates these trajectories. More specifically, we were interested in how monolingual and multilingual children’s performance on disambiguation and retention trials developed over time, and how performance on the former may impact the success in the latter. For this, we designed disambiguation trials, which juxtaposed a novel to a familiar item (either a *ball* or *car*), retention trials which juxtaposed the new item (from the disambiguation trials) to a trained item (seen in a prior training phase), and familiar word trials (*car* vs *ball*). Like the above research designs, we tested 'retention' by measuring the accuracy on selecting an item that was shown to children within an experiment, and we do not make claims about their ability to memorise this word-object mapping beyond the scope of the experiment.

First, we focussed how the trajectory of disambiguation unfolds for multilingual children aged from 18 to 30 months, as previous studies (Byers-Heinlein & Werker, 2009) had indicated that disambiguation in this group might emerge later due to their multilingual background. However, Kalashnikova and colleagues (2018) found that bilinguals as young as 18 months showed the disambiguation effect. Differences in how the target window was defined for analysis may have contributed to these diverging results, as their post-target window was longer (i.e. 0 – 3000ms) than in other studies (e.g. 360 – 2000ms in Byers-Heinlein & Werker, 2009). In these studies, only children aged 18 months and 24 months were tested. In the present study, we aimed to gain better insight into the multilingual trajectory of disambiguation by extending the age range of interest.

Furthermore, researchers have not reached a consensus yet as to what constitutes disambiguation, as some studies defined disambiguation as the accuracy on disambiguation trials (accuracy on familiar and novel target item taken together) (e.g. Yow et al., 2017), which could conflate the success on the accuracy of the familiar item with the actual disambiguation of the new item. In the present study, we defined disambiguation as the successful mapping of the novel label, excluding familiar labels, during disambiguation trials. We predicted that multilingual children would disambiguate to a lesser extent than monolinguals for all ages with disambiguation emerging slightly later than in monolinguals, as was found in previous studies (e.g. Byers-Heinlein & Werker, 2009). In addition to age, we also predicted that vocabulary size would be a critical modulating factor with regards to the use of disambiguation, as found in previous studies (e.g. Kalashnikova et al., 2018). In the present study, we also examined the interplay between the two and which factor, age or vocabulary, is a more reliable predictor of the children's ability to disambiguate and retain new words.

The study also sought to answer if children growing up with more than one language were able to perform similarly on retention trials, and how performance on the different retention items unfolded from the ages of 18 to 30 months. For this, we designed one trial type (a novel vs a trained item) that allowed us to test retention performance on a previously, ostensively trained item, and a fast-mapped item seen during the disambiguation trials. Put simply; we investigated how children differed in their ability to retain a novel label that was mapped either during unambiguous teaching trials versus fast-mapped disambiguation trials. Bion, Borovsky, and Fernald (2013) showed that monolingual children as young as 17 months could retain object-word mappings after ostensive teaching trials. We predicted that the ability to retain the ostensively mapped word would be high in both mono- and multilingual children. For the retention of the fast-mapped item, we predicted that both groups would score lower than on ostensive retention, but that their performance would increase with age and vocabulary size. Moreover, for multilingual children, we predicted that even though they might exhibit the disambiguation effect, retention might not be guaranteed, as shown in Kalashnikova et al. (2018).

In the present study, we predicted that at least the monolingual children who perform well on disambiguation trials, and thus, make more use thereof, would be the ones retaining novel object-word links better. However, that effect was predicted to be present only when children had been confronted with a case of ambiguity between two or more possible referents. In a situation where there is no doubt what a new label refers to, the use of disambiguation is not necessary to make a correct mapping. The mapping of a novel target item, e.g. *nil*, presented in unambiguous teaching trials at the start of the experiment should not show the disambiguation effect as only one object could be the referent for the label. Hence, in this case, we did not expect that children's use of disambiguation impacts on the retention of this word-object mapping. However, the mapping of another novel target item, e.g. *dax* presented in an ambiguous context next to a familiar item, needed to be disambiguated before it could be mapped and retained. Here, we expected that children who disambiguate more would be more accurate at object-word mappings. Finally, we also examined how children's performance on disambiguation and retention trials was modulated by age and vocabulary size.

To summarise, we predicted that multilinguals would make use of disambiguation, albeit to a lesser extent and later on. For retention, we predicted that neither group would have difficulties retaining the trained item and that both groups would perform lower in the more effortful retention of the fast-mapped item. Here, we also predicted that multilingual children might not be able to retain the fast-mapped mapping despite the potential use of disambiguation. We also predicted that at least monolingual children would perform better on retention if they also performed well on disambiguation trials.

Material and methods

Participants

A total of 96 children participated in the study. Children belonged to the monolingual or multilingual group. Forty-three children belonged to the *Monolingual* group (19 female) and forty children to the *Multilingual* group (12 female, 28 bilingual, 12 trilingual). The age range for the monolinguals was from 17.56 to 32.15 months (M_{age} = 24.94) and for the multilinguals from 17.46 to 32.71 months (M_{age} = 23.92). The latter were raised in multilingual homes with English as one of their languages. The monolinguals did not differ from the multilinguals with regards to their socioeconomic status (SES) based on the Scottish Index of Multiple Deprivation (SIMD). The SIMD is calculated with the postcode of their residence. The means of both groups lie in the top half of the calculated deciles (1 = contains 10 % of the most deprived areas in Scotland), with 7.42 for the monolingual (SD = 2.76, range = 1 to 10) and 6.65 for the multilingual group (SD = 2.61, range = 2 to 10). Thirteen children (of which five monolingual, four bilingual, four trilingual) were excluded from the final sample due failure to calibrate or to capture sufficient gaze data for analyses (10), to complete the task due to extreme fussiness (2), or to comprehend the task (1).

Language Background

All participating families were asked to complete the 'The CDI: Words & Sentences (Toddler form)' part of the MacArthur-Bates Communicative Development Inventories (Fenson et al., 1993; Fenson et al., 2007). This questionnaire is suitable for children aged from 16 to 30 months and assesses not only the size of children's expressive vocabulary, but also how they combine words into sentences. Since the focus of this comprehension study was the acquisition of words, the relevant metric used is the former, bearing in mind that children's comprehensive vocabulary size was likely larger. Parents were asked to mark the words that children understand and use, rather than just understand, as this is easier to assess for parents.

For monolingual children, the size of expressive vocabulary ranged from 0 to 628[1] words ($M = 251.10, SD = 185.40$), and for multilingual children from 5 to 530 words ($M = 175.60, SD =$

[1]. One multilingual child had an expressive vocabulary of zero at testing. However, the caregiver detailed that the child was able to understand many of words detailed on the CDI questionnaire. Parents were instructed only to select the words that their child verbalises. Thus, the number of words understood by children was higher, which was also the case for this child. We explicitly checked if this child performed different on

174.42). Vocabulary size for the two groups did not differ significantly from each other ($W = 1051, p = .083$). A more detailed overview of the sample demographics can be found in Table 1.

All multilingual children had English as one of their first languages. Multilingual children received their languages either from both parents, or different parents, with children being exposed to three or more languages also receiving input through nurseries or ambient language. The additional languages were Arabic, Danish, French, Gaelic, German, Greek, Hungarian, Italian, Lithuanian, Mandarin, Norwegian, Polish, Portuguese, Russian, Slovenian, Spanish, and Valenciano. Parents of multilingual children were interviewed after the experimental session while children were playing in the play area. We assessed current exposure, cumulative exposure of English, and age of first exposure for English and all their other language by using the Bilingual Language Experience Calculator (BiLEC, Unsworth, 2013). The amount of current exposure was ascertained by asking caregivers how much exposure their child received in each language using a percentage scale. Most parents had no difficulty answering this question. However, if at a later stage, they realised they might have forgotten about an element, we revised their previous statement. The cumulative length of exposure the BiLEC gathers the following information for the child: a) how much each caregiver and other adults living with the child spoke the language(s) in the years before the study participation; b) if the child attended nursery or day-care in this period, and if so, what the language of instruction was, and c) what languages were used on holidays. It was rather easy to ask about the period before they participated in this study as we tested children of a young age which meant parents had a good recollection of the language situation. From this data, cumulative exposure was calculated by averaging how much a child was exposed to English at home for each

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familiar word trials (which depicted *car* and ball), and no difference compared to other participants was found indicating that this child understood the task at hand and could be included in further analyses.

yearly period whilst also considering waking/sleep hours. The exact calculations can be found in the BiLEC Manual (v5, 2016).

Stimuli

To investigate whether children's use of disambiguation and retention was modulated by their language background, as well as age and vocabulary size, we developed an eye-tracking task where children were presented with two juxtaposed images of objects. Stimuli were monosyllabic words in all four conditions. To account for accurate reaction time measurements, only words that began with a plosive or nasal were used as these allow for the word onset to be determined with the high precision (Moss, 1996). The familiar items and words used were *ball* and *car*. The stimuli used for the trained and novel condition, *nil* and *dax*[2] respectively, were pseudo-words that adhere to the phonotactic properties of English. The images for the *ball, car* and *nil* were coloured 3D drawings selected from the TarrLab Object DataBank (1996). The image representing the *dax* was a 3D-rendering of a green modern garlic press found through a simple Google search (Figure 1). All items were presented on a black background in consistent pairs, except in unambiguous teaching trials. Auditory stimuli were recorded by a female native Standard Scottish English speaker who was instructed to speak in an infant-directed manner. All items appeared with each of the three carrier phrases (Table 2).

[2] During testing, it became apparent that *dax* was not an ideal label, as it could be confused with the plural of *duck*, as well as the homophonous German word *Dachs* for English *badger*.

The experiment was divided into four conditions, of which each had eight trials. Trials were pseudo-randomised by target item with a repeating order of *familiar, familiar, trained, novel* throughout the testing blocks. Trial types were:

- Familiar word trials (FF) which juxtaposed the *ball* with the *car*. This condition was included to ensure children understood the task
- Disambiguation trials (FN) which juxtaposed the novel item *dax* with either one of the familiar items
- Novel word retention trials (TN) which juxtaposed the trained, familiarised item of the training phase (*nil*) with the novel item *dax*. This condition was split by target item to test two types of retention.:
    - if children were able to retain the ostensively familiarised word-object mapping from the training phase (trained item was the target)
    - if children were able to retain the novel word-object mapping presented during disambiguation trials (novel item was the target)
- Familiarity trials juxtaposing the familiar and trained item (for future analysis)

Apparatus

The visual stimuli were presented on a 23-inch screen with auditory stimuli being played from one loudspeaker on either side of the monitor concealed behind a black curtain. Data were collected using a Tobii TX300 eye-tracker via E-Prime presentation software using extensions for Tobii. Recordings were sampled at a refresh rate of 60 Hz. For the duration of the experiment, children sat on their caregiver's lap approximately 60 cm away from the screen in a dimly lit room. Caregivers were instructed to keep their gaze low and remain behind their child to avoid the erroneous recording of their eye movements. They were also asked to refrain from prompting their child or reacting in any way to the stimuli. The experimenter remained next to the child and caregiver throughout the experiment monitoring the progress. At the beginning of the experiment, a 5-point infant calibration took place. After the experiment, children received stickers, and caregivers were compensated for their time.

Procedure

Before children participated in the study, they were invited to play in the laboratory in order to establish rapport between the experimenter. The experiment itself consisted of two phases, training and testing. The training phase comprised eight unambiguous, ostensive teaching trials (referred to as the OT condition) in which children were familiarised with the item nil. This new object-word mapping was modelled after Bion et al. (2013). The training phase was concluded with a short break and then followed by the testing phase, which consisted of two presentation blocks (each with 16 trials). The experiment had 40 trials in total. Each trial began with a fixation cross that was paired with an auditory cue (a ping sound) to attract children's attention to the screen. A baseline presentation of the images on the screen for 3000 ms followed before the auditory stimulus was presented. After the onset of the auditory stimulus, the images remained on screen for a further 6500 ms. In the testing phase of the experiment, each of the four items appeared as the target eight times, with the target item being presented on either side of the screen half of the time. The trials were pseudo-randomised, and no item could be the target for more than two consecutive trials. The testing phase always started with a familiar word trial, and trial order was by target item (cycling through familiar, trained, novel items in this order). Informed consent was given by children's caregivers before testing, and parents remained in their child's presence at all times.

Eye-tracking analyses

Looking duration and fixations were collected for the baseline phase of each trial, and the remaining 6500 ms after the onset of the auditory stimulus. The analysis window for the testing phase was defined from 360 to 2000 ms after the target word onset. This starting point has been taken to indicate the time needed to process the word and initiate eye movement (e.g. Dahan, Swingley, Tanenhaus, & Magnuson, 2000). Any reaction or eye movements beyond 2000 ms are less likely to be responses to the target word itself (Fernald, Perfors, & Marchman, 2006; Swingley & Fernald, 2002). In line with Byers-Heinlein and Werker (2009), we removed trials with more than 62.5% of track-loss from the pre-target window (0 to 2000ms after word onset); in other words, children had to have looked at the areas of interest at least 750ms during the first 2000ms after target onset. Looks towards the target item (*TargetLook* in models, tables, and figures) were coded as “1” and looks towards the competitor as “0”. Accuracy was defined as proportions of looks towards the target item over looks towards target and competitor and was our dependent variable.

For the statistical analysis of each condition, we commenced with a null model, against which each built model was compared. We used a stepwise bottom-up approach and compared models via likelihood ratio tests. For the final models, ROC curve analyses were performed. The closer the calculated C-value reaches 1, the better the performance of the model. A value near 0.5 would mean that a model is not better than chance level. For the complete data analysis, we used `R` (R Core Team, 2019), and for mixed-effect modelling, in particular, the `lme4` package (Bates, 2005; Bates & Sarkar, 2007).

To answer how children’s development impacted on their performance on disambiguation and retention trials, we also checked whether and how predictor variables related to each other. As age and vocabulary size were naturally correlated (in our case $\rho = .78, p < .001$), we disentangled the individual contribution of impact each of these two variables had and created a new variable for residual age predicting age by vocabulary. Due to a high number of data points, continuous variables, namely children's age and their vocabulary size, were rescaled to allow for model convergence.

Results

Table 3 presents children's accuracy across the experimental conditions.

Familiar word trials

In order to ensure children had understood the task, we presented them with familiar word trials (FF) whereby a familiar word pair (*ball* vs *car*) was shown. We first assessed whether the performance accuracy (overall proportions) for each group was above chance level adopting one-sample t-tests. With an accuracy of .70 ($SD = .16$) on average, monolingual children performed significantly above chance ($t(40) = 8.05, p < .001, \mu = .5$). Similarly, multilingual children performed at .68 ($SD = .13$) accuracy, which was also significantly above chance level ($t(39) = 8.67, p < .001, \mu = .5$).

Disambiguation trials

To address whether children disambiguated, and how their age, vocabulary size, and language background modulated the use of disambiguation, we looked at the disambiguation condition (FN). In this condition, children were presented with pairs of images of which one was always one of the familiar ones, and the other was the novel item *dax*. For all subsequent analyses, we collapsed both familiar items into one variable. We defined disambiguation as the accuracy on trials where the novel item *dax* was the target during disambiguation trials. To see whether children performed above chance, and hence, were able to disambiguate, one-sample t-tests were performed on both groups, with monolingual children performing above chance at an accuracy of .67 ($SD = .20, t(41) = 5.47, p < .001, \mu = .5$), whereas multilingual children's accuracy was below at .58 ($SD = .27$) which did not reach significance, but yielded a trend ($t(38) = 1.78, p = .08, \mu = .5$). As children had a wide age range, the non-significance of the t-test can likely be traced back to younger children's lower accuracy cancelling out that of older children. As previously shown (Byers-Heinlein et al., 2014), multilingual children tend to be delayed in the emergence of disambiguation. Hence, we performed a binomial mixed-effect regression analysis for these trials to disentangle this potential conflation of age.

Our analysis for disambiguation trials resulted in two models, one describing the entire sample, the other describing the multilingual children. Both models regarded the individual variance as a given (accounting for with a by-target slope on the subject random intercept) and had a by-TrialId random intercept. The random effect structure was kept as maximal as possible (Baayen, Davidson, & Bates, 2008; Barr, 2013; Barr, Levy, Scheepers, & Tily, 2013; Bell, Fairbrother, & Jones, 2019; Jaeger, 2008; Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017). Children's age was entered and directly compared; however, models with vocabulary size as predictor variable resulted in better models, and hence age as a covariate was removed.

Main analysis: Disambiguation mediated by Vocabulary size

Fixed effects for the optimal model were Target type (**familiar**, novel) and Language group (**monolingual**, multilingual) with vocabulary size as a covariate. The optimal model contained Vocabulary rather than Age as the predictor, as vocabulary increased the fit of the model significantly ($\chi^2\,(0) = 4.72, \mathrm{p} < .001$). The optimal model showed no significant main effects but yielded a significant two-way interaction between Target type and Language group ($e^{\beta} = .29, SE =$

1.80, $z = .12$). This result reflects that multilinguals behave differently than monolingual children on the disambiguation trials (Table 4). The interaction is visualised in Figure 2. Through a confusion matrix, we assessed the accuracy of our model. Out of possible 42'574 observations, our model correctly predicted 74% of the cases making it a robust model. The C-index for this model was $C = 0.77$.

Sub-group analysis

To unpack the two-way interaction found in Model 1 (Table 4), we split the dataset by Group, and ran the same model removing the fixed effect for Group. For the monolingual group, no significant effects were found indicating that they treated the novel and familiar targets similarly, and in both conditions, accuracy was above chance. For multilingual children, we found a main effect of Target type ($e^{\beta} = .16, SE = 1.73, z = .04$), and a significant two-way interaction between Target type and Vocabulary size ($e^{\beta} = 3.25, SE = 1.76, z = 8.03$; Table 5). The interaction is visualised in Figure 3. This interaction indicates that with growing vocabulary size, multilingual children started to disambiguate[3].

Retention trials

[3] Although age as predictor did not improve our models significantly, we included an additional graph to show how age modulated multilingual children's performance in our supplementary material. As we extended the age range from 24 to 30 months compared to previous studies looking at disambiguation in multilingual children, this might be of interest.

To answer the question of how children's language background, their age, and vocabulary size impacted on their ability to retain novel word-object mappings, we performed two analyses, as two types of retention were tested within the same trials (TN); firstly, *ostensive retention* and secondly, *retention via fast mapping*.

Ostensive retention

Ostensive retention was tested to address whether retention on a fundamental level was possible for these children. Neither monolingual nor multilingual children had difficulties in performing above chance ($\mu = .5$) on trials where the trained item *nil* was the target ($M_{mono} = .66, SD = .19, t(39) = 4.08, p < .001; M_{multi} = .66, SD = .25, t(37) = 4.04, p < .001$ respectively). These results also indicated that the two groups did not differ in their performance of retaining object-word mappings after unambiguous training. To test whether children had retained the label of the trained item and were not simply familiarised to its shape, we performed a sub-analysis for each group to compare infants' pre-naming and post-naming tendencies for the *nil.* We added "Part of Experiment" as predictor variable with the following levels: Baseline Duration (reference level), Pre Target Duration (time after baseline pre-naming of target), Target Duration (duration in which target label was auditorily presented), and Rep Duration (duration in which target label was repeated). Both the monolingual and multilingual children significantly increased their looks towards the target in the post-naming portions of the trial: Target Duration ($e^{\beta} = 1.34, SE = 1.01, z = 34542.54, p < 0.001;\ and\ e^{\beta} = 1.22, SE = 1.03, z = 712.60, p < 0.001\ respectively$); and Rep Duration ($e^{\beta} = 1.54, SE = 1.04, z = 47426.56, p < 0.001;\ and\ e^{\beta} = 2.09, SE = 1.05, z = 7748628.70, p < 0.001$ respectively).

Retention via fast mapping

The picture for retaining the novel item *dax* mapped during disambiguation trials differed as expected. Monolingual children performed at an accuracy of .58 ($SD = .25$) almost reaching significance above chance ($t(37) = 1.96, p = .058$). As before, older children with larger vocabularies performed better, which cannot be assessed using a simple t-statistic. Multilingual children, however, performed at chance level ($M = .50, SD = .24, t(37) = .04, p = .965$). Subsequently, we ran a new set of logistic mixed-effect regression models to investigate how vocabulary size impacted on children's success in retention trials. The analysis of the retention condition was analogous to disambiguation trials.

Main analysis: Retention via fast mapping modulated by vocabulary

Fixed effects for the optimal model were Target type (trained, **novel**) and Language group (**monolingual**, multilingual) with vocabulary size as a covariate. The analysis of retention accuracy showed a main effect of vocabulary size, as children with larger vocabularies performed better on these trials ($e^{\beta} = 2.14, SE = 1.38, z = 10.35$). The main effect of target type did not reach significance, nor did we find a group effect or significant interactions (Table 6). Visualisations of the main effect for vocabulary size can be found in Figure 4. The model had a prediction accuracy of 72.35% and a C-index of C = .78. The optimal model contained Vocabulary rather than Age as the predictor, as vocabulary increased the fit of the model significantly ($\chi^2\ (0)\ = 12.13, \mathrm{p}\ <\ .001$).

Disambiguation: Mapping or retention constraint?

To address the question of whether the use of disambiguation leads to better retention of object-word mappings, we calculated the proportional use thereof for each child and entered this as a prediction term in our optimal retention model. The proportional use of disambiguation was determined by calculating a mean accuracy score for the disambiguation condition for each child.

Main analysis: Retention modulated by disambiguation

Fixed effects for the optimal model were Target type (trained, **novel**), Language group (**monolingual**, multilingual), and then for each individual calculated Disambiguation rate with vocabulary size as a covariate. The optimal model showed a main effect for Language group ($e^{\beta} = 15.20, SE = 1.75, z = 8129.22$), Disambiguation rate ($e^{\beta} = 37.37, SE = 1.96, z = 215.12$), target type ($e^{\beta} = 8.75, SE = 1.77, z = 45.17$), and Vocabulary size ($e^{\beta} = 1.87, SE = 1.18, z = 41.67$). The group effect reflects that multilinguals' performance differed from that of monolinguals. The effect on target type, again, reflects that the trained item yielded a different performance to the novel item. As before, the effect on vocabulary size indicates that performance improved for children with larger vocabularies. Also, our added variable of disambiguation rate resulted in a main effect, reflecting the fact that the use of disambiguation affected their retention performance. However, we also found a significant three-way interaction between Language group, Target item, and Disambiguation rate ($e^{\beta} = 47.94, SE = 2.77, z = 44.54$; Table 7). The model had a prediction accuracy of 72.35% and a C-index of $C = .78$. To check how age might modulate children's performance, we also ran the same model with age as a covariate instead of vocabulary. This model did not yield convergence.

Sub-group analysis

To gain further understanding of this interaction, we split the data by Group first. For the monolingual children, we found a significant main effect for Disambiguation rate ($e^{\beta} = 31.90, SE = 2.54, z = 41.15$), Target type ($e^{\beta} = 7.19, SE = 2.23, z = 11.73$), and Vocabulary size ($e^{\beta} = 1.73$, $SE = 1.20,\ z = 19.65$), as well as a significant two-way interaction between Target type and Disambiguation rate ($e^{\beta} = .08,\ SE = 2.98,\ z = .10$; Table 8). The visualisation of this interaction can be found in the left pane of Figure 5. The interaction illustrates that the use of disambiguation modulated monolingual's performance on retaining both the trained and novel item. Specifically, performance on retaining the novel item improved for the children who disambiguated more.

The results for multilingual children, however, differed. Here, the sub-group analysis only yielded a main effect of Vocabulary size ($e^{\beta} = 2.14$, $SE = 1.36$, $z = 11.82$), but no other main effects or interactions (Table 9). In other words, for multilingual children, no improvement on retention was found as even with high levels of disambiguation overall performance on retaining the novel item was at chance level.

Discussion

In a developmental eye-tracking study with mono- and multilingual aged from 18 to 30 months, the aim was to expose the role disambiguation plays with regards to retention, or rather a precursor thereof. We investigated children's success in disambiguation trials and how it was modulated by their language background, age, and vocabulary size. Furthermore, we explored whether the same children were able to retain word-object links presented to them in an unambiguous and ambiguous context, and how the aforementioned factors modulated their accuracy. Lastly, we shed light onto the link between mapping and retention by ascertaining whether children who disambiguated also showed better performance on retention.

We tested children's use of disambiguation; a constraint said to support word learning that has been only observed in some, but not other contexts, such as monolingual vs multilingual language backgrounds. Concurrently, the view that disambiguation is a language-specific word learning strategy was challenged, and newer approaches provide evidence that disambiguation is based on more domain-general attentional biases (Horst et al., 2011; Samuelson et al., 2017). Under this account, disambiguation was concluded to be a default mapping strategy supporting word learning to some extent; however, word learning entails more than simply mapping the correct object to the corresponding label. In order to remember a word-object link, it must be reactivated consistently under the presence of other competitors until those are pruned. Hence, it becomes more apparent that a single instance of disambiguation or fast-mapping of a word-object link cannot lead to proper learning. Nevertheless, disambiguation being a first and foremost mapping strategy during situation time does not necessarily negate its supporting role in a precursor of retention, as it builds the first step down the slow learning path of developmental time. In other words, children who disambiguate might still have an advantage when remembering a fast-mapped word-object link. This supporting role of disambiguation in retention has not been widely tested yet, and so far, results have been somewhat inconclusive (Bion et al. 2013; Kalashnikova et al., 2018). Furthermore, our study contributes to the understanding of how fast mapping and slow learning unfold and interact in multilingual children, a missing aspect of the associative network model that has yet to receive more attention.

Disambiguation boosted by vocabulary size in monolingual and bilingual children.

Our analyses and results of the disambiguation trials showed that all children performed better with increasing vocabulary size in English. Thus, the emergence of disambiguation was modulated by children's English linguistic experience. By this, we mean not only the number of languages a child is exposed to, but also their English vocabulary. Multilingual children started to disambiguate and performed like their monolingual peers as their English vocabulary size grew indicating that the emergence of the disambiguation effect for multilingual children requires a richer vocabulary, and thus, in turn, more time. Bearing in mind that these children have to split the exposure to each of their languages over their waking hours, i.e. they had reduced exposure in English than their monolingual peers possessed at the same age. This means that their vocabularies in each language tend to be smaller, whereas their combined overall vocabulary size will likely approximate or surpass that of a monolingual child (Pearson, Fernandez, Lewedeg, & Oller, 1997). Our final model showed that English vocabulary size explained children's behaviour better than age in terms of disambiguation. This finding is in line with previous research which found that the composition of children's lexicon is more indicative of their use of disambiguation than age (Byers-Heinlein et al., 2013).

These results support an associative network account, as to make use of disambiguation, a child's lexicon must have a sufficient structure, or in other words a sufficient amount of word-object links (Kalashnikova, Mattock, and Monaghan, 2016). Multilinguals make use of disambiguation once their vocabulary size has reached a specific size, meaning they need to have more words established in their English lexicon before they show the effect. This suggests that in the meantime children with a multilingual background may rely on other word-learning heuristics in order to establish a lexicon before they use disambiguation in certain situations. This also supports the idea that other word-learning strategies seem to be more prevalent and useful for multilinguals. Such strategies would notably support the idea of many-to-one mappings and might thus be favoured by multilinguals. This does not preclude multilingual children from making use of disambiguation per se, but they are likely to encounter more learning situations in which other, less restrictive heuristics lead to better word learning. Our results also answer the question as to whether multilinguals might have a differently structured lexicon: the fact that multilingual children are capable of using disambiguation as a mapping constraint shows that their mental lexicons do not differ structurally to those of their monolingual peers.

Do monolingual and bilingual children retain in the same way?

Before discussing the results on retention, we reiterate that children's performance was based on retaining the fast-mapped object-word link within the same session after a minimal delay. It is highly probable that children will have forgotten this link shortly after their study participation. Hence, when we talk about 'retention' here, we want to emphasise that the measured performance on retention trials highlights a precursory and initial form of retention, rather than fully-fledged learning and long-term retention. The analyses performed on retention trials indicated that retaining a novel word-object pairing mapped during referential ambiguity remains difficult for children of such a young age. These findings corroborate what previous literature found (Bion et al., 2013; Horst & Samuelson, 2008). Whereas retention of the trained item was done successfully in both the monolingual and multilingual group as early as 18 months, retaining a new mapping that had to be inferred via disambiguation posed a challenge. Overall, children's retention abilities increased as the size of their vocabularies grew. Age was not entailed in our final model, as it did not make significant contributions to explaining the variance on their performance. In the retention analysis, there was a difference of retaining the new fast-mapped pairing between the two language groups, as only monolingual children performed above chance. This raises the question of whether these performance differences can be attributed to the use of disambiguation or not. One caveat in our experiment is that it could not fully disentangle whether the success on retaining the novel object was due to actual establishment of the mapping (during the disambiguation trials) or 'reverse' disambiguation triggered by recalling the trained item. Since the disambiguation process takes place regardless of item type, as in having to engage in the process-of-elimination, the 'reverse' disambiguation of the trained *nil* cannot be entirely ruled out. All children retained the trained object very well and treated it similarly to the familiar words. If children had shown an increased 'reverse' disambiguation effect on the trained *nil*, then the multilingual children should have performed much better on the novel word retention trials and portrayed similar disambiguation rates found in the disambiguation trials. However, future studies investigating the link between disambiguation and retention could address the above issue by including two novel items for children to be disambiguated and juxtaposing these two during the retention trials. We decided not to do so as adding another new item might have overwhelmed children at a such a young age, and in fact, multilinguals' chance performance indicated that one novel item already posed a challenge.

Relationship between disambiguation and retention

The use of disambiguation did not constitute an advantage of retention for every child. Although the use of fast-mapping constraints in the ostensive teaching trails was not necessary, we found an effect for monolingual children, but not multilingual children. Learning words is made up of in-the-moment referent selection, where disambiguation can be helpful especially in situations of referential ambiguity (such as in our disambiguation trials), and long-term retention, which requires repeated activation of word-object links (Kucker et al., 2015). Thus, no guarantee can be given as to whether a label is successfully retained after only a few fast mappings. However, mapping a novel label to its referent employing disambiguation should, one would assume, at least facilitate retention. If a mapping is established, then it should, in theory, make future retention more accessible as the first link that will go onto the slow long-term learning has been made. Throughout our experiment, children were presented with at least four occasions to make the expected link. Four occasions might not have been enough to strengthen the word-object mapping. However, monolingual children who disambiguated did, in fact, show higher accuracy on retaining the fast-mapped item. The higher their individual success rate on the disambiguation condition, and thus mapping the novel word-object link correctly more often, the better was their performance during the retention condition. Interestingly, we did not find this in the multilingual group. In this group, it made no difference whether their rate of disambiguation was low or high, as they still performed at chance level. These findings show that disambiguation might be a suitable mapping strategy for multilinguals at a specific moment in time when they have to select a referent, but it does not lead to learning in the long run. This is although they can disambiguate and do so, as their performance on disambiguation trials showed. This could be due to several reasons.

Multilingual children may require more activations of the same object-word mapping before they consider the competition with other referents as settled. Due to their learning of translational equivalents, they are more likely to accept many-to-one mappings at this age, and thus, competing referents are not ruled out as quickly when forming semantic associations. Our results support this idea, as multilingual children performed at chance level with regards to retaining the fast-mapped item, as well as past research which suggested that multilingual children are more likely to suspend the ME assumption to accept overlapping names for the same referent (Kalashnikova et al., 2016; Kandhadai, Hall, & Werker, 2017). Monolingual children, on the other hand, are not yet required to build many-to-one mappings this early, as the acquisition of synonyms usually happens later in their development. Thus, their mapping process does not face as much competition from other possible referents, or at least it is resolved earlier in the process of linking fast mapping with long-term retention.

Moreover, mapping and retention are processes developing on distinct, yet interactive timescales. Previous research, as well as our results, have provided evidence that fast-mapping via disambiguation is delayed for multilingual children. Albeit developing independently, this delay might contribute to a delay in retention performance for children from multilingual backgrounds. The fact that both groups in our experiment disambiguated and the difference in retention performance inform that disambiguation starts as default mapping strategy for every child, albeit delayed for multilinguals, and later develops into a more reliable word-learning strategy for monolingual children. This means that disambiguation develops dynamically across the developmental trajectory and is impacted by factors such as language background, translational equivalents, vocabulary size, and exposure. Monolingual children refine their use of disambiguation from a pure mapping constraint to a more sustained strategy that facilitates the short-term precursory retention of the fast-mapped word-object link. Multilingual children employ disambiguation as default when no other information about the referents is available (Kalashnikova et al., 2018). Unlike Kalashnikova et al. (2018: 10), we would not go as far as calling disambiguation a "genuine word-learning strategy across linguistic development", as neither ours nor their study investigated long-term retention of the fast-mapped word-object link. Nonetheless, our findings corroborate that monolingual eventually use disambiguation differently. However, rather than regarding this as a lack of refinement in multilingual children, we see it as encouragement for the research community to investigate the possible other strategies upon which multilingual children rely. Multilingual children's performance at chance level suggests that between the ages of 18 to 30 months old, these strategies have yet to emerge.

In our study, we faced certain limitations because its trial order which was done by target item rather than condition. This meant that in some cases, retention trials preceded disambiguation trials. In turn, it was more difficult to infer whether children had retained the novel mapping upon encountering it during the retention trials, or whether they engaged in another round of disambiguation. A follow-up analysis revealed that children treated the novel item *dax* differently between the disambiguation and the retention trial leading us to conclude that children did indeed show different behavioural patterns depending in which context the *dax* was presented. Although future studies could address this issue by creating two separate experimental blocks for disambiguation vs retention trials, it has to be noted that as soon as more than one trial prompting the disambiguation of the same item is part of any experiment, a learning effect will take place. Hence, the complete disentanglement of disambiguation and retention is impossible, as long as researchers have to expose children to multiple rounds of the same word-object mapping due to children's maturational memory constraints.

Conclusion and future directions

In summary, we found that disambiguation can be found in children with multilingual language experience. Learning a new word consists of two different processes, namely fast mapping and slow learning, that are linked, but develop independently. It appears that children growing up in a multilingual environment rely on other constraints that help them hone these processes. Thus, disambiguation should be, first and foremost, considered a mapping strategy with a potential extension as 'retention' strategy for monolingual children. Eventually, further research needs to be carried to increase our understanding of multilingual word learning. Especially the investigation of the underlying mechanisms that drive retention and its developmental trajectory should receive more focus, as it is not yet clear how these constraints can be described.

Other directions to explore the difference in using disambiguation as 'learning strategy' include investigating real-time gaze data to determine patterns, as well as how variables such as cumulative length of exposure, current exposure, or quality of input impact on disambiguation and retention for multilingual children. Another aspect of the disambiguation effect that has not yet been researched is the possibility of different types of disambiguation upon which multilingual children might rely. In other words, it would be unhelpful to a multilingual child to rely on disambiguation in a cross-linguistic word learning situation as it would lead to prevention of many-to-one mappings. However, if multilingual children find themselves in a predominantly monolingual situation, they might be more likely to use disambiguation as it would satisfy the ME assumption that one referent possesses only one label. As the present study only involved one of the children's languages, namely English, multilingual children were in a rather monolingual mode where they had to suppress their other first languages. This means they were tested on within-language disambiguation, which they do rely on albeit with a delay. Developing an experiment that includes language-switch mode trials will keep both languages active, and therefore, test between-language disambiguation. This co-activation of both languages in a bilingual might lead to less use of disambiguation in multilingual children.

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Table 1: Sample demographics. Means (and standard deviations). NB: In the main analysis bilingual and trilingual children were part of one group ("Multilingual")

	Monolingual		Bilingual		Trilingual	
N	43		28		12	
Age (in months)	24.62		24.38		22.58	
SES	7.32	(2.87)	6.75	(2.70)	6.92	(2.75)
CDI	236.31	(180.01)	219.54	(186.31)	71.00	(164.20)
Current English exposure (average % per week)			0.67	(0.19)	0.42	(0.16)
Cumulative English exposure (in years)			1.08	(0.48)	0.56	(0.50)
AfE English (m;d)	0;0	-	0;27	(3;3)	1;24	(3;18)
Current Other Language 1 exposure (average % per week)			0.34	(0.18)	0.37	(0.16)
Cumulative Other Language 1 exposure (in years)			0.70	(0.41)	0.42	(0.49)
AfE Other Language 1 (m;d)			0;20	(3;14)	0;13	(1;14)
Current Other Language 2 exposure (average & per week)					0.22	(0.10)
Cumulative Other Language 2 exposure (in years)					0.31	(0.36)
AfE Other Language 2 (m;d)					1;5	(2;26)

(Abbreviations: N = number of children; SES = Socioeconomic status; CDI = MacArthur-Bates Communicative Development Inventories ; AfE = Age of first exposure)

Table 2: Carrier phrases and items

Carrier phrase	Label	Item
Look at the …! …!	*Ball*	Familiar (F)
Find the …! …!	*Car*	Familiar (F)
Where is the …? …?	*Nil*	Trained (T)
	Dax	Novel (N)

Table 3: Accuracy (means and SDs) for each target in each condition by group

Group	Condition	Target	*M*	*SD*
Monolingual	Familiar (familiar vs familiar)	*ball*	0.60	0.49
		car	0.83	0.38
	Disambiguation (familiar vs novel)	*ball*	0.64	0.48
		car	0.75	0.43
		dax	0.66	0.47
	Ostensive Teaching	*nil*	0.98	0.12
	Familiarity (familiar vs trained)	*ball*	0.69	0.46
		car	0.79	0.41
		nil	0.76	0.43
	Retention (novel vs trained)	*dax*	0.55	0.50
		nil	0.63	0.48
Multilingual	Familiar (familiar vs familiar)	*ball*	0.57	0.50
		car	0.77	0.42
	Disambiguation (familiar vs novel)	*ball*	0.73	0.44
		car	0.74	0.44
		dax	0.58	0.49
	Ostensive Teaching	*nil*	0.99	0.09
	Familiarity (familiar vs trained)	*ball*	0.65	0.48
		car	0.66	0.47
		nil	0.62	0.48
	Retention (novel vs trained)	*dax*	0.48	0.50
		nil	0.67	0.47

Table 4: Model 1 – Formula: $\boldsymbol{TargetLook \sim Target * Vocabulary\ (scaled) * Group\ + (1|TrialId) + (1 + Target|Subject)}$

	e^{β}	Std. Error	z value	p-values
(Intercept)	2.93	1.41	22.67	0.002**
Target (novel)	0.66	1.62	0.43	0.395
Vocabulary (scaled)	1.01	1.32	1.04	0.968
Group (multilingual)	1.50	1.51	2.67	0.325
Target (novel):Vocabulary (scaled)	1.38	1.50	2.22	0.425
Target (novel):Group (multilingual)	0.29	1.80	0.12	0.034*
Vocabulary(scaled):Group (multilingual)	0.79	1.51	0.56	0.562
Target(novel):Vocab(scaled):Group(multilingual)	2.14	1.82	3.55	0.206

Table 5: Model 2 – Formula: $\boldsymbol{TargetLook \sim Target * Vocabulary\ (scaled) + (1|TrialId) + (1 + Target|Subject)}$

	e^{β}	Std. Error	z value	p-value
(Intercept)	4.99	1.42	94.69	0.000***
Target (novel)	0.16	1.73	0.04	0.001***
Vocabulary (scaled)	0.74	1.42	0.42	0.387
Target(novel):Vocabulary (scaled)	3.25	1.76	8.03	0.037*

Table 6: Model 3 – Formula: $\boldsymbol{TargetLook \sim Target * Group * Vocabulary\ (scaled) + (1|TrialId) + (1 + Target|Subject)}$

	e^{β}	Std. Error	z value	p-value
(Intercept)	0.74	1.47	0.47	0.447
Target (novel)	1.63	1.59	2.85	0.295
Group (multilingual)	1.03	1.59	1.07	0.943
Vocabulary (scaled)	2.13	1.38	10.27	0.020*
Target (novel): Group (multilingual)	1.30	1.70	1.63	0.625
Target (novel): Vocabulary (scaled)	0.92	1.44	0.78	0.808
Group: Vocabulary (scaled)	0.71	1.61	0.48	0.467
Target (novel): Group (multilingual): Vocabulary (scaled)	1.66	1.70	2.60	0.339

Table 7: Model 5 – Formula: $\boldsymbol{TargetLook \sim Target * Group * Disambiguation\ rate + Vocabulary\ (scaled) + (1|TrialId) + (1 + Target|Subject)}$

	e^{β}	Std. Error	z value	p-value
(Intercept)	0.08	1.63	0.01	0.000***
Group (multilingual)	15.20	1.75	129.22	0.000***
Disambiguation rate	37.37	1.96	215.12	0.000***
Target (trained)	8.75	1.77	45.17	0.000***
Vocabulary (scaled)	1.87	1.18	41.67	0.000***
Group (multilingual):Disambiguation rate	0.01	2.29	0.00	0.000***
Group (multilingual):Target (trained)	0.16	2.00	0.07	0.010**
Disambiguation rate: Target (trained)	0.07	2.16	0.03	0.000***
Group (multilingual):Disambiguation rate: Target (trained)	47.94	2.77	44.54	0.000***

Table 8: Model 5 (monolingual children) – Formula: $\boldsymbol{TargetLook} \sim \boldsymbol{Target} * \boldsymbol{Disambiguation\ rate} + \boldsymbol{Vocabulary}\ (\boldsymbol{scaled}) + (\mathbf{1}|\boldsymbol{TrialId}) + (\mathbf{1} + \boldsymbol{Target}|\boldsymbol{Subject})$

	e^{β}	Std. Error	z value	p-value
(Intercept)	0.09	1.96	0.03	0.000***
Disambiguation rate	31.90	2.54	41.15	0.000***
Target (trained)	7.19	2.23	11.73	0.014*
Vocabulary (scaled)	1.73	1.20	19.65	0.003**
Disambiguation rate: Target (trained)	0.08	2.98	0.10	0.024*

Table 9: Model 6 (multilingual children) – Formula: $\boldsymbol{TargetLook \sim Target * Disambiguation\ rate + Vocabulary\ (scaled) + (1|TrialId) + (1 + Target|Subject)}$

	e^{β}	Std. Error	z value	p-value
(Intercept)	1.37	1.82	1.68	0.602
Disambiguation rate	0.30	2.46	0.26	0.180
Target (trained)	1.01	2.26	1.02	0.987
Vocabulary (scaled)	2.14	1.36	11.82	0.014*
Disambiguation rate: Target (trained)	5.79	3.16	4.60	0.127

Figure 1: Stimuli (from left to right: ball, car, nil, and dax)

Figure 2: Interaction between target and language background (marginal effects) on disambiguation trials

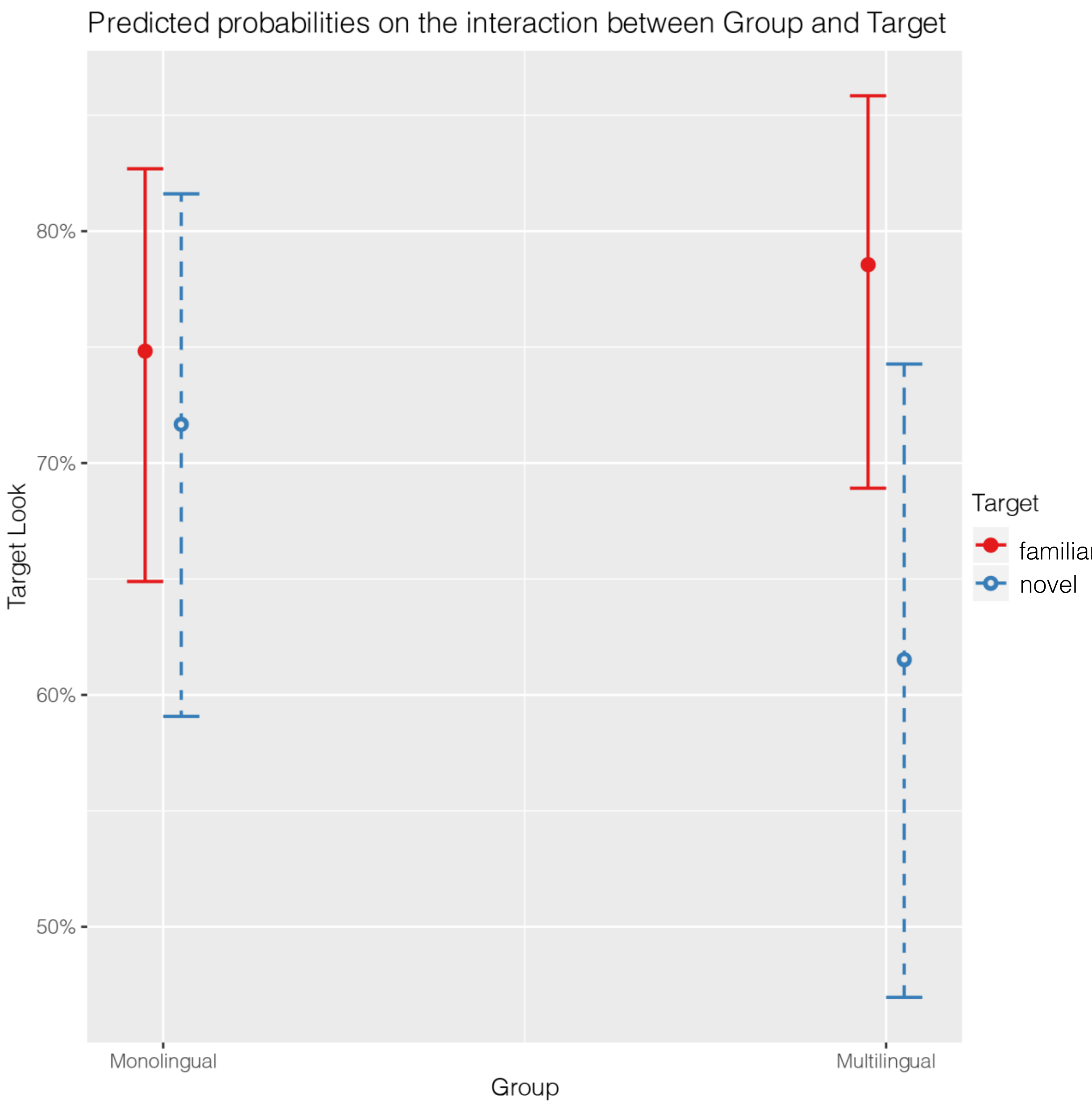

Figure 3: Interaction between target type and vocabulary size (marginal effects) on disambiguation trials for multilingual children

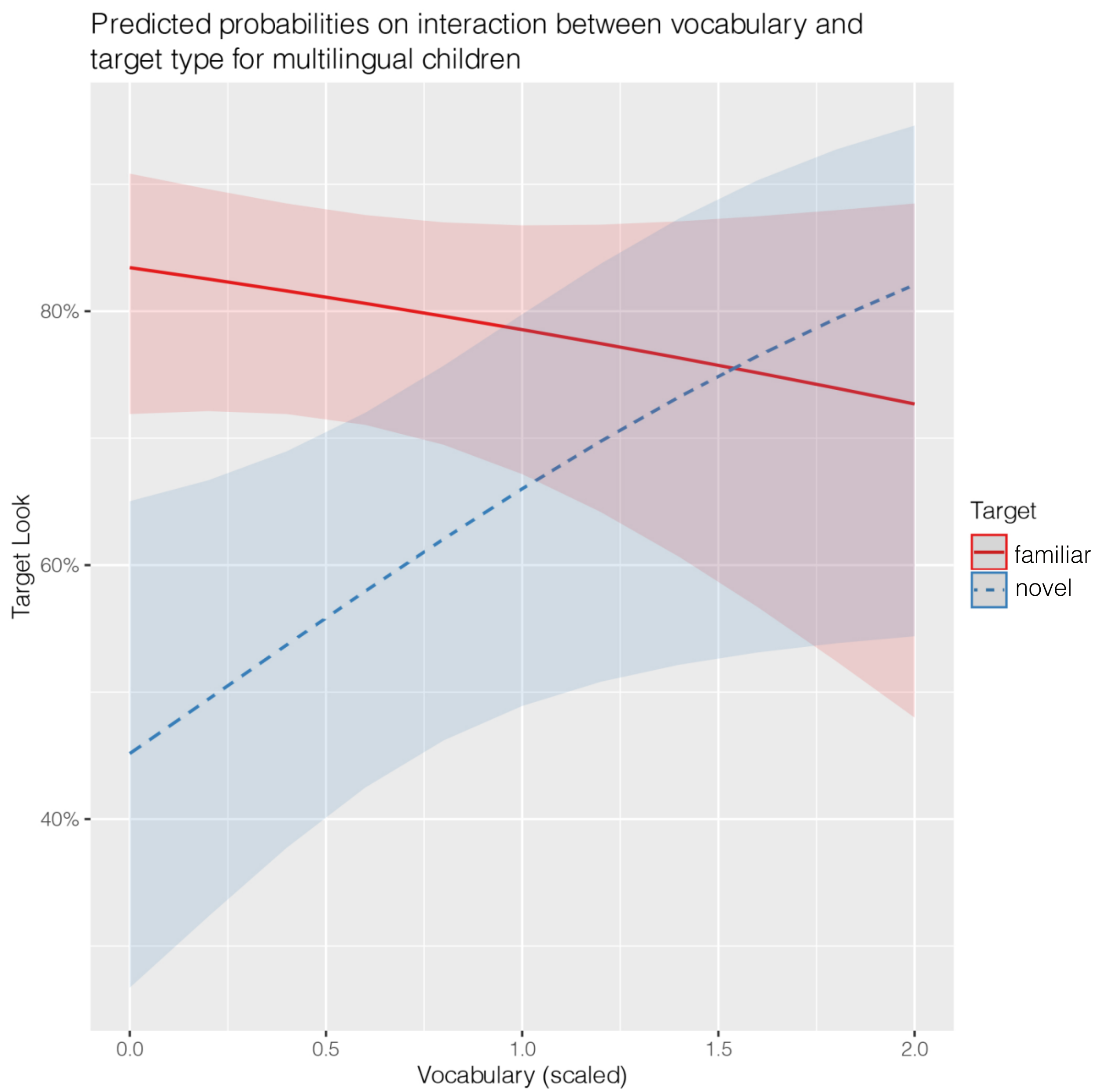

Figure 4: Main effect for vocabulary (marginal effects) on retention via fast-mapping trials

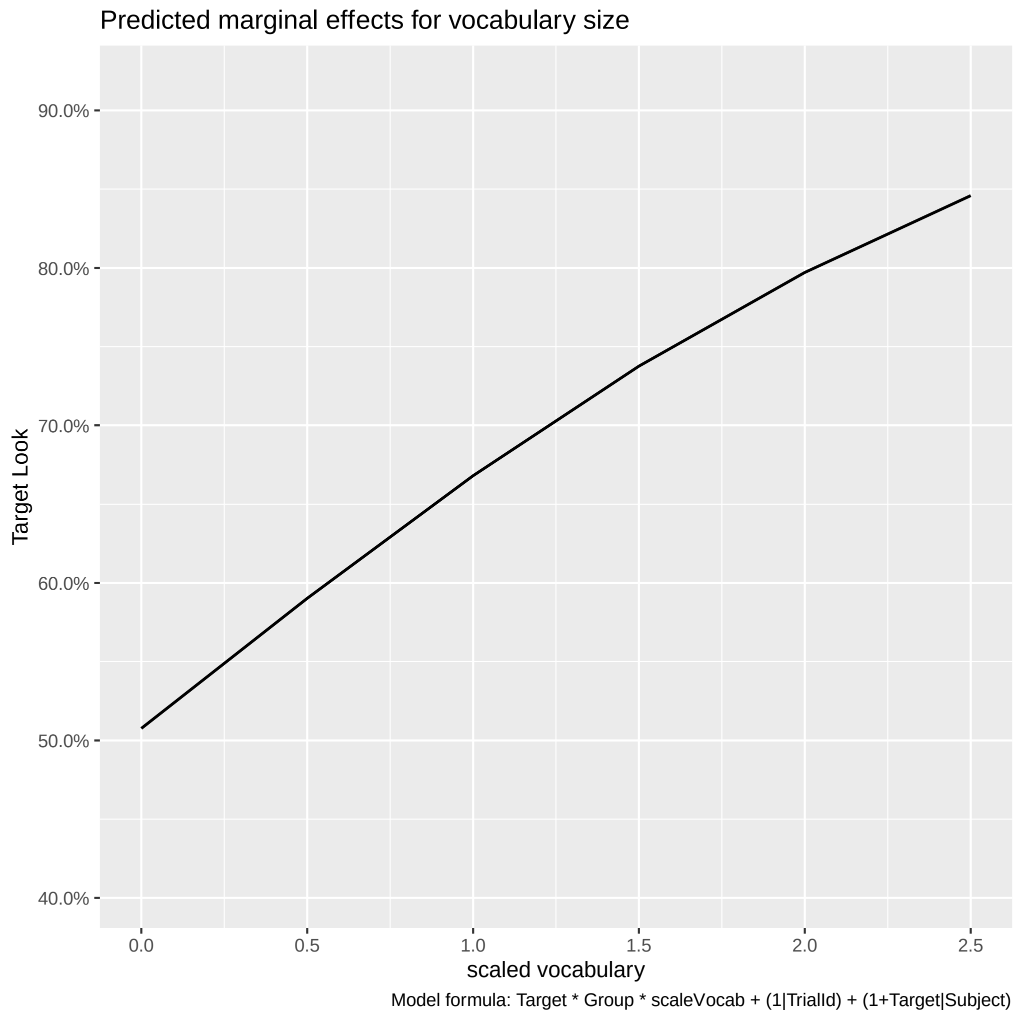

Figure 5: Interaction between proportional use of disambiguation, group and target item (marginal effects) on retention trials