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Failure to show robust noun-referent associations in German-learning infants

Running title: Noun-referent associations in German-learning infants

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Abstract

Work with the looking-while-listening paradigm suggested that six-month-old English-learning infants associated several common nouns with pictures of their referents. This was evidenced by systematic fixations towards the named target picture (while one distractor picture was present). However, Norwegian-learning infants did not systematically fixate the target pictures until they were 8- to 9-months old, suggesting a cross-linguistic difference in the onset of noun comprehension. Moreover, their success in this task appeared to be modulated by aspects of stimulus pairing, specifically frequency differences between target and distractor: High (resp. low) frequent targets attracted more fixations if they were paired with low (resp. high) frequent distractors. In the present eye-tracking study, we tested 42 monolingual German-learning infants aged six to 14 months by means of a looking-while-listening paradigm. Infants saw two pictures side-by-side on a screen, whilst an unfamiliar male talker named one of both. Overall, infants did not fixate the target picture more than the distractor picture. In line with previous results, infants' performance on the task was higher when the target and distractor word differed within their word frequency operationalized by the parental rating of word exposure. Therefore, our results further emphasize cross-linguistic differences in early word learning and strengthen the view that infants might use extra-linguistic cues within the stimulus pairing, such as frequency imbalance, to disambiguate between two potential referents.

Keywords: word comprehension¹, language acquisition², word learning³, eye-tracking⁴, infant cognitions

Introduction

Where is the bottle? Researchers have been interested in the time when infants start to connect the articulated label “bottle” with its visual referent, for instance, a picture of the bottle. The investigation of such noun-referent associations has been of particular interest, as those seem to be a first step within the important milestone of word comprehension in infancy (Swingley, 2009). The most upfront approach is to use a *parental report*, and simply ask infants' caregivers if they think their infant does or does not understand the word bottle. The MacArthur-Bates Communicative Developmental Inventory (MCDI; Fenson et al., 1994; Fenson et al., 2007) is a widely adopted parental report on children's receptive and productive vocabulary. The accumulation of multiple MCDI reports across different age groups and languages provided a useful approach to get insight into infants' early word comprehension (see Wordbank Project [<http://wordbank.stanford.edu>]; Frank et al., 2017). Overall, parents reported their infants understood first words around eight months of life (Fenson et al., 1994). However, results from these subjective parental reports are not without challenges (for a full review please see Frank et al., 2021).

Another promising tool to tackle early word comprehension more directly by testing the infant itself is the *looking-while-listening paradigm* (LWL-paradigm; Fernald, 1985; Fernald et al., 2008). Here, infants see two visual stimuli (e.g., a picture of a bottle and picture of a hat) presented side-by-side, whilst hearing an utterance that matches only to one of the two visual stimuli (e.g. “Look at the bottle!”). If an infant associates the word (‘bottle’) with its referent (picture of the bottle), the infant is expected to look longer to the picture of the corresponding referent, compared to the distractor picture (Fernald et al., 2008; Swingley, 2012). Mostly in the past decade, several studies used the LWL-paradigm to investigate English-learning infants within their first year of life. Infants listened, for example, to either “mommy” or “daddy” paired with videos of their own parents (Tincoff and Jusczyk, 1999), to either “hand” or “feet” paired with videos of unknown hands and feet (Tincoff and Jusczyk, 2012), or to common nouns like „banana“ or „teddy“ paired with prototypical pictures of respective referents (Bergelson and Swingley, 2012; 2015; Syrnyk and Meints, 2017). Even though all studies varied within their stimulus pairing and underlying analytic measures, the results suggest that the first signs of noun-referent associations in infants arise at six to nine months.

Findings of LWL-studies not only pinpointed word comprehension earlier in an infant's life than typically reported by parents (Fenson et al., 1994), but several of them also showed a rather weak correlation between individual performance of infants and respective parental report (Bergelson and Swingley, 2013; 2015; 2018; Kartushina and Mayor, 2019). However, it

should be noted that few studies did suggest a rather strong relation between both measures (Styles and Plunkett, 2009; Syrnyk and Meints, 2017). Several reasons can be accounted for the lack of accordance between evidence from parental reports and the LWL-paradigm. For instance, different criteria for a word to be counted as understood within both measures might cause conflicting results (for a full review please see Frank et al., 2021). Indeed, further studies have shed light on potential design dimensions that might enable infants to show signs of word comprehension earlier than can be concluded from parental reports (Bergelson and Aslin, 2017; Bergelson and Swingley, 2018; Kartushina and Mayor, 2019). Subsequently, we want to shortly introduce four experimental parameters that link to the variability of findings obtained with the LWL-paradigm so far: talker familiarity, target language, stimulus pairing, and infants' age.

First, the *familiarity of the talker* articulating the target words: Does it matter if the target words are articulated by a to the infant familiar talker (e.g. parent) or by an unfamiliar talker? So far, it appeared that English-learning 6-month-olds' word comprehension was not impaired if an unfamiliar female talker produced highly socially relevant stimuli (Tincoff and Jusczyk, 1999; 2012). Furthermore, English-learning 8- to 9-month-olds showed word comprehension for common nouns produced by an unfamiliar female talker (Syrnyk and Meints, 2017). However, results from a recent study suggested, that an unfamiliar talker might hinder word comprehension (Bergelson & Swingley, 2018). Here, 8- to 10-month-old infants failed to associate the tested words with their referents when articulated by an unfamiliar talker, whilst 6- to 7-month-olds and 11- to 14-month-olds performed equally well regardless of the familiarity of the talker. Herewith, implying a u-shaped development of understanding unknown talkers within the first year of life. Regardless of the portrayed inconsistencies, who articulates the target words potentially affects an infant's performance within the LWL-paradigm and should therefore be investigated further.

Second, the *target language* might modulate infants' performance within the LWL-paradigm (Kartushina and Mayor, 2019). Up to now, most studies have exclusively investigated English-learning samples (Bergelson, 2020). Thus, little is known about potential cross-linguistic differences in the onset of word comprehension evidenced by the LWL-paradigm. One study investigating Norwegian-learning infants found evidence for a cross-linguistic shift in the early onset of word comprehension (Kartushina and Mayor, 2019). Here, Norwegian-learning infants did not associate nouns articulated by an unknown female talker with their corresponding referents until they were 8- to 9-months of age, thus two months later than the previously investigated English-learning infants (Bergelson and Swingley, 2018). This was especially striking, as within the MCDI reports parents of Norwegian-learning and English-

learning infants did not report any remarkable differences in the number of words their infants understood (see Kartushina and Mayor, 2019; Frank et al., 2021). Nonetheless, as Kartushina and Mayor (2019) argue the fact that Norwegian is phonologically more complex than English might have contributed to their findings. Importantly, these results highlight the need to assess word comprehension using LWL-studies within a broader range of target languages (Bergelson, 2020).

Third, the target words themselves and especially the *stimulus pairing* of these target words appear to modulate the infant's performance within the LWL-paradigm (Bergelson, 2020). Certain aspects of the stimulus pairing might increase or decrease the performance and vary extensively across different LWL-studies which makes cross-study comparisons difficult (Delle Luche et al., 2015). Besides cues like perceptual similarity (Arias-Trejo and Plunkett, 2010) or semantic relatedness between target and distractor word (Bergelson & Aslin, 2017), word frequency of targets and distractors modulated infants' responses in the LWL-paradigm (Kartushina and Mayor, 2019). Herewith, it was easier for infants to detangle the target from the distractor picture, when one label was from rather high (resp. low) word frequency, while the other was from rather low (resp. high) word frequency. To establish the word frequency experienced by children, the authors referred to the Child Language Data Exchange System (CHILDES; MacWhinney, 2000). The CHILDES database includes multiple transcripts of interactions between caregivers and their children across a variety of target languages. By deriving the absolute count of any given word, word frequency can be estimated. This absolute difference in word count for stimulus pairs (frequency imbalance) was positively related to the performance within the LWL-paradigm for 8- to 9-month-old Norwegian-learning infants listening to an unfamiliar talker (Kartushina and Mayor, 2019). Additionally, a comparable positive relation was found in a post-hoc analysis of data from Bergelson and Swingley (2012) recorded from 6- to 7-month-old English-learning infants listening to their caregiver. This suggests that infants used frequency imbalance information as one important cue to succeed within the LWL-paradigm (Kartushina and Mayor, 2019).

Lastly, we want to address *infants' age* and its relation to the performance within the LWL-paradigm. The previously introduced LWL-studies investigated infants ranging from six to fourteen months of age (Bergelson and Swingley, 2012). At first sight, one would presume infants to show a gradual improvement in early word comprehension by age. This expected linear increase in word comprehension upholds for the parental reports. Not surprisingly, parents report infants to understand more words, as older infants get (Bergelson, 2020). Yet, such a gradual increase in performance is not reflected within the LWL-paradigm. Here, infants'

age did not correlate to their performance (Bergelson and Swingley, 2012). Moreover, infants between 6- to 13-months showed little improvements within the LWL-paradigm and a more sizeable improvement not until 14-months of age (Bergelson and Swingley, 2012; 2015; Bergelson, 2020). At least, for words articulated by a familiar talker. As already noted, for an unfamiliar talker the performance development might rather follow a u-shaped curve, which Bergelson and Swingley, 2018 interpret in terms of a phonological restructuring of the lexicon (starting with less detailed representations, entries become more detailed over time, temporarily hindering the recognition of slight variation). Nevertheless, both studies suggest a non-linear development, that contrasts with the linear development that is reflected in the parental report (Bergelson, 2020).

All in all, the foregoing research highlighted the importance of specifying early word learning for different target languages and different experimental parameters, e.g. talker familiarity (Bergelson and Swingley, 2018) and word frequency differences of stimulus pairings (Kartushina and Mayor, 2019). With the present work, we planned to contribute data from 6- to 14-month-old German-learning infants listening to an unfamiliar talker. Thereby, we directly tie in with the unfamiliar talker condition of Bergelson and Swingley (2018) and the study of Kartushina and Mayor (2019). Based on their previous findings, we expect to find word comprehension in measures of the LWL-paradigm within the tested age span. We test if German-learning infants show the onset of early word comprehension within the LWL-paradigm as English-learning infants around 6- to 7-months of life (Bergelson and Swingley, 2018) or only later (e.g., around 8- to 9-months of life as shown for Norwegian-learning infants by Kartushina & Mayor, 2019). More preciously, we want to address the question if we can replicate the u-shaped trajectory of word comprehension that English-learning infants show given an unfamiliar talker (Bergelson and Swingley, 2018) within the German-learning sample and new stimulus material. Exploratively, we investigated the relationship between the word frequency imbalance of the tested stimulus pairs and the infant's performance within the LWL-paradigm. If infants used the additional frequency information for their success within the task, this should be reflected within a positive correlation between the frequency imbalance of the stimulus pairs and the performance in the LWL-paradigm (Kartushina and Mayor, 2019).

Method

Participants

The study was approved by the local ethics committee of the University of Tuebingen (11-14-2018). Data collection took place at the laboratory of the psychological institute in Tuebingen

or at family's homes between November 2018 and February 2020. All families were recruited in the area around the University of Tuebingen via e-mail, phone, and in person. Families participated in a larger study that investigated language development with multiple smaller experiments, one of them being the of interest LWL-paradigm. Families were compensated with a children's book (worth approx. 10 Euros).

In total, we tested 70 infants between 6 to 14 months of age.¹ We discarded data from 28 infants. Eleven of those infants heard another language than German at their homes and 17 infants contributed an insufficient amount of data (see Results). All 42 infants of the final sample ($M = 10.24$ months, $SD = 2.63$ months, 29 female) were raised monolingual, carried full-term (> 37 weeks of pregnancy), and had no chronic ear infection at the time of testing. The highest maternal education level ranged from ten educational years to a university degree. The majority (62 %) of mothers completed a bachelor's degree or higher.²

To align the present analyses, we formed age groups based on Bergelson and Swingley (2018) with infants 6-7 months, 8-10 months, and 11-14-months. See Table 1 for further demographic information of the final sample distributed across the three age groups.

Table 1

Age in months (M , SD , range) and sample distribution in all four age groups

	Age group		
	6-7 months	8-10 months	11-14 months
$N_{\text{female}} / N_{\text{total}}$	6 / 10	13 / 15	10 / 17
$M_{\text{age in months}}$	6.79	9.68	12.77
$SD_{\text{age in months}}$	0.63	0.89	1.49
$\text{Range}_{\text{age in months}}$	6.07-7.83	8.10-10.77	11.13-15.13 ^a

Notes. ^a Deviations are due to the procedure of calculating age in months with on average 30 days per month. However, all included infants fitted the age criterion at the time of testing.

¹ Note, that we tested additional 20 infants between 4 to 5 months of age. Data quality within the 18 monolingual infants was low. On average they provided only data to 2.88 of our 14 stimulus pairs, and 44 % of infants provided not enough data to compute any proportion indices. Therefore, and for higher comparability to previous studies, we excluded the whole age group from all further analysis.

² Parents of the participating infants were more highly educated than would be expected for a representative German sample. This reflects the selection bias in psychological research in general (Henrich et al., 2010) and in research on psychological development in particular (Nielsen et al., 2017).

Material

Looking-while-listening paradigm

The looking-while-listening paradigm (Fernald et al., 2008; Swingley, 2009) was implemented with Presentation® (Neurobehavioral Systems Inc., Albany, CA, US) and presented on an ASUS-Notebook (17.30 inch) with a screen resolution of 1920 x 1080 pixels. The Tobii X2-60 Compact® (Tobii Technology AB, Stockholm, Sweden) collected infants' eye gaze with an average accuracy of 0.40 degrees under optimal conditions, sampling binocular from 60 Hertz (for further details see Tobii Technology AB, 2014).

We used 28 German disyllabic nouns with stress on the first syllable as target words (see Appendix, Table A1). Word selection was based on a parental screening questionnaire for 12-month-old infants (ELFRA-1; Grimm and Doil, 2006) or words were further typically thought to be familiar to young infants or already been used in prior research (Bergelson and Aslin, 2017). All target words were embedded in carrier phrases (e.g. "Look at...") and recorded by a male German native speaker. The talker was instructed to use infant-directed speech prosody.

All 28 discrete pictures (see Appendix, Table A1), visualizing the target words, were acquired on Shutterstock.com (Shutterstock Inc, 2021). The LWL-task presented pictures of each stimulus pair simultaneously side-by-side (500 pixels left or right from the screen center) on a white background. The size of the target pictures was nearly constant (width resp. height = 700 800 pixels). We used videos of different objects (e.g. rattle) accompanied by different sounds (e.g. horn) as attention getters out of the Tobii Studio Software® inventory. To center infants' eye gaze, a flashing dot was used (225 x 225 pixels).

Questionnaires

Within a demographical questionnaire, parents answered questions about their infant (age, sex, preemie, ear infection), themselves (e.g. highest school education, native language, speaking other languages than German with their infant), and (where applicable) about their partner (the same information as for themselves). Within the vocabulary questionnaire, the caregivers estimated their infant's receptive and productive vocabulary of 41 words, among them the 28 target words. Parents evaluated whether they believe their infant (i) "understands" or (ii) "understands and speaks" or (iii) "does not understand" the word. Additionally, parents rated their infant's daily exposure to each word. Parents were asked how often they believed their infant heard the word on a five-point Likert scale ("1" = "rarely" to "5" = "several times a

day”). Mean values on this five-point Likert scale were later used as the frequency measure for each target word.

CHILDES sample

Kartushina and Mayor (2019) relied their word frequency measure on the absolute word count derived from the Norwegian CHILDES database (<https://childes.talkbank.org/access/Scandinavian/>; MacWhinney, 2000). To guarantee comparability we computed the frequencies of our targets based on the German CHILDES database (<https://childes.talkbank.org/access/German/>; MacWhinney, 2000). Overall, 64 German-learning children (out of 119) heard at least one of our 28 target words during the communicative situations that were transcribed in CHILDES. This sample was aged between 10.07 months and 12.17 years ($M = 34.43$ months, $SD = 13.75$ months). However, data for children from middle and late childhood appear to be a somewhat problematic measure of word frequency in the scope of the present study. For example, the absolute exposure to the word ‘diaper’ might dramatically change for a twelve-year-old child, compared to a twelve-month-old child. Considering the whole Norwegian CHILDES database children’s age spanned only between 13.76 to 33.07 months ($M = 24.93$ months, $SD = 4.64$ months), leading to a more relatable age group for the tested infant sample. Therefore, we adjusted our CHILDES sample to a sub-sample of children under 33 months of age, resulting in 51 children between 10.07 to 32.95 months of age ($M = 25.69$ months, $SD = 4.53$ months), who heard at least one of our 28 target words.

Procedure

The infant’s caregiver gave their informed consent before the approximately 45 to 60 minutes long study started. In the following, we describe only the relevant aspects for the outlined research question. Parents completed the demographical and vocabulary questionnaire. For the LWL-task, the participating infant sat on the lap of her caregiver, who wore opaque glasses. Both faced a computer display (distance approx. 60 cm), preferably in a dimly lit room. Before the LWL-task started, the two experimenters instructed the caregiver to interact as little as possible and not to talk to her infant during the LWL-task. Before starting the experiment, the experimenter started a five-point infant-adjusted eye-tracking calibration. By the calibration procedure, the geometric characteristics of the participants’ eyes are estimated (as implemented in the Tobii Studio Software®). If necessary, the experimenter reran the calibration multiple

times until the characteristics of the infant's eyes could be reliably extracted and used together with an internal, anatomical 3D eye model to calculate the gaze data (see www.tobiipro.com). In total, infants saw 28 trials in the LWL-task. Each stimulus of every yoked stimulus pair was once named as the target. Thus, each stimulus pair was presented twice, once in each half of the experiment. Within one infant, both stimuli of a yoked stimulus pair remained on the same presentation side. Infants were randomly assigned to one of the four experimental orders, counterbalancing for the side on which the pictures occurred within each yoked stimulus pair (left vs. right screen side) and which stimulus was first named as the target within each yoked stimulus pair (Swingley, 2012). The sequence of the stimulus pairs within the experimental halves was randomized. The time course of one trial is illustrated in Figure 1 and was identical for the presentation of all stimulus pairs. The inter-trial interval was 1000 milliseconds (ms). After every fifth trial, infants saw one of five different attention getters in randomized order, to keep their attention on the computer screen. In sum, the LWL-task took approximately 4 minutes and 30 seconds.

Figure 1. Time course of one trial (-1000 to 7000 ms) exemplified by the stimulus pair bottle-hat.

Results

All analyses were conducted with the R software (R Core Team, 2020) and aligned with Bergelson and Swingley (2018). We conducted only non-parametric tests (two-sided Wilcoxon signed-rank test against chance, Kruskal-Wallis test), except for the Pearson correlation tests, and evaluated statistical significance based on the α -level of .05. We used the BayesFactor package to compute Bayes factors, with default priors of `ttestBF`, `anovaBF`, and `correlationBF` (Morey and Rouder, 2015). We reported BF_{01} , hence the likelihood of the data given the null hypothesis (H_0) relative to the alternative hypothesis (H_1). Therefore, values greater one indicated evidence *for the null hypothesis* (H_0). We used the evidence categories from Lee and Wagenmakers (2014), based on Jeffreys (1961), to interpret the strength of evidence. Pre-

processed data, and R-scripts are available here https://osf.io/72tjz/?view_only=bb78b0c0a3e74b4b94c4dbd92c971317.

Data exclusion

To control for extreme fussiness, we discarded all trials with infants looking less than 12.5 % to the screen during each trial (per stimulus pair: $M = 6.57$ trials, $SD = 3.34$ trials). Due to insufficient data, we excluded 17 infants who provided data to less than 4 of our tested 14 stimulus pairs. This corresponds to less than one-quarter of all tested stimulus pairs, to keep data loss as minimal as possible.

Object-label associations as proportion index

We expected infants who understood the target word within the LWL-task to look more at the target picture than at the distractor picture upon hearing the target word named (Bergelson and Swingley, 2012). To operationalize this looking preference, we calculated proportion indices (PI's) over the post target window of interest (368 to 3505 ms after the onset of the spoken target word, due to technical restraints slightly modified [± 5 ms] but based on Bergelson and Swingley, 2018). The PI calculates infants' fixations to the target picture (relative to all fixations to the screen) in relation to infants' fixation to the picture when it was a distractor (relative to all fixations to the screen; see Bergelson & Swingley, 2012). The PI could range from -1 to +1. More fixations to the target than the distractor picture within both presentations of the stimulus pair result in positive PI's and thus are interpreted as an indicator for noun-referent associations (Bergelson and Swingley, 2012). We reported only one PI per stimulus pair, because of the presentation of yoked stimulus pairs, the PI for each individual stimulus pair is arithmetically redundant (Bergelson and Swingley, 2012).

In the following analyses, we operationalized noun comprehension by two different mean measures: (i) proportion index by infant, calculated overall stimulus pairs (PI-by-infant), and (ii) proportion index by stimulus pair, calculated over all infants (PI by item). See Figure 2 for an illustration of (i) PI-by-infant. On average 7.67 stimulus pairs ($SD = 2.77$ stimulus pairs) were provided to calculate the PI-by-infant. In total 17 of 42 infants showed a positive PI-by-infant ($Mdn = -0.016$, $IQR = 0.18$). Contrary to our expectation, the mean PI-by-infant was not significantly different from zero, $V = 442.00$, 95 % CI [-0.039, 0.046], $p = .91$, Cohen's $d = 0.026$, $BF_{01} = 5.91$ (moderate evidence for H_0 : $PI = 0$). See Figure 3 for an illustration of the (ii) PI-by-item. On average 45 % of infants ($SD = 3.68$ infants) provided data to compute the PI by item. In total 7 out of 14 stimulus pairs showed a positive mean PI by item ($Mdn = 0.0035$,

$IQR = 0.046$). Contrary to our expectation, the PI by item was not significantly different from zero, $V = 59.00$, 95% CI $[-0.023, 0.074]$, $p = .71$, Cohen's $d = 0.21$, $BF_{01} = 2.83$ (anecdotal evidence for H_0 : $PI = 0$).

Figure 2. Mean proportion index per infant as a function of infants age in days and clustered into the three age groups. Age groups performance is indicated by the individual boxplots. Each dot corresponds to the individual performance of one infant.

Figure 3. Mean proportion index by item (PI-by-item) for all age groups and standard errors.

PI-by-infant and PI-by-item per age group

Unexpectedly, neither the PI-by-infant nor the PI-by-item differed significantly between the age groups, PI-by-infant: $\chi^2(2, N = 42) = 0.43, p = .81, BF_{01} = 4.66$, PI-by-item: $\chi^2(2, N = 42) = 1.53, p = .47, BF_{01} = 3.83$. In line with previous findings (Bergelson & Swingley, 2012) infants' age in days did not correlate with the PI-by-infant, $r(40) = .083, p = .60, BF_{01} = 2.57$. Nonetheless, we conducted the planned separate statistical tests for each age group, to gain further insight into their noun comprehension. All descriptive and statistical results for each age group are displayed in Table 2. For none of the age groups, the PI by infant or PI-by-item differed significantly from zero, all $ps \geq .43$. Furthermore, Bayes factors supported this null effect with anecdotal to moderate evidence, $BF_{01} = 2.61-4.01$. For visualization purposes Figure 4 shows the time course of infants' target fixation separately for each age group.

Table 2

Descriptive distribution (Mdn) of both PI's, and two-sided Wilcoxon signed-rank test results, 95 % CI's, Cohen's d, Bayes factor and evidence interpretation for all age groups

		Age group		
		6–7 months	8–10 months	11–14 months
<i>N</i>_{Positive} / <i>N</i>_{Total}	PI-by-infant	5 / 10	7 / 15	8 / 17
	PI-by-item	4 / 14	8 / 14	6 / 14
<i>Mdn</i>	PI-by-infant	-0.0073	-0.014	-0.025
	PI-by-item	-0.020	0.049	-0.0090
Wilcoxon test	PI-by-infant	$V = 22.00, p = .63$	$V = 67.00, p = .72$	$V = 74.00, p = .93$
	PI-by-item	$V = 39.00, p = .43$	$V = 65.00, p = .46$	$V = 53.00, p > .99$
95 % CI	PI-by-infant	[-0.12, 0.067]	[-0.047, 0.090]	[-0.083, 0.096]
	PI-by-item	[-0.10; 0.069]	[-0.054, 0.12]	[-0.056; 0.15]
Cohen's <i>d</i>	PI-by-infant	0.16	0.20	0.0086
	PI-by-item	0.14	0.24	0.21
<i>BF</i>₀₁	PI-by-infant	2.90	2.93	4.01
	PI-by-item	3.29	2.61	2.84
Evidence for <i>H</i>₀	PI-by-infant	anecdotal	anecdotal	moderate
	PI-by-item	moderate	anecdotal	anecdotal

Vocabulary questionnaire

Caregivers reported that their infants understood on average 11.55 words of the 28 target words ($SD = 6.47$ words, $range = 0-24$, Mode = 14 [5 out of 42 parents]). In line with previous studies (Bergelson and Swingley, 2013; 2015; 2018; Kartushina and Mayor, 2019), there was no significant correlation between the results from the LWL task (PI-by-infant) and the number of as understood reported target words within the vocabulary questionnaire, $r(40) = .11, p = .50$, $BF_{01} = 2.36$ (anecdotal evidence for $H_0: r = 0$). The number of target words reported as understood increased with infants age in days, $r(40) = .46, p < .005$, $BF_{01} = 0.047$ (moderate evidence for $H_1: r \neq 0$). Suggesting a linear increase of infants' receptive vocabulary based on parental reports, which supports previous claims (Bergelson, 2020).

Figure 4. Infants mean proportion of looks to the target (ordinate), averaged over the time course of the trial from the onset of the target word up to 4000 ms (abscissa). Vertical black lines indicate the time window of interest. Horizontal black line indicates looking to the target (above .50) or looking to the distractor (below .50).

Explorative analysis: Frequency imbalance

Word frequency by parental vocabulary questionnaire

Post-hoc we computed the frequency imbalance within our stimulus pairs based on the parental report on word frequency within the vocabulary questionnaire. We computed the absolute frequency imbalance for each stimulus pair by subtracting the mean word exposure ratings of the 28 parental word evaluations within each stimulus pair. On average, stimulus pairs' word frequency differed by 1.01 points ($SD = 0.69$ points) on the five-point Likert-Scale. The largest frequency imbalance was found for the stimulus pair brush-diaper with an average of 2.42 Likert points difference. "Diaper" was rated more frequently ($M = 4.68$), than "brush" ($M = 2.26$). The smallest frequency imbalance was found for the stimulus pair bottle-hat, with an average of 0.05 Likert points difference. "Hat" was rated slightly more frequently ($M = 3.72$), than "bottle" ($M = 3.67$). In the whole sample frequency imbalance correlated significantly positive with PI-by-item, $r(12) = .49$, $p < .05$, $BF_{01} = 0.24$ (moderate evidence for H_1 : $r > 0$). This indicates that stimulus pairs with higher frequency imbalance were associated with a higher PI-by-item. The frequency imbalance distribution of the parental report in relation to PI-by-item is shown in Figure 5 (A). We investigated the relation between frequency imbalance of stimulus pairs separately within each age group. For age groups, 6-7 months and 11-14 months resulted no significant correlation (all $rs(12) \leq .047$, all $ps \geq .49$, $BF_{01} = 0.49$).

Age group 8-10 months showed a significant positive correlation, $r(12) = .65$, $p < .01$, $BF_{01} = 0.20$ (moderate evidence for $H_1: r > 0$). Suggesting, that the positive relation between frequency imbalance of stimulus pairs and LWL-performance within the whole sample is mostly driven by the performance of the 8- to 10-month-old infants.

Word frequency imbalance by CHILDES database

Aligned to Kartushina and Mayor (2019), we estimated the frequency imbalance based on the absolute word count. The absolute word count was derived from the German CHILDES database via the *childesr* package (Braginsky et al, 2020). Here, car-plate had the highest frequency imbalance ($\Delta\text{frequency} = 5267$) and fork-soup the lowest frequency imbalance ($\Delta\text{frequency} = 18$). Surprisingly, the relation between the CHILDES frequency data and our PI-by-item was negative, $r(12) = -.43$, $p = .94$, $BF_{01} = 2.36$. However, this negative correlation was mostly driven by the high deviation of the stimulus pair car-plate ($\Delta\text{frequency} = 5267$). This absolute frequency imbalance was more than three times higher than the second-highest frequency imbalance of the stimulus pair baby-bird ($\Delta\text{frequency} = 1475$). Thus, when excluding the stimulus pair car-plate, the correlation with the LWL-task performance for the whole sample was positive, $r(11) = .27$, albeit not significant, $p = .18$, $BF_{01} = 0.34$ ($H_1: r > 0$). See Figure 5 (B) for an illustration. Regarding age groups separately no significant correlation was evident between LWL-task performance and frequency imbalance, all $rs(11) \leq .26$, all $ps \geq .19$, $BF_{01} = 0.35-0.52$. Importantly, the German frequency measure did not significantly correlate with the frequency measure derived from the parental report, $r(12) = -.21$, $p = .47$, $BF_{01} = 1.51$.

Figure 5. Mean frequency imbalance, based on (A) German parent reports of word exposure, and (B) German CHILDES database in relation to the PI-by-item for the whole sample. A higher mean frequency imbalance reflects a greater difference in word exposure between the words within each stimulus pair. Please note that due to the high deviation the stimulus pair ‘car-plate’ is not displayed for the German CHILDES database.

Discussion

The present study aimed to replicate the foregoing results, that infants within their first year of life link nouns articulated by an unknown talker with corresponding visual referents (Bergelson and Swingle, 2018; Kartushina and Mayor, 2019). Unexpectedly, we failed to replicate these findings with German-learning infants. Neither the whole sample nor the individual age groups (6-7 months, 8-10 months, and 11-14 months) showed reliably more fixations to the target, in relation to the distractor picture within the used LWL-paradigm. Exploratively, we investigated the relationship between the frequency imbalance of the stimulus pairs and the infants’ performance on the LWL-paradigm. Here, we could replicate the finding that infants’ performance within the LWL-paradigm was higher for stimulus pairs with a higher word frequency imbalance (Kartushina and Mayor, 2019). In line with previous work (Kartushina and Mayor, 2019), this was most evident for infants between 8- to 10-months, suggesting that infants used frequency imbalance as a cue to succeed within the LWL-paradigm.

Taken together, results of the LWL-paradigm suggest that German-learning infants between six to 14-months did not link the 28 tested common nouns articulated by an unfamiliar male talker to corresponding visual referents. This contrasts with the evidence from the parental reports, suggesting that infants within this sample understood at least some of these tested nouns. We want to stress, that the applied LWL-paradigm varied in more than just the target language from its conceptual replication (Bergelson and Swingley, 2018; Kartushina and Mayor, 2019). Thus, even though we aligned the analysis and dependent measure, it is difficult to detangle the reasons why German-learning infants did not show indices of early word learning in the present study. In the following, we introduce differences within the stimulus material, and general aspects of the stimulus pairings, that might have affected infants' performance within the present work. Subsequently, we will address the surprisingly low performance of the 11- to 14-months-old infants and their potential implications.

Differences in the stimulus material

First, contrary to previous studies, which used mono- and disyllabic target words (e.g. eleven English monosyllabic words like "car", four English disyllabic words like "bottle" and one trisyllabic English word like "banana"; Bergelson and Swingley, 2012; 2018), we *only tested two-syllabic words* here. Thereby, we might have underestimated infants' word comprehension, due to overly difficult target words. That said, our parental vocabulary questionnaire suggested otherwise. Considering the age span from six- to nine-months, parents of this German-learning sample reported even more "understood" words – 27 % of the target words – than parents in the study from Bergelson and Swingley (2012; 2018) – 13 % of the target words. Thus proposing, that our tested target words were appropriate for the investigated age span.

Second, in contrast to the conceptual replication (Bergelson and Swingley, 2018; Kartushina & Mayor, 2019), we used a *male unfamiliar talker* instead of a female unfamiliar talker. Neighboring research fields propose that female and male voices might differently affect infants' responsiveness (Richoz et al., 2017; Sulpizio et al., 2018), thus making it likely that the gender of the talker might modulate infants' attention during the LWL-task. As no previous LWL-study has addressed this before, it is uncertain if and in what manner the gender and possible associated voicing characteristics of the unfamiliar talker shaped the results within the present work.

Aspects of stimulus pairing

First, as previously introduced, the *semantic relation* of the target and distractor word can hinder infants' in the LWL-paradigm (Bergelson and Aslin, 2017). Six-month-old English-learning infants failed to associate a target with its referent picture, for instance, the word mouth, when paired with a high semantic related distractor 'nose' articulated by their parent. Yet, they successfully made the connection within a condition where 'mouth' was paired with a semantic unrelated distractor 'ball' (Bergelson and Aslin, 2017). Contrary to previous studies using words from different word categories within the stimulus pairs (Bergelson and Swingley, 2012; 2018; Kartushina and Mayor, 2019), three of our used stimulus pairs (e.g. rabbit-bug, finger-hair, spoon-pillow) comprised two words out of the same word category (see <http://wordbank.stanford.edu> for word categories; Frank et al., 2017). Consequently, this might have impaired word comprehension within these stimulus pairs and further challenged the whole performance within the task (Bergelson and Aslin, 2017). However, mean performance within these same-category stimulus pairs (PI-by-item: $M = 0.052$, $SD = 0.09$) was not lower compared to the different-category stimulus pairs (PI-by-item: $M = 0.009$, $SD = 0.09$). Neither did it systematically co-occur with other aspects of stimulus pairing, such as a high-frequency imbalance of the stimulus pair estimated by the parental report (same-category frequency imbalance: $M = 0.98$, different-category frequency imbalance: $M = 1.02$).

Second, as reported the explorative analysis showed a higher performance within the LWL-paradigm for stimulus pairs with a higher *frequency imbalance rated by the parents*. Bayes factors suggested moderate evidence for this relation. Moreover, if age groups were tested separately, this pattern upheld only for infants between 8- to 10-months. This is in line with the previously investigated Norwegian-learning sample (Kartushina and Mayor, 2019), and therewith fits the claim that not all age groups reliably use frequency imbalance as an extra-linguistic cue to recognize referents of spoken words (Kartushina and Mayor, 2019; Frank et al., 2021). In sum, it seems that the here tested German-learning infants, especially between 8 to 10 months, used the frequency imbalance of the stimulus pairs as a cue to disambiguate between the target and distractor picture. This might reveal those early strategies link labels and referents based on frequency of occurrence: An often-heard label should link to an often-seen object (and vice versa). If this strategy is not working later on, very young children might base their word learning on other cues and show somewhat worse performance. Thus, next to the phonological restructuring of the proto-lexicon (see Bergelson & Swingley, 2018) alternative explanations based on different learning strategies might also be considered for the interpretation of u-shaped trajectories in infant LWL-data.

Even though we replicated the positive relation between infants' LWL-performance and the frequency imbalance, this was only evident for the frequency measure derived from the parental report and not as expected for the measure derived from the German CHILDES database (Kartushina & Mayor, 2019). Moreover, both measures did not positively correlate, which might reflect the different operationalization both measures use to assess word frequency. In the following, we want to address this lack of accordance and raise a potential explanation. How frequently parents use a specific word within the recorded communicative situations might be highly influenced by external situational factors. Therefore, questioning the representativity of word frequency within the CHILDES data, especially if they do not cover day-long observations. Even more so, in the light of recent results, that some words tend to co-occur dominantly in specific rooms (Custode and Tamis-LeMonda, 2020). Thus, when documenting a free play interaction in the living room it is unlikely to hear the word "diaper" frequently, even though it is frequently used in the everyday life of the infant. Besides the already discussed and somewhat adapted age range, other demographical factors such as the maternal education level (Hart and Risley, 1995) might influence the word frequency and are not matched to the here tested sample, when relying on the CHILDES database. Given the limited possibility to control for such potentially influencing confounding factors, we assume the operationalization of word frequency based on the parental report of the tested infants is the better option. Indeed, comparing the frequency imbalance estimates of the tested 42 parents to the frequency imbalance estimates of additional 105 parents of infants within the same age span (parents filled out the same vocabulary questionnaire, but infants did not participate in the LWL-study) revealed a high agreement between both parental groups, $r(12) = .96, p < .001$.

To further strengthen the evidence for the relationship between frequency imbalance based on parental reports and the performance within the LWL-paradigm, we reanalyzed the data of Kartushina and Mayor (2019). Surprisingly, here frequency imbalance based on parental report correlated significantly negative to the performance within the LWL-paradigm of the 8- to 9-month-old infants, $r(5) = -.73, p = .040$. Herewith, implying the opposite to our observation. This might be due to a non-linear relation between the reported frequency of their parental reports and the Norwegian CHILDES frequencies. In their data, high frequent words tended to show a ceiling effect within the parental report, thus are reported to have a minimum frequency difference, and could, therefore, account for this negative correlation. This might have been an effect of their specific parental report used. They measured word frequency on a six-point Likert scale by asking parents to consider word exposure since birth (and not current daily word

exposure like we did). These results clearly merit further exploration, to clarify potential differences in the operationalization of word frequency.

In sum, those outlined differences in the stimulus material and especially the aspects of stimulus pairing, are known to crucially affect the success of infants within the LWL-paradigm (Bergelson and Aslin, 2017; Kartushina and Mayor, 2019; Bergelson, 2020). Retrospectively, it is impossible to detangle the effects of such experimental parameters on the LWL-task performance from the potential effects of the target language.

No noun comprehension in 11- to 14-month-old infants?

Surprisingly, even the oldest age group of 11- to 14 months-old infants failed to associate the common nouns with their referent. This is striking, as the parent report indicated those infants understood 48 % of our tested target words. Additionally, performance within this age group has been quite stable in previous LWL-studies (Bergelson and Swingley, 2012; 2015; 2018) and infants in this age span are assumed to show a non-linear improvement within their LWL-task performance (Bergelson, 2020). Indeed, when investigating the time course of the German-learning infant's target fixations (see age group 11-14 months in Figure 4), they did fixate the target picture more shortly upon hearing the target word with a peak around two seconds after hearing the target word. Visually judging, this fixation pattern of the oldest age group (illustrated in Figure 4) is similar to previous studies, that did show word comprehension in their proportion indices as well (Bergelson and Swingley, 2012; 2018; Kartushina and Mayor, 2019). Here, however, with all Bayes factors supporting the null hypothesis with anecdotal to moderate evidence, the proportion indices suggest that 11- to 14-month-old infants did not show noun comprehension. This lack of accordance might be explained due to an unappropriated window of interest. Older infants tend to get bored easily and then fixate the distractor more after correctly identifying the target picture (Fernald et al., 2008). The chosen window of interest might have been too long and should be individually adapted for the wide range of age groups. In fact, the time window when those infants fixated the target more (see age group 11-14 months in Figure 4) overlaps with the previously suggested ideal time window to reveal target recognition (1200 to 2200 ms after target onset; Swingley, 2012). However, determining the underlying window of interest is a tricky procedure especially for different age groups, and highly influences the results of the analytic measures, such as the proportion index (Fernald et al., 2008). Therefore, we refrained from such a post adaption of the window of interest because it is prone to biases.

Conclusion

Results of this LWL-study indicate that German-learning infants between 6- to 14-months failed to associate the tested nouns with their referents. Overall, especially for infants between 8- to 10-months of age, performance seems to be modulated by the frequency imbalance of the stimulus pairs. For stimulus pairs that highly differ within their word frequency, infants' performance was enhanced. This further emphasizes the already claimed assumption that frequency imbalance serves as a cue within the LWL-paradigm (Kartushina and Mayor, 2019) and extends respective evidence to a new target language. Without doubt, further studies are needed to confirm or question a failure of German-learning infants to show robust noun-referent associations. Even though prior work supports a cross-cultural difference in the onset of word comprehension (Kartushina and Mayor, 2019; Frank et al., 2021), we think there is accumulating evidence that target language alone *should not* be considered as the sole explanation for this null effect. First and foremost, all alternative differences between those cross-cultural LWL-studies, such as the stimulus material, should be explored. Importantly, by contributing data of a new target language and emphasizing potential influences of experimental parameters, as well as raising concerns about fundamental operationalization questions, the present work contributes to this ongoing process of elaborating and enhancing our understanding of the LWL-paradigm.

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Appendix

Table A1

Pictures presented as stimulus pairs are displayed next to each other. Target words (German and the English Translation) and word frequency imbalance (based on vocabulary questionnaire [parental freq] and CHILDES database[CHILDES freq]) are presented with each stimulus pair.

Stimulus Pair
Target word	Auto Teller	Baby Vogel	Becher* Traktor	Blume Nase	Bürste Windel*
Translation	car plate	baby bird	cup tractor	flower nose	brush diaper
Parental freq	0.59	0.54	1.88	1.20	2.42
CHILDES freq	5267.00	1475.00	207.00	683.00	354.00
Stimulus Pair
Target word	Käse Schlüssel	Löffel Kissen*	Finger Haare	Flasche Mütze	Gabel Suppe
Translation	cheese key	spoon pillow	finger hair	bottle hat	fork soup
Parental freq	1.04	1.82	0.39	0.05	1.68
CHILDES freq	74.00	568.00	188.00	451.00	18.00
Stimulus Pair
Target word	Gurke* Hose	Hase Käfer*	Puppe Katze	Tasse Brille	
Translation	cucumber pants	rabbit bug	doll cat	mug glasses	
Parental freq	0.88	0.74	0.60	0.36	
CHILDES freq	947.00	344.00	120.00	119.00	

Note. Words, that did *not* derive from the ELFRA-1 (Grimm and Doil, 2006) questionnaire are marked with an asterisk (*). Parental Freq ranged between 1 to 5 on a Likert-Scale, whilst CHILDES Freq reflects the absolute word count of the German CHILDES database (MacWhinney, 2000).

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