Limited evidence of test-retest reliability in infant-directed speech preference in a large pre-registered infant sample

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Abstract

Test-retest reliability – establishing that measurements remain consistent across multiple testing sessions – is critical to measuring, understanding, and predicting individual differences in infant language development. However, previous attempts to establish measurement reliability in infant speech perception tasks are limited, and reliability of frequently-used infant measures is largely unknown. The current study investigated the test-retest reliability infant speech preference in a large sample (N=158) in the context of the ManyBabies1 collaborative research project (hereafter, MB1; Frank et al., 2017; ManyBabies Consortium, 2020) of infant-directed speech preference (hereafter, IDS) over adult-directed speech (hereafter, ADS; Cooper & Aslin, 1990). Labs of the original MB1 study were asked to bring in participating infants for a second appointment retesting infants on their IDS preference. This approach allows us to estimate test-retest reliability across three different methods used to investigate preferential listening in infancy: the head-turn preference procedure, central fixation, and eye-tracking. Overall, we find no consistent evidence of test-retest reliability in measures of infants' speech preference (overall r = .09, 95% CI [-.06,.25]). While increasing the number of trials that infants needed to contribute for inclusion in the analysis revealed a numeric growth in test-retest reliability, it also considerably reduced the study's effective sample size. Therefore, future research on infant development should take into account that not all experimental measures might be appropriate to assess individual differences between infants, and hence, the interpretation of findings needs to be treated with caution.

Keywords: language acquisition; speech perception; infant-directed speech; adult-directed speech, test-retest reliability

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Obtaining a quantitative measure of infants' cognitive abilities is an extraordinarily difficult endeavor. The most frequent way to assess what infants know or prefer is to track overt behavior. However, measuring overt behavior at early ages presents many challenges: participants' attention span is short, they do not follow instructions, their mood can change instantly and their behavior can often be described as unstable and volatile. Therefore, most measurements are noisy and the typical sample size of an infant study is small (around 20 infants per group), resulting in low power (Oakes, 2017). In addition, there is individual and environmental variation that may add even more noise to the data (e.g., Johnson & Zamuner, 2010). Despite these demanding conditions, reliable and robust methods for assessing infants' behavior are critical to understanding infant development.

In order to address these challenges, the ManyBabies collaborative research consortium was formed to conduct large-scale conceptual, consensus-based replications of seminal findings to identify sources of variability and establish best practices for experimental studies in infancy (Frank et al., 2017). The first ManyBabies collaborative research project (hereafter, MB1, ManyBabies Consortium, 2020) explored the reproducibility of the well-studied phenomenon that infants prefer infant-directed speech (hereafter, IDS) over adult-directed speech (hereafter, ADS, Cooper & Aslin, 1990). Across many different cultures, infants are commonly addressed in IDS, which typically is characterized by higher pitch, greater pitch range, and shorter utterances, compared to the language used between interacting adults (Fernald et al., 1989). A large body of behavioral studies finds that infants show increased looking times when hearing IDS compared to ADS stimuli across ages and methods (Cooper & Aslin, 1990; see Dunst, Gorman, & Hamby, 2012 for a meta-analysis). This attentional enhancement is also documented in neurophysiological studies showing increased neural activation during IDS compared to

ADS exposure (Naoi et al., 2012; Zangl & Mills, 2007). IDS has also been identified as facilitating early word learning. In particular, infants' word segmentation abilities Thiessen, Hill, & Saffran (2005) and their learning of word-object associations (Graf Estes & Hurley, 2013; Ma, Golinkoff, Houston, & Hirsh-Pasek, 2011) seems to be enhanced in the context of IDS. In sum, IDS seems to be beneficial for early language development.

Within MB1, altogether 67 labs contributed data of 2,329 infants showing that babies generally prefer to listen to IDS over ADS. Nevertheless, the overall effect size $d = 0.35$ was much smaller than the meta-analytic effect size of $d = 0.67$ reported by Dunst et al. (2012). The results revealed a number of additional factors that influenced the effect size. First, older infants showed a larger preference of IDS over ADS. Second, the stimulus language was linked to IDS preference, with North American English learning infants showing a larger IDS preference than infants learning other languages. Third, comparing the different methods employed, the head-turn preference procedure yielded the highest effect size, while the central fixation paradigm and eye-tracking methods revealed smaller effects. Finally, exploratory analyses assessed the effect of different inclusion criteria. Across methods, using stricter inclusion criteria led to an increase in effect sizes despite the larger proportion of excluded participants (see also Byers-Heinlein, Bergmann, & Savalei, 2021).

However, there is a difference between a result being reliable in a large sample of infants and the individual measure of an individual infant being reliable. In studies tracking individual differences, the measured behavior during an experimental setting is often used to predict a cognitive function or specific skill later in life. Individual differences research of this kind often has substantial implications for theoretical and applied work. For example, research showing that infants' behavior in speech perception tasks can be linked to later language development (see Cristia, Seidl, Junge, Soderstrom, & Hagoort, 2014 for a meta-analysis) has the potential to identify infants at risk for later language delays or disorders. However, a necessary precondition for this link to be observable is that individual differences between infants can be measured with high reliability at these earlier stages, in order to ensure that measured inter-individual variation mainly reflects differences in children's abilities rather than measurement error. How reliable are the measures used in infancy research?

Previous attempts to address the reliability of measurements are either limited to adult populations (Hedge, Powell, & Sumner, 2018), or have been conducted with small sample sizes (e.g., Houston, Horn, Qi, Ting, & Gao, 2007). For example, Colombo, Mitchell, and Horowitz (1988) used a paired comparison task, in which infants were familiarized with a stimulus and for the test trials presented with the familiarized and a novel stimulus side-by-side. Results indicated that infants' novelty preference was extremely variable from task to task. Assessing infants' performance from one week to another revealed that infants' attention measures were moderately reliable. However, reliability seemed to increase with the number of tasks infants were able to complete in the younger age group, suggesting that reliability is influenced by the number of assessments. In addition, infants' performance from 4 to 7 months was longitudinally stable but somewhat smaller than the week-to-week reliability. Cristia, Seidl, Singh, and Houston (2016) also retested infant populations by independently conducting 12 different experiments on infant speech perception at three different labs with different implementations of the individual studies. Hence, it was only after completed data collection that the data was pooled together by the different labs revealing potential confounds. Nevertheless, the results showed that reliability was extremely variable across the different experiments and labs and overall low (meta-analytic r = .07).

Against this background, the current study investigates test-retest reliability of infants' performance in a speech preference task. Within MB1, a multi-lab collaboration, we examine whether infants' preferential listening behavior to IDS and ADS is reliable across two different test sessions. We also aim to address whether time between test and retest or infants' language background influences the reliability of the preference measure.

Our study was faced with a critical design choice: what stimulus to use to assess test-retest reliability. A first constraint of our study was that, since it was a follow-on to MB1, any stimulus we used would always be presented after the MB1 stimuli. One option would be simply to bring back infants and have them hear exactly the same stimulus materials. A weakness of this design would be the potential for stimulus familiarity effects, however, since infants would have heard the materials before. Further complicating matters, infants might show a preference for or against a familiar stimulus depending on their age (Hunter & Ames, 1988). The ideal solution then would be to create a brand new stimulus set with the same characteristics. Unfortunately, because of the process how MB1 stimuli were created, we did not have enough normed raw recordings available to make brand new stimulus items that conformed to the same standards as the MB1 stimuli.

We therefore chose an intermediate path: we reversed the ordering of MB1 stimuli. Average looking times in MB1 were always lower than 9s per trial, even for the youngest children on the earliest trials (the group who looked the longest on average), so most children in MB1 did not hear the second half of most trials. Thus, by reversing the order, we had a perfectly matched stimulus set that was relatively unfamiliar to most infants. The disadvantage of this design was that infants who looked longer might be more likely to hear a familiar clip that they had heard in the previous study. If infants then showed a familiarity preference – an assumption which might not be true – the end result could be to inflate our estimates of test-retest reliability slightly, since longer lookers would on average look longer at retest due to their familiarity preference. We view this risk as relatively low, but do note that it is a limitation of our design.

The current study also explores whether there are any differences in test-retest reliability between the three widely used methods: central fixation (hereafter, CF), eye-tracking, and the head-turn preference procedure (hereafter, HPP). Exploring differences in CF, eye-tracking, and HPP, Junge et al. (2020) provide experimental and meta-analytic evidence in favor of using the HPP in speech segmentation tasks. Similarly, the MB1 project reported an increase in the effect size for HPP compared to CF and eye-tracking (ManyBabies Consortium, 2020). HPP requires gross motor movements relative to other methods, such as CF and eye-tracking paradigms, for which subtle eye movements towards a monitor located in front of the child are sufficient. One possible explanation for the stronger effects with HPP may be a higher sensitivity to the contingency of the presentation of auditory stimuli and infants' head turns away from the typical forward-facing position. While these findings suggest that HPP may be a more sensitive index of infant preference, they do not necessarily imply higher reliability for individual infants' performance using the different methods. Hence, it remains an open question whether the same measures that produce larger effect sizes at the group-level also have higher test-retest reliability for individual infants (Byers-Heinlein, Bergmann, et al., 2021). Therefore, assessing the test-retest reliability of the different preference measures is crucial, so that researchers can make informed decisions about the appropriate methods for their particular research question. Critically, only measures with high test-retest reliability should be used for studies of individual differences.

Method

Preregistration

Prior to the start of data collection, we preregistered the current study on the Open Science Framework (https://osf.io/v5f8t; see S1 in the Supplementary Materials for further details).

Data Collection

A call was issued to all labs participating in the original MB1 study on January 24th, 2018 (ManyBabies Consortium, 2020). The collection of retest session data was initially set to end on May 31st, 2018, one month after the end date of the original MB1 project. Due to the fact that the original MB1 project extended the time frame for data collection and the late start of data collection for the MB1 test-retest study, we also allowed participating labs to continue data collection past the scheduled end date.

Participants

Contributing labs were asked to re-recruit their monolingual participants between the ages of 6 to 12 months who had already participated in the MB1 project. If participating labs had not committed to testing either of these age groups, they were also allowed to re-recruit participants from the youngest age group of 3- to 6-month-olds and/or the oldest age group of 12- to 15-month-olds. Labs were asked to contribute half (n=16) or full samples (n=32); however, a lab's data was included in the study regardless of the number of included infants. The study was approved by each lab's respective ethics committee and parental consent was obtained for each infant prior to participation in the study.

Our final sample consisted of 158 monolingual infants from 7 different labs (Table 1). In order to be included in the study, infants needed a minimum of 90% first language exposure, to be born full term with no known developmental disorders, and normal hearing and vision. We excluded 11 participants due to session errors and 11 participants who did not have at least one valid trial per condition (IDS and ADS) at their first or second session. The mean age of infants included in the study was 245 days (range: 108 – 373 days).

Materials

Visual stimuli. The visual stimuli and instructions were identical to MB1. For the central fixation paradigm and eye-tracking, labs used a multicolored static checkerboard as the fixation stimulus as well as a multicolored moving circle with a ringing sound as an attention-getter between trials. For the HPP method, labs used their standard procedure, as in MB1.

Speech stimuli. We used the identical training stimuli of piano music from MB1. A second set of naturalistic IDS and ADS recordings of mothers either talking to their infant or to an experimenter was created for the retest session by reversing the order of clips within each sequence of the original study This resulted in eight new sequences of natural IDS and eight new sequences of natural ADS with a length of 18 seconds each.

Procedure. Infants were retested using the identical procedure as during the first testing day: central fixation, HPP, or eye-tracking. Participating labs were asked to schedule test and retest session 7 days apart with a minimum number of 1 day and a maximum number of 31 days. However, infants whose time between test and retest exceeded 31 days were still included in the analyses ($n = 3$). The mean number of days between test and retest was 10 (range: 1 - 49).

A total of 18 trials, including two training, eight IDS, and eight ADS trials, were presented in one of four pseudo-randomized orders. Trial length was either infant-controlled or fixed depending on the lab's standard procedure, that is a trial stopped either if the infant looked away for 2 seconds or after the total trial duration of 18 seconds. The online coding experimenter and the parent listened to music masked with the stimuli of the study via noise-cancelling headphones. If the experimenter was in an adjacent room separate from the testing location, listening to masking music was optional for the experimenter.

Data exclusion. A child was excluded if they had a session error, i.e., an experimenter error (e.g., inaccurate coding, or presentation of retest stimuli on the first test session), or equipment failure (visual stimuli continued to play after the end of a trial). Trials were excluded if they were marked as trial errors, i.e., if the infant was reported as fussy, an experimental or equipment error occurred, or there was parental interference during the task (e.g., if the parent spoke with the infant during the trial). Trials were also excluded if the minimum looking time of 2 s was not met. If a participant was unable to

Table 1

Statistics of the included labs. n refers to the number of infants included in the final analysis.

Lab	Method	Language	Mean age (days)	N
babylab-potsdam	HPP	German	227	22
babyling-oslo	Eyetracking	Norwegian	249	10
brookes-babylab	central fixation	English	267	18
InfantCog-UBC	central fixation	English	147	7
infantll-madison	HPP	English	230	30
lancslab	Eyetracking	English	236	16
wsi-goettingen	central fixation	German	280	39
wsi-goettingen	HPP	German	242	16

contribute at least one IDS and one ADS trial for either test or retest, all data of that participant was excluded from the test-retest analyses.

Results

IDS preference

First, we examined infants' preferences for IDS in both sessions. Two two-samples t-tests revealed that the children in Session 1, $t(157) = 6.47$, $p < .001$, and in Session 2, $t(157) = 4.19$, $p < .001$, showed a preference of IDS over ADS (see Table 2 for the average looking times in each session), replicating the main finding from MB1. In the first session, 68.35% of infants showed a preference for IDS, and in the second session, 63.29% of infants showed a numerical preference for IDS. In order to test whether there was a difference in the strength of the preference effect across sessions, we fit a linear mixed-effects model

Table 2

Looking times in s for each session and condition

Trial type	Session 1 *Mean*	Session 1 *SD*	Session 2 *Mean*	Session 2 *SD*
ADS	7.72	2.77	6.96	2.92
IDS	8.76	2.85	7.75	2.75

predicting infants' average difference in looking time between IDS and ADS from test session (1 vs. 2), including by-lab and by-participant random intercepts. There was no significant difference in the magnitude of infants' preference between the two sessions, β=-0.30, *SE*=0.24, *p*=.208.

Reliability

We assessed test-retest reliability in two ways. First, we fit a linear mixed-effects model predicting IDS preference in Session 2 from IDS preference in Session 1, including a by-lab random intercept. The results revealed no significant relationship between IDS preference in Session 2 and Session 1 (Table 2). Second, we calculated the Pearson correlation coefficient. While a simple correlation coefficient might overestimate the test-retest reliability in our sample because it does not control for the differences between different labs and methods (HPP, CF, and eye-tracking), we felt it was important to also conduct a Pearson correlation as it is commonly used to assess reliability. The size of the correlation coefficient was not statistically different from zero and the estimate was small, $r = .09$, 95% CI $[-.06, .25]$, $t(156) = 1.19$, $p = .237$. 41.77 percent of the infants reversed their direction of preference for IDS versus ADS from the test to the retest session.

To test whether the results were different for a specific method, we calculated the Pearson correlation coefficients and the multilevel analyses for HPP, central fixation and eye-tracking separately (see Table 4). There was no evidence that method moderated

Table 3

Coefficient estimates from a linear mixed effects model predicting IDS preference in Session 2.

	Estimate	SE	t	p
Intercept	0.874	0.456	1.920	0.102
Session One	0.035	0.085	0.414	0.679

test-retest reliability. Neither the Pearson correlation coefficients nor the coefficients of the multilevel analysis were significant, all p-values > .286. In planned secondary analyses, we found that participant age, language background, and time between test sessions also did not moderate the relationship between IDS preference in session 1 and session 2 (see Suppmentary Materials, S2). Taken together, we find no significant evidence of test-retest reliability across our preregistered analyses.

Results with different inclusion criteria

To this point, all analyses were performed using the inclusion criteria from MB1, which required only that infants contribute at least 1 trial per condition for inclusion (i.e., one IDS and one ADS trial) . However, more stringent inclusion criteria yielded larger effect sizes in MB1. We therefore conducted exploratory analyses assessing test-retest reliability after applying progressively stricter inclusion criteria, requiring 2, 4, 6, and 8 valid trials per condition. Applying stricter criteria - and thereby increasing the number of test trials - increased reliability numerically from r = 0.07 to r = 0.34 (Figure 1). In part due to a decrease in sample size, only one of these correlations was statistically significant (namely when requiring a minimum of 6 trial pairs): 2 valid trial pairs, $t(152) = 0.90$, $p = .367$; 4 valid trial pairs, $t(143) = 1.03$, $p = .306$; 6 valid trial pairs, $t(98) = 2.23$, $p = .028$; 8 valid trial pairs - all trials in both sessions - $t(22) = 1.68$, $p = .108$. The

Table 4

Coefficient estimates from a linear mixed effects model predicting IDS preference in Session 2 for each method separately.

Method	estimate	SE	pvalue	cor	pvalue2
HPP	0.151	0.137	0.276	0.134	0.276
Eyetracking	0.034	0.162	0.835	0.021	0.919
central fixation	-0.195	0.125	0.125	0.080	0.530

analyses provide tentative evidence that stricter inclusion criteria may lead to higher test-retest reliability, but at the cost of substantial decreases in sample size.

General Discussion

The current study investigated the test-retest reliability of infants' preference for IDS over ADS. Infants of the original MB1 project were retested on a reversed order of stimuli in order to assess if their listening pattern would be similar to that of their initial assessment. While we replicated the original effect of infants' speech preference for IDS over ADS in the current MB1 follow-up study for both test and retest session on the group-level using the same MB1 protocol, we found that infants' speech preference measures had no test-retest reliability. In other words, we were unable to detect any stable individual differences of infants' speech preference. This finding is in line with other research indicating a rather low test-reliability for different developmental paradigms (Cristia et al., 2016). Given that most experimental procedures conducted in developmental research are interested in the comparison of groups, individual differences between participants within a specific condition are usually minimized by the experimental procedure while differences between conditions are maximized. Therefore, the infant preference measure may be a

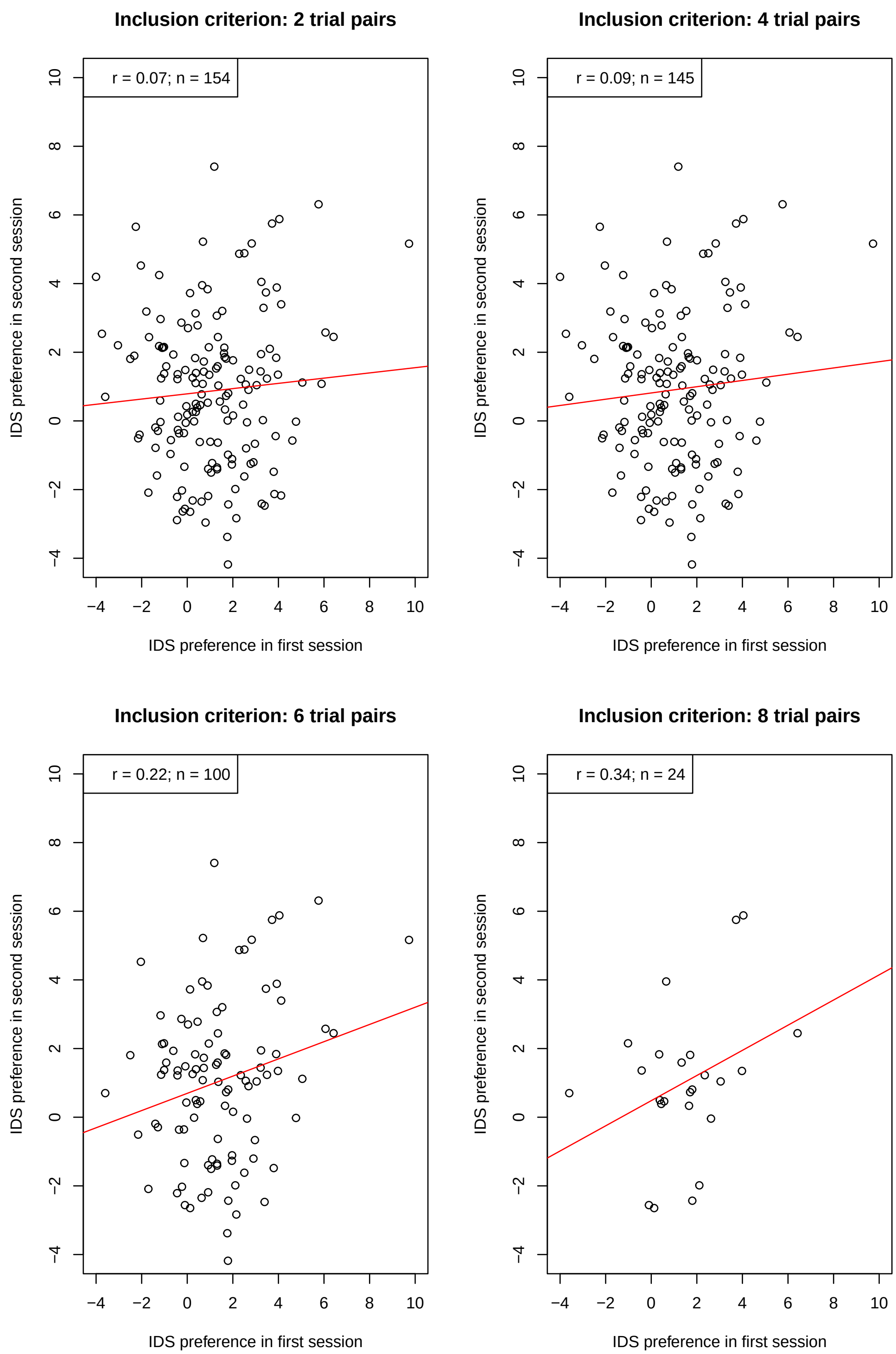

Figure 1. IDS preferences of both sessions plotted against each other for each inclusion criterion. n indicates the number of included infants, r is the Pearson correlation coefficient as the indicator for reliability.

good approach to capture universal phenomena but does not seem to be appropriate for examining factors that may lead to individual differences in development.

Consistent with general psychometric theory (e.g., DeBolt, Rhemtulla, & Oakes, 2020) a larger number of included test trials was associated with higher reliability. However, in our dataset, this association was based on exploratory analyses and was only found descriptively, hence, a replication is warranted. A similar effect on the group-level was found in the MB1 project, where a stricter inclusion criterion led to bigger effect sizes (ManyBabies Consortium, 2020).

In our study, as in the MB1 original study, higher reliability through strict exclusions came at a high cost. In particular, with the strictest criterion, only a small portion of the original sample size, that is 24 out of 158 infants, could be included in the final sample for this particular analysis. In other words, applying a stricter criterion leads to a higher drop out rate and reduces the actual sample size enormously. In the case of studies in the field of developmental science, where there are many practical restrictions in collecting large samples of infants (e.g., birth rate in the area, restricted lab capacities, budget restrictions), a strict drop out criterion might not be easy - if even possible at all - to implement. Note that studies in developmental science already have above average drop out rates (Miller, 2017). In addition, drop out may not be random, and so having high drop out rates can further limit the generalisability of a study. Particularly in the context of turning individual differences measures into diagnostic tools, high drop-out rates have an additional limitation of not being broadly usable.

An alternative approach to increase the number of valid trials might be to also increase the number of collected trials. In this case, a participant can have a high number/proportion of invalid trials and still be included into the final sample as the absolute number of trials is high and thereby decreasing trial-to-trial variability (DeBolt et al., 2020; see Silverstein, Feng, Westermann, Parise, & Twomey, 2021 for an example).

While this approach might sound promising, it must be seen if this is realistic, because the attention span of a typical participant of a developmental study is rather short. Therefore, prolonging the experimental procedure to maximize the absolute number of trials might also be practically challenging. Further potential attempts in obtaining higher numbers of valid trials may include changes in the procedure (e.g., Egger, Rowland, & Bergmann, 2020) or implementing multi-day test sessions (Fernald & Marchman, 2012). As our results are only based on the particular phenomenon of IDS preference (albeit, with three widely used methods: HPP, central fixation; eye-tracking) it is essential to further assess the underlying reliability of these measures within other areas of speech perception. While most infants prefer IDS over ADS (Dunst et al., 2012), predicting a pattern of preference, for instance, within speech segmentation tasks, i.e. familiar versus novel words, seem not that straightforward (Bergmann & Cristia, 2016). Especially in the context of relating a direction of preference to later language development, there seem to be controversial findings. That is, both familiarity and novelty responses have been suggested to be predictive of infants' later linguistic abilities (DePaolis, Vihman, & Keren-Portnoy, 2014; R. S. Newman, Rowe, & Ratner, 2016; R. Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006). In light of findings from the current study, researchers conducting longitudinal studies with experimental data from young infants predicting future outcomes should be cautious as there may be inter-individual variability affecting their preferences.

Limitations

While we had an above average sample size for a study in developmental research, we were unable to reach the number of participants collected within the original MB1 study. In addition to a delayed call, the extra effort of having to schedule a second lab visit for each participant and the fact that there were already other collaborative studies taking place simultaneously (MB1B, Byers-Heinlein, Tsui, Bergmann, et al., 2021; MB1G, Byers-Heinlein, Tsui, Van Renswoude, et al., 2021), might have contributed to the rather low turnout. A higher sample size and a larger number of participating labs from different countries might have enabled us to test for possible differences of the test-retest reliability of the different methods (HPP, central fixation, eye-tracking) and NAE versus non-NAE language backgrounds. Further, a larger sample size might have enabled us to conduct meaningful tests of moderators such as age of the child on the test-retest reliability.

A further limitation concerns the stimuli. While the order of the clips within trials presented to the participating children in the second session was different than in the first session, the exact same stimulus material as in MB1 was used in both sessions. In particular, all children heard the exact same voices in Session 1 and in Session 2. From a practical point of view, it was the easiest solution. However, familiarity effects might have influenced infants' looking behavior. Assuming that only infants with longer looking times in Session 1 might have had the chance to recognize the voices in Session 2 from their session a week ago as familiar clips would only be towards the end of trials, infants with shorter looking times might not have had the opportunity to listen to the voices from their first session. Therefore, for some children, familiarity with the stimulus material might have led to artificially lowering test-retest reliability.

Conclusion

Following the MB1 protocol, the current study could not detect test-retest reliability of infants' preference measures for IDS over ADS. Subsequent analyses showed that a stricter criterion for the inclusion of data points may enhance the test-retest reliability at the cost of high drop out rates. Developmental studies which rely on stable individual differences of their participants need to consider the underlying reliability of their measures, and we recommend a broader assessment of test-retest reliability in infant research.

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