Running title: LARGE-SCALE COLLABORATIVE APPROACH

Building theories of consistency and variability in children's language development:

A large-scale data approach

Angeline Sin Mei Tsui

Virginia A. Marchman

Michael C. Frank

Stanford University

Corresponding author: Angeline Sin Mei Tsui. Email: astsui@stanford.edu

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Abstract

Young children typically begin learning words during their first two years of life. On the other hand, they also vary substantially in their language learning. Similarities and differences in language learning call for a quantitative theory that can predict and explain which aspects of early language are consistent and which are variable. However, current developmental research practices limit our ability to build such quantitative theories because of small sample sizes and challenges related to reproducibility and replicability. In this chapter, we suggest that three approaches – meta-analysis, multi-site collaborations, and secondary data aggregation – can together address some of the limitations of current research in the developmental area. We review the strengths and limitations of each approach and end by discussing the potential impacts of combining these three approaches.

Keywords: Large-scale datasets, Meta-analysis, Multisite studies, Replication, Theory-building

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Introduction

Young children learn language incredibly quickly. Shortly after birth, infants show heightened sensitivity to sounds from all languages (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) and then later during the first year of life, refine their sensitivity to sounds that are specific to their native language (Kuhl et al., 2006; Werker & Tees, 1984). In tandem with sharpening their perceptual ability in detecting sounds in their native language, infants also demonstrate remarkable abilities in learning words. They can recognize frequently heard words as young as 6 months of age (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 2012). Most children can produce a handful of words by 12 months (Fenson et al., 1994) and are saying more than a hundred by six or eight months later. And by the end of their second year, they typically demonstrate that they can combine words into simple sentences, showing signs of beginning to master the grammar of their native language.

Although most children follow a similar trajectory in these major language milestones, there are also major individual differences in children's language achievements. For example, some children start producing words before or around age 1, whereas others are "late talkers" who only begin to produce recognizable words at around age 2 years (Fenson et al., 1994). Apart from the individual differences in the age at which they produce their first words, children also differ in terms of how many words they know at a particular age and the rate with which they learn words over the course of development (Bates, Dale & Thal, 1994; Frank, Braginsky, Yurovsky & Marchman, 2021). Crucially, individual differences in the achievement of early language milestones are associated with children's later academic, cognitive and social functioning as well as life achievements (e.g., Morgan et al., 2015; Ramey & Ramey, 2004). Thus, while there are some consistencies across children in the language milestones they achieve

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there is also substantial variation in the timing and rate of learning. Understanding both the consistency and variation in children's language development – and developing theories that explain and predict them – are key goals for research in this area. An ideal for this area would be the construction of quantitative theories that connect theoretical hypotheses to specific predicted patterns of data (Guest & Martin, 2020; Wilson & Collins, 2019).

Unfortunately, current research practices have several key weaknesses that handicap the ability to develop such theories. First, recent studies have suggested that research in psychology faces issues of replicability (the ability to collect new data in an experimental paradigm and observe a similar result) and even reproducibility (the ability to redo a particular analysis on the same dataset and recover the same numerical results). For example, Open Science Collaboration (2015) sought to reproduce 100 findings from top-tier psychological journals but found that fewer than half of the studies successfully replicated the original significant findings (see also Anderson et al., 2016; Gilbert et al., 2016). Further, research data are not often publicly accessible. In the past, there were no policies on data sharing from psychological journals or professional societies (e.g., the American Psychological Association). It has not been until recently that researchers have become more aware of the importance of data sharing in psychology research. Many journals have imposed “open data” policies that recommend or mandate data sharing, resulting in an increase in the number of articles sharing data publicly upon publication (Kidwell et al., 2016; Nuijten et al., 2017). Yet, even when data are shared, sharing does not guarantee that the results reported in the publications are reproducible. In several studies, only a small proportion (ranges from 17% to 37%) of findings can be reproduced without author assistance (Chang et al., 2015; Eubank et al., 2016; Hardwicke et al., 2018).

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Together, the issues of replicability and reproducibility cast doubt on how robust the data are in psychological research, limiting our confidence in using the data to build models and theories. These issues are exacerbated in developmental research because most developmental work is based on small samples (Frank et al., 2017; Davis-Kean & Ellis, 2019; Oakes, 2017). It is generally difficult and costly to test infants and young children. Infants and young children have short attention spans, and therefore, can only engage in a testing session for a relatively short period of time. In addition, infants and young children often refuse to pay attention or participate in an experiment (partly due to short attention spans), therefore the attrition rate of infants and young children in experimental settings is often high. The reliance on small samples in developmental science also leads to concerns of spurious, non-replicable findings (Type I errors) and low statistical power in detecting an effect (Type II errors) (Button et al., 2013).

In addition, a vast majority of research in psychology, including developmental research, relies on convenience samples in Western, educated, industrialized, rich, and democratic (WEIRD) societies (Bornstein, Jager, & Putnick., 2013; Henrich, Heine, & Norenzayan, 2010). Thus, research in this area lacks sample diversity, limiting the generalizability of findings across populations and contexts. In developmental research, sample diversity is essential for building theory as researchers often focus on the core and universal learning mechanisms underpinning children's development. Current findings point to the substantial differences between Western, educated, industrialized societies and non-Western societies in children's environments. For example, cultural differences in how parents interact with their children may lead to substantial differences in cognitive development (Keller & Kärtner, 2013), to how parents engage their children in different types of tasks (Lancy, Bock, & Gaskins, 2010), and to how often children spend time with other non-parental caregivers (e.g., older siblings) and peers (Legare, Sobel, &

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Callanan., 2017). All these findings have suggested an urgent need for increasing sample diversity in developmental research as most current research still mainly tests children in WEIRD societies (Nielsen, Haun, Kärtner, & Legare, 2017).

The goal of this chapter is to suggest a set of research strategies that work to address these concerns. The core of our approach is to gather large datasets to study and model young children's language development. This approach is not new, but builds upon prior pioneering open-data approach and studies. Large-scale, open datasets, such as the Child Language Data Exchange System (CHILDES; MacWhinney, 2000; MacWhinney & Snow, 1985) and the Cross Linguistic Lexical Norms (CLEX; Jørgensen, Dale, Bleses & Fenson, 2010), have provided researchers with valuable tools to assess children's language development. Outside of language development, large-scale longitudinal research has also provided groundbreaking databases that yield rich information about human health and development over-time in a multi-disciplinary way. For example, the Dunedin Multidisciplinary Health and Development Study (see Poulton, Moffitt & Silva., 2015 for a review) tracks more than 1000 people over 40 years and assesses participants' health in multiple dimensions, including mental health, physical health (e.g., cardiovascular health), and psychosocial functioning. Such work is rarer in the domain of cognitive development, but even in this subfield, researchers have created rich data sources such as Databrary, which archives video data on infants and young children (Gordon, Millman, Steiger, Adolph, & Gilmore., 2015; see Davis-Kean & Jager, 2017 for a review of other examples of secondary databases in developmental research). These examples illustrate how developmental researchers have used large-scale datasets to answer important developmental questions.

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In the current chapter, we discuss how three large-scale approaches: meta-analysis, collaborative, multisite studies, and the aggregation of secondary data, can together offer researchers tools to move forward in building quantitative theories of developmental science while beginning to address issues like reproducibility/replicability and sample diversity. Importantly, we propose that no single approach can address all weaknesses but together these three approaches can offer a way forward.

The chapter is organized in three sections. In the first section, we describe how meta-analysis can help us to gather data in the existing literature to overcome issues related to small samples and also to shed light on current theories of children's development. The second section describes collaborative, multi-site studies, which can overcome publication bias issues associated with meta-analysis and can promote best practices and replications in developmental science. Finally, we will describe how aggregating existing raw data from individual researchers can provide a stronger foundation of information than a single researcher alone can achieve. Such aggregation approaches can allow analyses and modeling on large datasets, which can provide insights on children's development in a relatively longer period of time. We close with a more general perspective on what is needed to build generalizable theories in the field, with a hope that this perspective will be incorporated in future theoretical models and research.

Meta-analysis provides an approach for the investigation of the existing literature

Meta-analysis is a statistical method that summarizes empirical findings across different studies in the existing literature. In essence, this method offers a quantitative way for measuring an overall effect size from different studies that address the same question and can provide a statistical tool for researchers to investigate what underlies variability in effect sizes across different studies.

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Strengths

Meta-analyses provide researchers with a tool to examine data from the current literature without collecting new data. Indeed, developmental scientists have increased their use of meta-analysis to study children's language and cognitive development. To facilitate reproducibility, developmental researchers in cognition and language development have archived meta-analytic data in an open-resourced repository – MetaLab (Bergmann et al., 2018). MetaLab compiles information across meta-analyses and facilitates exploration of the effect sizes from various studies and how they vary across ages, tasks, and populations.

A major advantage of meta-analysis is that it allows researchers to overcome issues of small samples in a typical single developmental study. Meta-analysis allows inferences about the robustness of experimental effects, but it can also be used to explore moderators like age in order to characterize the developmental trajectory of an effect.

For example, Bergmann and Cristia (2016) conducted a meta-analysis that examined infants' ability to segment words from fluent speech in their native language. The researchers found that infants overall showed a preference for attending to familiar words over novel words, confirming the key finding that young infants before age 1 generally show a familiarity preference in a natural speech segmentation task. Crucially, this meta-analysis tested how a key infancy looking time model – Hunter and Ames (1988) – can explain the potential changes in infants' preference to familiar words over novel words changes across different ages. According to Hunter and Ames (1988), infants' looking preference for familiar over novel stimuli reflects their processing speed. Thus, in comparison to younger infants, older infants who are more cognitively mature can more fully process the stimuli in the experiment and are expected to exhibit a preference for novel over familiar stimuli (novelty preference). After summarizing 168

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studies that examined infants from 6- to 24-months of age, Bergmann and Cristia found no evidence to suggest that infants across different ages change their preference from familiar words to novel words, even after statistically controlling for infants' language background and other methodological procedure factors. This finding is surprising and also challenges the well-accepted view in the field that older infants have a preference for novel over familiar stimuli.

Similarly, in another meta-analysis that examined 12- to 20-month-old infants' skills in associating novel words to objects in a laboratory task called the Switch task, Tsui, Byers-Heinlein and Fennell (2019) summarized 141 studies and explored how different methodological factors and infants' language backgrounds affect infants' performance in the task. In the Switch task, the infant is habituated to pairs of words and objects (e.g., word A is paired with object 1). On test trials, the infant is shown a new word with that previously-seen object (e.g., word B is now paired with object 1). If the infant detects the switch between the original and new word-object pair, they should be surprised and look longer to the Switch test trial (i.e., wrong word-object pair) than to the Same test trial (i.e., correct word-object pair). The meta-analysis found that infants performed better when they are tested with dissimilar-sounding words (phonemes within words that were more distinguishable) and when they were provided with additional facilitative cues (e.g., perceptual cues that highlighted the phonemes within words), lending support to another key theory in infant speech perception, the PRIMIR framework (Werker & Curtin, 2005).

This meta-analysis also discovered a surprising result: bilingual infants outperformed monolingual infants in the Switch task. This finding was unexpected because bilingual infants have twice as much to learn from their language environment (i.e., sounds, words, and

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grammatical structures from two languages). Thus, current theoretical frameworks for bilingual infant development (e.g., Curtin, Byers-Heinlein & Werker, 2011) have suggested that bilingual infants may be slower and at best on par with their monolingual peers in word learning. By combining studies in Switch task literature, this meta-analysis suggested a potential bilingual word learning advantage, inviting further research and theoretical work to revise current theories of bilingual infants' language acquisition.

Apart from assessing the overall learning effect and testing the current theories of children's development, meta-analysis can also provide some insights into improving research practices in our field. By aggregating 12 developmental meta-analyses, Bergmann and colleagues (2018) confirmed that most studies in infancy research are largely underpowered, even taking into account studies with a medium effect size. They also reported that the effect sizes of children's skills across studies using different experimental methods vary substantially, pointing out the importance of carefully selecting a sensitive measurement of children's skills. Further, the authors also found some evidence of common questionable research practices that lead to decreased replicability (e.g., adding participants to obtain significant results after peeking into pilot data).

Limitations

Although meta-analysis is an important tool for combining studies to improve the likelihood of detecting an overall effect size and in testing current theories of children's development, the technique also has a number of limitations. First, meta-analyses are necessarily restricted by the limitations of the literature. As mentioned earlier, most developmental research has been conducted using convenience samples in WEIRD societies (Nielsen et al., 2017). Thus, data included in the meta-analyses likely lack substantial sample diversity. Furthermore,

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meta-analyses reflect the level of publication bias that is present in the literature. Publication bias refers to the phenomenon that statistically significant results are more likely to be published in the field, which leads to overestimation of effect sizes in meta-analysis (Dickersin, Chan, Chalmers, Sacks, Smith., 1987). Statisticians have proposed a number of approaches to assess publication bias and have also offered tools to correct some amount of publication bias (e.g., Duval & Tweedie, 2000). However, these approaches are at best approximate; they cannot reconstruct literature that does not exist. Thus, the overall effect size from any meta-analyses is likely an overestimate to one degree or another.

Second, as illustrated above, meta-analyses allow researchers to explore what explains the heterogeneity of findings in the literature, providing a way for researchers to examine children's developmental trajectory and to test current theories in developmental science. However, the observed variability in the effect size in meta-analyses is often a combination of variability driven by publication bias, different methodologies and samples, theoretical variables, and individual differences across studies, among other factors. Thus, many meta-analysts have found that a large proportion of variance in their meta-analyses (e.g., ~70% in Bergmann & Cristia, 2016; ~85 - 90% in Tsui, Byers-Heinlein & Fennell, 2019) cannot be explained by the theoretical variables that they include as moderators. This finding suggests that meta-analysis is also limited in its ability to explain heterogeneity across different experimental measurements.

Finally, the methods that researchers used for testing children at different ages are often different, even though they may appear superficially to be the same experiment task. Often developmental researchers tailor their experiment to children at different ages. For example, researchers may give 12-month-olds a longer time to learn and use a simpler task variant (e.g., teaching only one word). In contrast, as older children are expected to be more cognitively and

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linguistically mature, researchers may give 24-month-old children a shorter time to learn and use a more complex task variant (e.g., teaching multiple words). While this tailoring is a reasonable strategy and appropriate for many experimental contexts, the result is that younger and older children are not necessarily tested in experiments with similar degrees of difficulty. Thus, the observed differences across age may simply reflect the differences in experimental procedures.

In summary, by aggregating individual studies and examining how different theoretical variables explain heterogeneity of the effect size across studies, meta-analyses can be a tool to examine consistency (e.g., whether infants show an overall learning effect in an experiment) and variability (e.g., whether infants show difference in performance across ages and language backgrounds) in children's language development. However, meta-analyses are subject to publication bias and are limited to the samples and research questions studied in the current literature. The next approach we review – collaborative, multisite studies – can help to address some of the limitations of meta-analyses.

Collaborative, multi-site studies as a promising approach to examine differences across individuals, samples and sites

In recent years, there has been a dramatic increase in collaborative replications in psychology that aim to assess replicability in the field and understand what underlies variability across different laboratories/sites (e.g., Klein et al., 2014; Open Science Collaboration, 2015). Inspired by these recent collaborative replication projects in psychological science, Frank and colleagues (2017) proposed the ManyBabies Consortium, a group that uses collaborative, multisite studies to promote replications and best practices in developmental psychology research. By collecting data across different laboratories/sites, ManyBabies aims to conduct research that (i) tests hypotheses about validity and replicability of key findings in infancy with a

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consensus paradigms, (ii) improves theory by understanding how infants develop across a wide range of ages, languages, and cultural experiences, (iii) quantifies the sources of variability across sites/laboratories and establishes best practices; and (iv) increases diversity of participants, researchers and research questions. Thus far, ManyBabies has launched projects that cover a wide range of developmental phenomena, including infants' preferences for infant-directed speech (MB1), theory of mind (MB2), abstract rule learning (MB3), social evaluation (MB4), and looking preferences for familiar vs novel stimuli (MB5).

Strengths

By collecting data via multisite collaborations, ManyBabies provides a framework for bringing researchers together to carry out the same experiment following a common set of guidelines. To promote reproducibility and reuse, all MB projects used materials, data, and analysis code that are shared via open source platforms, such as Open Science Framework and Github.

To illustrate this approach, we will discuss the findings of MB1, a multi-site developmental research effort that examined whether infants show preferences for infant-directed speech (IDS) over adult-directed speech (ADS) (ManyBabies Consortium, 2020). IDS refers to a special speech register in which caregivers talk to their infants. In comparison to ADS, IDS has exaggerated prosodic characteristics (i.e., higher pitch and greater pitch variability), shorter and slower utterances, contains more pauses, and reflects simplified grammatical structures (e.g., Fernald et al., 1989; Trainor & Desjardins, 1997). Over the past years, researchers have found that infants from different language backgrounds and cultures prefer listening to IDS over ADS (e.g., Cooper & Aslin, 1994; Fernald, 1985; Hayashi, Tamekawa, & Kiritani, 2001; Kitamura & Lam, 2009; Pegg, Werker, & McLeod, 1992; Santesso,

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Schmidt, & Trainor, 2007). However, these studies varied in terms of infants' age, language backgrounds, as well as the experimental methods used (including both procedures and stimuli). Although infants' overall IDS preference across studies was confirmed by a meta-analysis (Dunst et al., 2012) (effect size = 0.67), as discussed earlier, this meta-analysis (like all meta-analyses) is likely to be subject to publication bias. Further, most of the past studies mainly tested infants in small samples. As a result, the meta-analytic estimate might be an overestimate of infants' IDS preference (Button et al., 2013) and any moderator effects (e.g., age) might not be measured appropriately.

In MB1, researchers measured infants' looking time to an uninformative visual stimulus (i.e., a colorful checkerboard) while the infants listened to audio clips of either IDS or ADS. The procedure was infant-controlled, such that auditory stimuli were presented only as long as infants looked at the screen. Thus, differences in the duration of infant looking to IDS vs. ADS on different trials reflect the degree to which they prefer IDS over ADS. Importantly, MB1 tested infants across a range of language backgrounds using the same stimulus: North American English IDS and ADS. Testing infants with the same stimuli across laboratories eliminated the possibility that differences in stimuli across laboratories were a source of methodological variability. This decision also encouraged more laboratories to participate in MB1 as each individual laboratory did not need to create new stimuli. Further, using identical language stimuli allowed researchers to explore the effect of native language on the magnitude of infants' IDS preference. While every participating laboratory was required to use the same stimuli, they could use their own preferred method to run the experiment. In the final dataset, labs used central fixation methods, the head-turn preference procedure, and corneal-reflection eye tracking. This

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variation allowed the MB1 researchers to investigate whether differences in experimental methods could explain variability of infants' performance across the different sites.

With a total sample of 2,329 monolingual infants from 3 to 15 months across 67 sites and 16 countries, MB1 was the largest experimental study of infant speech perception ever conducted. The study found an overall preference for IDS, as well as several other interesting effects. First, older infants showed a stronger preference for IDS than younger infants, a result consistent with Dunst et al.'s (2012) meta analysis but is inconsistent with other smaller-scale past studies (e.g., Hayashi et al., 2001; Newman & Hussain, 2006). This finding highlights the differences between smaller-scale and larger-scale studies, and supports the importance of large-scale studies to make more precise measurements of the developmental trajectory of children's skills/learning. In addition, infants exposed to North American English had a stronger preference for the North American IDS in MB1 than infants exposed to other language varieties, replicating findings from past work (e.g., Werker et al., 1994; Pegg et al., 1992). While language background is not an explicit experimental manipulation, this language experience effect suggests that familiarity with stimulus language may play a role in infants' preferences. Finally, the experimental method a lab used also moderated effect size, such that the IDS preference was strongest for laboratories using the head turn procedure as compared with those using central fixation and eye-tracking methods. This finding highlights the importance of considering methodology when planning sample sizes for infancy studies.

Collaborative, multi-site projects can serve as a stepping stone for increasing the sample diversity and generalizability of findings. MB1 tested a diverse sample from 67 laboratories in 16 countries. Despite this impressive participation, most of the participating laboratories in MB1 (89%) were from Europe and North America and only a few were from Australia and Asia. None

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of the participating laboratories were from Africa or South America. Thus, the data in MB1 mostly sampled infants in WEIRD populations, restricting the generalizability of the MB1 findings to infants growing up in other cultural contexts.

To address this issue, a new project extends MB1 to African populations via the MB1 Africa project (Tsui et al., under review). MB1 Africa aims to increase sample diversity and generalizability of the MB1 findings, as well as to connect researchers in underrepresented groups to the ManyBabies Consortium. Thus far, MB1 Africa has recruited 11 laboratories from sub-Saharan Africa and is projected to collect data from over 300 African infants in total. These laboratories cover regions in the central-east (e.g., Kenya), the west (e.g., Senegal) and the south (e.g., South Africa). This wide coverage of regions provides researchers with a special leverage to study a vast difference in language spoken in different places in Africa. For example, African researchers in Kenya suggested that target participants vary in terms of at least 5 different languages (e.g., English, Swahili, Kiswahili, Kikuyu, Dholuo) and 7 different ethnic groups (e.g., Kikuyu, Bantu, Mkamba, Luo, Teso, Luhya, Kisii). By collecting data across a number of diverse regions in Africa, this project can explore whether variations in infants' demographic factors within non-WEIRD societies may affect their IDS preferences.

The complementary relationship between meta-analysis and multi-lab replication

While the magnitude of infants' IDS preferences was affected by age, language backgrounds and the procedure used, in aggregate, monolingual infants in MB1 showed a preference for North American English IDS over ADS. This is consistent with Dunst and colleagues' meta-analysis that showed an overall IDS preference. However, the effect size in MB1 ($d = 0.35$) was much smaller than that reported in Dunst et al.'s meta-analysis ($d = 0.67$). The discrepancy between meta-analyses and registered replication projects is not uncommon in

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psychology (Kvarven et al., 2020). While part of the reasons for this difference could be related to publication bias in the meta-analysis, the differences may also reflect the different theoretical variables that are controlled in the meta-analysis versus MB1 (Kvarven et al., 2020; Lewis, Mathur, VanderWeele, & Frank, under review). For example, Dunst et al (2012) was limited to studies that tested infants with their native languages. As MB1 showed that infants show stronger IDS preference when they were tested in their native language, the stronger overall effect size in Dunst et al., (2012)'s meta-analysis may be related to this language familiarity effect (Bergmann et al., in prep). Furthermore, MB1 also adopted an analysis approach that allowed researchers to include infants who had some missing data in the analysis. Indeed, exploratory analysis of the MB1 dataset suggested that the observed effect size of IDS preference increased if researchers adopted a more stringent criteria that included only infants with less missing data. Perhaps studies in the meta-analysis typically included infants with very little or no missing data in the analysis. Taken together, in comparison to meta-analysis, collaborative and multi-site projects can address the concerns of publication bias and also provide more fine-grained information about participants to researchers to explore questions that are not limited in data in the current literature.

Limitations

ManyBabies has been a success in gathering developmental scientists to work on collaborative, multi-site projects together. However, there are challenges and limitations of running large-scale, multi-site projects. One of the major challenges is that it takes substantial time and effort to manage a large-scale study (see Byers-Heinlein et al., 2020 for details of the experience in MB1). ManyBabies consists of a large group of researchers from different developmental areas. It takes time for the group to make decisions regarding a wide range of

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issues, including the initial phenomenon to investigate, the experimental design, the stimuli, and the study protocol. Before running the study, it is also important for the group to do a small pilot study to test feasibility of the experimental design and identify potential problems/failure in the protocol. Once pilot data suggest that the study is ready for data collection, researchers then need to pre-register the study by submitting a Registered Report to a journal. Only after the Registered Report is accepted in Stage 1 peer review can they issue a call for laboratories to participate in data collection. In our experience, preparation prior to data collection can take 2 to 3 years before data collection can begin. It also can take more than a year for all participating labs to complete data collection. Finally, cleaning and validating data from all the different laboratories can take another substantial period of time. Taken together, our experiences in MB1 and subsequent projects suggest that managing a large-scale, multi-site project requires a major commitment from a dedicated team of researchers and ideally, from a dedicated administrative staff.

Another challenge in running MB projects is obtaining funding. To support as many laboratories to participate in the project as possible, ManyBabies sought to obtain funding that could be distributed to a large number of laboratories rather than being tied to a single principal investigator and institution. This goal does not match many standard funding opportunities, however. Furthermore, in initial attempts to seek funding, ManyBabies applied for funding to support the development of new projects, rather than presenting projects that were already fully planned (as the planning itself would be an important target for grant support). This mismatch with traditional project-centered funding mechanisms has also been challenging. As a result, the group has received only a small number of grants, making it hard for laboratories with lower resources to participate in new ManyBabies projects.

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In summary, collaborative, multisite studies can gather large-scale experimental data and promote replications of key developmental research findings. These types of studies offer researchers subject-level information to examine what underlies heterogeneity of findings across sites, providing an important tool for researchers to examine the consistency (e.g., whether infants across sites and language backgrounds show similar effects) and variability (e.g., whether different experimental methods yield different effect sizes). However, such projects require substantial time, effort, and funding.

Building large-scale datasets that aggregate data from individual researchers

The final approach we review is the aggregation of previously-published datasets from individual researchers. Especially when a particular measure is used consistently across labs and communities, the aggregation of datasets from different labs and projects can offer an opportunity to construct a broader picture of children's language learning across children from many different laboratories. Secondary datasets have had a substantial impact on developmental science. For example, the Child Language Data Exchange System (CHILDES; MacWhinney 2000) is an open large database of transcripts of children's speech and speech to children across different languages and populations, providing researchers with fine-grained information about children's language development. This enterprise has been highly influential, leading to hundreds or perhaps thousands of publications.

To illustrate how this approach can be executed using another type of data, we describe Wordbank, a structured database that archives parent report data on children's vocabulary development using the MacArthur-Bates Communicative Development Inventory (CDI). The CDI (Fenson et al., 1994; 2007) is a widely-used parent report instrument that measures young children's language development. The American English CDIs come in two versions: the Words

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& Gestures (WG) form designed for typically-developing children from 8-18 months, and the Words & Sentences (WS) form designed for children 16 to 30 months. While each form asks about several aspects of children's early language skill (e.g., communicative and symbolic gestures, use of morphology and word combinations), a common feature is the vocabulary checklist which asks parents to indicate which words of a representative list their child "understands" or "understands and says." From these lists, children's receptive and expressive vocabulary size can be tallied.

Over the past decades, the American English CDIs have been shown to provide valid estimates of vocabulary in monolingual children 8 to 30 months. In addition, analyses have revealed important insights regarding early individual differences in vocabulary size, as well as prompted theorizing regarding critical features of the learning mechanisms that guide language acquisition, such as the link between lexical and grammatical development (Bates et al., 1994; Marchman & Bates, 1994; Bates & Goodman, 1999; Fenson et al., 1994; Hills, Maouene, Maouene, Sheya & Smith, 2009). Some monolingual CDI norms, such as North American English CDI norms (Fenson et al., 1994; 2007), are also well established, providing clinicians with a valid tool to screen for children's language delays early in life. However, in the past, researchers mostly had access to the CDI data collected in their own laboratories; there were no public resources that provided researchers with an opportunity to access CDI data from other laboratories or other languages. This lack of sharing restricted researchers' ability to perform broader analyses of children's vocabulary across demographic groups or languages.

Wordbank was designed to address these important developmental questions by aggregating secondary raw CDI data from individual researchers studying many different languages (Frank, Braginsky, Yurovsky, & Marchman, 2017; 2021). Wordbank was built on a

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prior norming database: the Cross Linguistic Lexical Norms site (CLEX; Jørgensen et al., 2010) but improved on it by allowing access to the underlying data and increasing the number of potential analyses that can be performed.

Strengths

Because Wordbank incorporates CDI data across different populations and languages, researchers can easily assess the replicability of patterns in children's vocabulary development by running the same analysis across different populations with different language backgrounds. A key feature of Wordbank is that it provides a platform with interactive analysis tools that are based on an application programming interface (API). This infrastructure offers web applications for users to browse and easily visualize the CDI data, and also allows users to export data in tabular and graphical formats for further analysis. There is also an R package (`wordbankr`) that provides a set of functions in the R statistical language for programmatic access to the data, allowing for the construction of fully reproducible analyses.

Wordbank also can increase the sample diversity of child language analyses, as it stores CDI data across many different populations and languages. To date, Wordbank contains data from 75,144 children across 29 languages. For example, using CDI data from over 32,000 children in Wordbank, Braginsky and colleagues (2019) estimated the acquisition trajectories of around 400 words in each of the 10 languages. The authors examined whether words were learned on average earlier or later based on corpus-derived properties of the words' linguistic environment and features of their meanings (e.g., word concreteness). They found that some predictors were consistent across the 10 languages, for example, word frequency in child-directed speech was a strong predictor of acquisition (especially for nouns) across languages. Such consistencies suggest similar mechanisms of word learning across languages.

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Further, Frank et al. (2021) also found consistent patterns for the association between maternal education (an index of the socioeconomic status, or SES) and children's productive vocabulary size in 12 languages. Although the extent of the relation between SES and children's vocabulary production varied across languages, the authors found that children whose mothers had a college education were likely reported to have larger productive vocabularies, an effect that was generally consistent across all languages. This result provided some support that SES-related differences in children's learning environments (e.g., quantity and quality of language input) may account for the link between maternal education and vocabulary outcomes. These two examples demonstrate that by leveraging a large-scale CDI dataset, researchers can increase sample diversity and also identify patterns that underlie word learning across different languages and populations.

Limitations

Despite the large number of children archived in Wordbank, there are still a number of limitations with this approach. First, the data are observations collected via parent report. While the CDI is reliable and valid in general, with cross-linguistic adaptations to create culturally-appropriate word lists, the data are still not from direct observation. And although parents are comprehensive observers of their children's language skill, they might be subject to biases that would over- or under-estimate children's knowledge (Feldman, 2000).

Further, the conclusions that can be drawn from the data in Wordbank are necessarily limited. In particular, the correlational nature of the data restricts our ability to draw causal conclusions. For example, while there is a strong and consistent cross-linguistic association between individual variation in children's vocabulary size and use of morphosyntax, such relations are inherently correlational, derived generally from a single observer (typically the

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mother), and based on a single methodology. In addition, we can only speculate regarding the implications of the correlations that exist, for example, that variations in SES and children's vocabulary reflect something about variations in the contexts of children's learning environments.

Further, we are not able to control the variability in Wordbank based on different biases in sampling and administration between datasets. For example, researchers may have administered their CDI forms differently, perhaps by providing different instructions to parents, leading to potential inconsistencies across different laboratories. In addition, researchers may have focused on a particular sub-groups of families due to practical or theoretical considerations. Finally, although there are a small number of other languages in the Wordbank dataset, the lion's share of the data come from WEIRD societies – mostly in North America and Europe.

As the example of Wordbank shows, secondary datasets can provide researchers with very rich databases that describe children's language development. Wordbank offers researchers a lens through which to examine both consistency and variability in children's language outcomes, such as gesture, vocabulary, grammar, and across different languages and populations. However, like other approaches, secondary datasets are necessarily restricted by the measure they use (e.g., parent report), the observational nature of the data, and the heterogeneous biases of the individual studies within the broader dataset.

Conclusions

We began this chapter by describing weaknesses of current developmental research that limit our ability to build quantitative theories about the consistency and variability of children's language development across individuals and across languages and cultures. These include concerns related to replicability, reproducibility, sample size, and sample diversity. A strong

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waying of summarizing this point is that the small experimental datasets typical in developmental science yield noisy and unrepresentative measurements that provide only weak constraints on theory.

In this chapter, we suggested that three approaches – meta-analysis, multisite collaboration, and secondary data aggregation – might offer promise in overcoming some of these limitations. Each of these approaches has its own strengths and weaknesses, so no single method can address all concerns. Nevertheless, a combination of all three methods may provide developmental researchers with tools to begin to address some important concerns in the field (e.g., small samples, sample diversity) and enrich the information that we can obtain. We highlighted examples from language development but we believe the point extends to many different subfields. In the future, we hope that researchers will continue to move in these, and hopefully, other new directions, continuing to seek ways to expand the size and diversity of their datasets and the scope and representativeness of the populations that they study. We hope that sharing how these approaches have moved us forward so far can set the stage for creating further innovation.

No one method is perfect. Developmental science – both the field of language development and the broader enterprise – can be advanced by the use of a wider range of data sources and approaches to theory building. Indeed, the idea of taking multiple approaches is a cornerstone of developmental science. Roger Brown may have said it best:

... we would like to express the distaste experimentalists must feel for the assumptions, compromises, and qualifications involved in the use of naturalistic data. We find that naturalistic studies build an appetite for experiment – for controls, complete data, large samples, and statistical analysis. But we also find the reverse. ... The history of

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psychology generally and of psycholinguistics in particular shows that careful experimental work provides no sure path to the truth. Neither does naturalism. There are rich opportunities for error in either method. But on the whole, the opportunities arise at different points, and when the methods are used in combination, the truth has a chance to appear. (Brown & Hanlon, 1970).

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