TRISTAN MAHR

MY DISSERTATION

Contents

1 [demo] Prerequisites

This is a *sample* book written in **Markdown**. You can use anything that Pandoc's Markdown supports, e.g., a math equation $a^2 + b^2 = c^2$.

For now, you have to install the development versions of **bookdown** from Github:

```
devtools::install_github("rstudio/bookdown")
```

Remember each Rmd file contains one and only one chapter, and a chapter is defined by the first-level heading `#`.

To compile this example to PDF, you need to install XeLaTeX.

Prospectus

2
Front Matter

About This Document

This document outlines the research questions, data, and methods for my dissertation. This proposal started out as a grant-writing project, so it has some of the touchstones of NIH F31 grant (Specific Aims, Significance, Approach), but these sections have been expanded considerably.

Dissertation Committee Members

- Jan Edwards, primary mentor and chair, Department of Hearing and Speech Sciences, University of Maryland
- Susan Ellis Weismer, official advisor at UW-Madison, Department of Communication Sciences and Disorders
- Margarita Kaushanskaya, Department of Communication Sciences and Disorders
- Audra Sterling, Department of Communication Sciences and Disorders
- David Kaplan, Department of Educational Psychology
- Bob McMurray, Department of Psychological and Brain Sciences, University of Iowa

Planned Dissertation Format

Three thematically related manuscripts, one for each specific aim, to be completed by Summer 2018.

3
Specific Aims

Individual differences in language ability are apparent as soon as children start talking, but it is difficult to identify children at risk for language delay or disorder. Recent work suggests word recognition efficiency—that is, how well children map incoming speech to words—may help identify early differences in children's language trajectories. Children learn spoken language by listening to caregivers, so children who are faster at recognizing words have an advantage for word learning. This view is borne out by some studies suggesting that children who are faster at processing words show greater vocabulary gains months later (e.g., Weisleder and Fernald, 2013).

We do not know, however, how word recognition itself develops over time within a child. This is an important open question because word recognition may provide a key mechanism for understanding how individual differences emerge in word learning and persist into early language development. Without a developmental account of word recognition, we lack the context for understanding individual differences in lexical processing. Thus, even the big-picture questions are unclear: Do early differences persist over time so that faster processors remain relatively fast later in childhood? Or, is such a question ill-posed because the magnitude of the differences among children shrink with age? I plan to address this gap in knowledge by analyzing three years of word recognition data collected in recently completed longitudinal study of 180 children.

In particular, I will examine the development of *familiar word recognition*, *lexical competition*, and *fast referent selection* (the ability to map novel words to novel objects in the moment). Through these analyses, I will develop a fine-grained description of how the dynamics of word recognition change year over year, and I will study how differences in word recognition performance relate to child-level measures (such as vocabulary and speech perception). I will complement these empirical analyses with computational cognitive models. With these models, I will simulate the word recognition data from each year and study how the models need to change to adapt to children's developing word recognition abilities. These simulations can identify plausible psychological mechanisms that underlie changes in word recognition behavior.

3.1 *Specific Aim 1 (Familiar Word Recognition and Lexical Competition)*

To characterize the development of familiar word recognition and lexical competition, I will analyze data from a visual world paradigm experiment, conducted at age 3, age 4, and age 5.

In these eyetracking experiments, children were presented with four images of familiar objects and heard a prompt to view one of the images. The four images included a target word (e.g., *bell*), a semantically related word (*drum*), a phonologically similar word (*bee*), and an unrelated word (*swing*). I will use a series of growth curve analyses to describe how children's familiar word recognition develop year over year. Of interest is how individual differences at Year 1 persist into Year 3. I will also analyze how expressive vocabulary and lexical processing develop together over time. Lastly, I will examine the children's looks to the distractors to study the developmental course of lexical competition from similar sounding and similar meaning words. Changes in sensitivity to competing words can reveal how lexical competition emerges as a byproduct of learning new words.

3.2 *Specific Aim 2 (Referent Selection and Mispronunciations)*

To characterize how fast referent selection develops longitudinally, I will analyze data from a looking-while-listening mispronunciation experiment, conducted at age 3, age 4, and age 5.

In these eyetracking experiments (based on White and Morgan, 2008; Law and Edwards, 2015), children saw an image of a familiar object and an unfamiliar object, and they heard either a correct production of the familiar object (e.g., *soup*), a one-feature mispronunciation of the familiar object (*shoop*), or a novel word unrelated to either image (*cheem*). The correct productions test familiar word recognition and the nonwords test fast referent selection. The mispronunciations test a child's phonological categories (whether the child permits, rejects, or equivocates about mispronunciations).

I will use growth curve analyses to study how children's responses to the three word types change over time. I will examine familiar word recognition and fast referent selection to determine which feature of lexical processing better predicts vocabulary growth. I plan to examine dissociations or asymmetries in these forms of processing within children as a way to empirically assess the claim that "novel word processing (referent selection) is not distinct from familiar word recognition" (McMurray, Horst, & Samuelson, 2012). Finally, I will examine how individual differences in vocabulary and speech perception predict responses to mispronunciations and novel words.

3.3 Specific Aim 3 (Computational Modeling)

To identify plausible psychological mechanisms underlying the development of word recognition, I will simulate the word recognition data using cognitive computation models.

The TRACE model of word recognition (McClelland and Elman, 1986) has been used to simulate word recognition data from adults (Allopenna et al., 1998), adults with aphasia (Mirman et al., 2011), toddlers (Mayor and Plunkett, 2014), and adolescents with language impairments (McMurray et al., 2010). In this model, incoming acoustic information activates perceptual units which in turn activate phoneme units which in turn activate word units. Connections are interactive, so the model can accommodate top-down processing effects and competition among units through inhibition. The model is controlled by psychological parameters like inhibition strength, activation decay rates, and lexicon size and composition. The advantage of using this model is how one can map different behavioral patterns onto changes in model parameterizations to develop a plausible psychological account of developmental changes. I will simulate the Year 1 word recognition data in TRACE, and I will study how the model's parameters need to change in order to accommodate data from Year 2 and Year 3. I will examine how different model parameters map onto individual differences in word recognition. For instance, under what modeling conditions are mispronunciations of familiar words accepted and do these conditions correspond to child-level differences in vocabulary or speech perception? These simulations will provide a psychological account for the developmental trends and individual variation in word recognition.

3.4 Summary

This project investigates how word recognition develops during the preschool years. There has been no research studying word recognition longitudinally after age two. Findings will show how individual differences in lexical processing change over time and can reveal how low-level mechanisms underlying word recognition mature longitudinally in children. These findings will have translational value by studying processing abilities that subserve word learning and by assessing the predictive relationships between early word recognition ability and later language outcomes.

4 Significance

4.1 Public Health Significance

Vocabulary size in preschool is a robust predictor of later language development, and early language skills predict early literacy skills at school entry (Morgan et al., 2015). By studying the mechanisms that shape word learning, we can understand how individual differences in language ability arise and identify strategies for closing language gaps between children. Word recognition—the process of mapping incoming speech sounds to known or novel words—has been shown to predict later language outcomes. We do not know how this ability develops over time, and we do not know when word recognition is most predictive of future outcomes. This project will provide an integrated account of how word recognition and its relationship with vocabulary size change from age 3 to age 5.

4.2 Scientific Significance

4.2.1 Lexical Processing Dynamics

Mature listeners recognize words by continuously evaluating incoming speech input for possible word matches through lexical competition. The first part of a word activates multiple candidate words in parallel, and these candidates compete so that the best-fitting word is recognized. For example, the onset "bee" might activate the candidates *bee*, *beam*, *beetle*, *beak*, *beaker*, *beginning*, and so on, but an additional "m" would narrow the candidates to just *beam*. Semantic relationships also influence lexical processing, and cascading phonological-semantic effects—e.g., where *castle* activates the phonologically similar *candy* which in turn activates the semantically related *sweet*â€"have been demonstrated (Marslen-Wilson and Zwitserlood, 1989). Both low-level phonetic cues and high-level grammatical, semantic and pragmatic information can influence this process, but the *continuous processing of multiple competing candidates* is the essential dynamic underlying word recognition (Magnuson et al., 2013).

What about young children who know considerably fewer words? Eyetracking studies with toddlers have suggested a developmental continuity between toddlers and adult listeners. Children recognize words incrementally (Swingley, Pinto, & Fernald, 1999), match truncated words to their intended referents (Fernald, Swingley, & Pinto, 2001), and use information from neighboring words in a sentence to facilitate word recognition. This information can be grammatical: Lew-Williams and Fernald (2007) found that Spanish-acquiring preschoolers can use grammatical gender on determiners (*el* or *la*) to anticipate the word named in a two-object word recognition task. The information can also be subcategorical phonetic variation: We found that English-acquiring toddlers look earlier to a named image when the coarticulatory formant cues on word *the* predict the noun of the sentence, compared to tokens with neutral coarticulation (Mahr, McMillan, Saffran, Ellis Weismer, & Edwards, 2015).

There is some evidence for lexical competition where children are sensitive to phonological and semantic similarities among words. Ellis Weismer, Haebig, Edwards, Saffran, and Venker (2016) showed that toddlers (14–29 months old) looked less reliably to a named image when the onscreen competitor was a semantically related word or perceptually similar image. In Law, Mahr, Schneeberg, and Edwards (2016), preschoolers (28–60 months old) demonstrated sensitivity to semantic and phonological competitors in a four-image eyetracking task. Huang and Snedeker (2011) presented evidence of cascading semantic-phonological activation in five-year-olds such that for a target word like *log*, children looked more to an indirect phonological competitor like *key* (competing through its activation of *lock*) than they looked to an unrelated image like *carrot*. In contrast to these studies which all demonstrate interference from similar words, Mani and Plunkett (2010) demonstrated cross-modal phonological priming effects in 18-month-olds. In this study, a picture of prime word (e.g., cat or teeth) was presented in silence; then two images (e.g., cup and shoe) were presented, one of which was named (*cup*). Children on average looked more to the target word (like *cup*) when it was primed by an image of a phonological neighbor (like *cat*), and the children performed at chance when the prime was not related to the named word. Mani, Durrant, and Floccia (2012) found a similar result for cascading phonological-semantic priming with 24-month-olds: Children looked more to a target *shoe* compared to a distractor *door* when primed by an image of *clock*, assumed to activate *sock* which primed *shoe*.

The above studies involved young children of different ages tested under different procedures, sometimes in different dialects and languages. Averaging these results together, so to speak, the studies suggest that early word recognition demonstrates some hallmarks of adult behavior: Continuous processing of words, integration of information from different levels of representation, and the influence of similar, unspoken words on recognition of a word. Nevertheless, we only have a fragmented view of how familiar word recognition and lexical competition develop within children.

One open question is how lexical competition develops within children. For example, do phonological similar words exert more interference during word recognition as children grow older? As a guiding hypothesis, we can think of word learning as a gradual process where familiarity with a word moves from shallow receptive knowledge to deeper expressive knowledge. In adult listeners, words compete and inhibit one another, so that a word is truly "learned" and integrated into the lexicon when it can influence the processing of other words (a line of reasoning reviewed by Kapnoula, et al., 2015). Increasing sensitivity to similar sounding words over time would reveal that children improve their ability to consider multiple candidates in parallel. By studying how sensitivity to similar-sounding and similar-meaning words develop over time and within ever-growing vocabularies, this project can reveal how children come to process words efficiently.

Another avenue for studying word recognition is to examine how listeners respond to unfamiliar or novel stimuli. A productive line of research has found that children are sensitive to mispronunciations during word recognition (e.g., Swingley & Aslin, 2000, 2002). White and Morgan (2008) presented toddlers with images of a familiar and novel object, and children heard a correct production of the familiar object, mispronunciations of the familiar object of varying severity, or an unrelated nonword. Toddlers looked less to a familiar word when the first segment was mispronounced. Moreover, they demonstrated graded sensitivity such that a 1-feature mispronunciation yielded more looks to an image than a 2-feature mispronunciation, and a 2-feature mispronunciation yielded more looks than a 3-feature one. Finally, in the nonword condition, the children looked more to the novel object than the familiar one, demonstrating *fast referent selection* as they associated novel words to novel objects in the moment. A similar pattern of effects was observed in the mispronunciation study by Law and Edwards (2015) with preschoolers mapping real words to familiar objects, nonwords to novel objects, and equivocating about mispronunciations of familiar words.

As with lexical competition, it is unclear how children's responses to mispronunciations and novel words change over time or how individual differences among children change over time. For example, do children become more forgiving of mispronunciations as they mature and learn more words? We might expect so, as children become more experienced at listening to noisy, degraded, or misspoken speech.

Another open question involves the development of fast referent selection. At face value, we might expect a child's ability to associate new words with unfamiliar objects to be more direct measure of word-learning capacity than a child's ability to process known words. Under this assumption, we would expect individual differences in fast referent selection to be highly correlated with vocabulary growth. But McMurray, Horst, and Samuelson (2012) propose that the same basic process is at play in both recognition of familiar words and fast association of nonwords. In experiments, the observed behaviors are the same: Children hear a word and direct their attention to an appropriate referent. This project can tackle these questions by describing how mispronunciations are processed as children grow older and by examining whether familiar word recognition and fast referent selection dissociate and which one is a better predictor of vocabulary growth.

4.2.2 *Individual Differences in Word Recognition*

We have a rough understanding of the development of word recognition, and these gaps in knowledge matter because young children differ in their word recognition abilities. These differences are usually measured using *accuracy* (a probability of recognizing to a word) or *efficiency* (a reaction time or some measure of how quickly accuracy changes over time). These differences are consequential too, as word recognition differences correlate with other language measures concurrently, retrospectively, and prospectively.

The best predictor of lexical processing efficiency is concurrent vocabulary size: Children who know more words look more quickly and reliably to a named word (e.g., Law & Edwards, 2015).

This fact deserves a brief reflection: Suppose the information processing mechanism behind word recognition were just a naïve table search. Then this finding is somewhat puzzling: Children with larger lexicons have to find a needle in a larger haystack—yet this apparent liability is an advantage. That is why the search analogy is naïve. One explanation follows from the earlier described idea about graded word learning: Children become better at recognizing words as they learn more words because they extract regularities and discover similarities among words and develop more efficient lexical representations—the haystack develops regularity and becomes easier to search.

Although it is a robust predictor of word recognition, vocabulary size is nonspecific. For lexical processing dynamics, vocabulary size can be considered an indicator for the organization and efficiency of a child's lexicon, but it also correlates with other (meaningful) differences. Vocabulary is related to differences in speech perception (Cristia, Seidl, Junge, Soderstrom, & Hagoort, 2014) and environmental factors like language input (e.g., Hart & Risley, 1995; Hoff, 2003). For instance, measures of speech perception at 6–8 months predict vocabulary size at 24 months (e.g., Tsao, Liu, & Kuhl, 2004; Kuhl et al, 2008), so processing predicts future vocabulary predicts concurrent processing.

A related complication is the apparent predictive validity of word recognition measures. Marchman and Fernald (2008) found that vocabulary size and lexical processing efficiency at age 2 jointly predicted working memory scores and expressive language scores at age 8. This result would suggest domain-general processing advantages influence word learning. Fernald and Marchman (2012) also found that late talkers who looked more quickly to a named word at 18 months showed larger gains in vocabulary by 30 months compared to late-talkers who looked more slowly at 18 months. Weisleder and Fernald (2013) found that lexical processing and language input at 19 months predict vocabulary size at 25 months and that lexical processing mediated the effect of language input.

Word recognition efficiency and vocabulary size are interconnected measures with concurrent and predictive associations. This project can clarify this relationship by examining the co-development of word recognition, vocabulary size, and speech perception. In particular, I will ask how individual differences in word recognition change over time alongside differences in vocabulary. I can also which features of word recognition (fast referent selection, lexical competition, etc.) are most predictive of vocabulary outcomes at age 5. The additional measures of speech perception can also help clarify the specific effects of vocabulary size on word recognition.

4.2.3 Computational Modeling

One way to bolster a theory of word recognition is to implement the theory in a computational model and simulate human behavior with the model. If the model can produce responses like those of human listeners, then the behavioral data support the model and the model's underlying theory. Models have adjustable parameters, and these generally correspond to plausible psychological constructs like the inhibition strength among competing units or a learning rate for modifying connections. Part of the simulation process therefore is to ask under what conditions a model simulates human behavior, and then interpret the simulations in terms of psychological mechanisms.

Here is a hypothetical example of this modeling strategy: Suppose we want to investigate the finding that a larger vocabulary size predicts more efficient word recognition. We would ask under which parameters (i.e., model settings) a model with a large lexicon outperforms one with a smaller lexicon at word recognition. It might be the case that these results occur only when parameters are set so that the representations of speech sounds are comparatively noisier in a model with fewer words. In this scenario, the models provide a plausible psychological interpretation for the empirical findings: Children develop better representations of speech sounds as they learn words, and these better representations enable more efficient word recognition. Granted, this example is just a hypothetical case, but it illustrates how I intend to use computational models as a way to describe word recognition trends and variation in terms of psychological mechanisms and processing parameters.

The TRACE model of speech perception and word recognition (McClelland & Elman, 1986) is well suited for this kind of simulation work. TRACE can simulate a dozen or so empirical results from speech perception literature (Strauss, Harris, & Magnuson, 2007, Table 1), and it has been used to simulate word-recognition data from adults (Allopenna, Magnuson, & Tanenhaus, 1998), and adults with aphasia (Mirman, Yee, Blumstein, & Magnuson, 2011), and toddlers (Mayor & Plunkett, 2014).

McMurray, Samelson, Lee, and Bruce Tomblin (2010) used TRACE to simulate word recognition results from adolescents with specific language impairment (SLI). They mapped certain theories about SLI onto different model parameters. To test the theory that listeners with SLI have impairments in acoustic perception, for example, they varied three of the model's parameters: amount of noise added to the model's mock-speech input (acoustic resolution), temporal spread of acoustic features in the input (temporal resolution), and rate of decay in the model's acoustic feature detectors (perceptual memory). Other theories of SLI (and other model parameters) provided a closer fit to the observed data than the perceptual deficit theory. Specifically, lexical decay—"the ability to maintain words in memory" (p. 23)—was the most important model parameter, implying that individual differences in word recognition for listeners with SLI are rooted in lexical processes, as opposed to perceptual or phonological ones.

This example shows how simulations with TRACE recast word recognition performance in terms of psychological processes. For this project, I will use TRACE to describe how cognitive processes and representations need to change to simulate the development of word recognition in preschoolers.

4.2.4 Summary

This project studies word recognition in children over three years, so it will provide the first longitudinal study of word recognition in preschoolers. Children in this cohort cover a range of vocabulary scores at Time 1, and this variability allows one to investigate individual differences in vocabulary and word recognition over time and assess the predictive value of these measures. Furthermore, this project studies word recognition in two experimental tasks that can tap into different aspects of word recognition. Specifically, a four-image experiment with semantic and phonological foils allows me to study how lexical competition develops, and a two-image experiment with nonwords and mispronunciations enables me to study how fast referent selection develops over time as well. I will use mixed effects modeling to study not just gross measures of accuracy or interference from distractors, but the time course and lexical dynamics of word recognition using growth curve analyses. These empirical models of the longitudinal word recognition data will be supported by computational models, so that the developmental changes can be described by plausible psychological mechanisms of word recognition.

A
Bibliography

Allopenna, P. D., Magnuson, J. S., and Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language*, 38(4):419–439.

Law, II, F. and Edwards, J. R. (2015). Effects of vocabulary size on online lexical processing by preschoolers. *Language Learning and Development*, 11(4):331–355.

Magnuson, J. S., Mirman, D., and Myers, E. (2013). Spoken Word Recognition. In Daniel Reisberg, editor, *The Oxford Handbook of Cognitive Psychology*. Oxford University Press.

Marslen-Wilson, W. D. and Zwitserlood, P. (1989). Accessing spoken words: The importance of word onsets. *Journal of Experimental Psychology: Human Perception and Performance*, 15(3):576–585.

Mayor, J. and Plunkett, K. (2014). Infant word recognition: Insights from TRACE simulations. *Journal of Memory and Language*, 71(1):89–123.

McClelland, J. L. and Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology*, 18(1):1–86.

McMurray, B., Samelson, V. M., Lee, S. H., and Tomblin, J. B. (2010). Individual differences in online spoken word recognition: Implications for SLI. *Cognitive Psychology*, 60(1):1–39.

Mirman, D., Yee, E., Blumstein, S. E., and Magnuson, J. S. (2011). Theories of spoken word recognition deficits in Aphasia: Evidence from eye-tracking and computational modeling. *Brain and Language*, 117(2):53–68.

Morgan, P. L., Farkas, G., Hillemeier, M. M., Hammer, C. S., and Maczuga, S. (2015). 24-Month-Old Children With Larger Oral Vocabularies Display Greater Academic and Behavioral Functioning at Kindergarten Entry. *Child Development*, 86(5):1351–1370.

Weisleder, A. and Fernald, A. (2013). Talking to children matters: early language experience strengthens processing and builds vocabulary. *Psychological science*, 24(11):2143–52.

White, K. S. and Morgan, J. L. (2008). Sub-segmental detail in early lexical representations. *Journal of Memory and Language*, 59(1):114–132.