Effect of online processing on linguistic memories

by

Michael McAuliffe

B.A., University of Washington, 2009

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Doctor of Philosophy

in

THE FACULTY OF ARTS
(Linguistics)

The University Of British Columbia
(Vancouver)

April 2015

Preface

At University of British Columbia (UBC), a preface may be required. Be sure to check the Graduate and Postdoctoral Studies (GPS) guidelines as they may have specific content to be included.

Table of Contents

List of Tables

List of Figures

Glossary

This glossary uses the handy `acroynym` package to automatically maintain the glossary. It uses the package's `printonlyused` option to include only those acronyms explicitly referenced in the LaTeX source.

GPS	Graduate and Postdoctoral Studies

Acknowledgments

Thank those people who helped you.

Don’t forget your parents or loved ones.

You may wish to acknowledge your funding sources.

Chapter 1

Introduction

Stuff I have introduced

Chapter 2

Background

Listeners of a language are faced with a large degree of phonetic variability when interacting with their fellow language users. Speakers can have different sizes, different genders, and different backgrounds that make speech sound categories, at first blush, overlapping in distribution and hard to separate in acoustic domains. In addition to properties of the speaker varying, properties of the listener's mindset can vary as well. Whether the listener has prior knowledge, or knowledge from another modality, about a speaker characteristic can affect their perception of that speaker's speech. Despite variability on the part of both the listener and the speaker, listeners can maintain a large degree of perceptual constancy, interpreting disparate and variable productions as belonging to one word type or sound category. Exposure to a speaker affects a listener's perceptual system for that speaker, increasing their ability to understand that speaker. Broadly, perceptual learning or perceptual adaptation in the speech perception literature refers to the updating of distributions corresponding to a sound category for a particular speaker.

In this dissertation, perceptual learning will be tested in conditions that manipulate the top-down biases of the listeners and the bottom-up properties of the exposure speaker. The hypothesis I test in this dissertation is that the more evidence a listener has toward a specific word, be it acoustic, lexical or semantic/sentential, the stronger the link between an ambiguous sound embedded in that word and a sound category will be. The more strong evidence that a listener accrues for a given sound category of a speaker, the more perceptual learning will take place. This chapter reviews the recent literature on perceptual learning in speech perception (Section 2.1), which has primarily focused on the duration of perceptual learning effects (Section 2.1.1), and the ability of listeners to generalize perceptual learning to new speakers and to new categories and contexts (Section 2.1.2). Additionally, literature on pertinent literature on attention (Section 2.2), lexical bias (Section 2.3) and semantic predictability (Section 2.4) will be reviewed. The perceptual learning literature has generally used consistent top-down and bottom-up processing conditions to elicit perceptual learning effects, and the goal of this dissertation is to examine the robustness and degree of perceptual learning across different processing conditions.

2.1 Perceptual learning

Norris et al. [29] began the recent set of investigation into perceptual learning in speech. Norris et al. [29] exposed one group of Dutch listeners to a fricative halfway between /s/ and /f/ at the ends of words like *olif* ”olive” and *radijs* ”radish”, and another group to the ambiguous fricative at the ends of nonwords, like *blif* and *blis*. Following exposure, both groups of listeners were tested on their categorization on a fricative continuum from 100% /s/ to 100% /f/. Listeners exposed to the ambiguous fricative at the end of words shifted their categorization behaviour, while those exposed to them at the end of nonwords did not. The exposure using words was further differentiated by the bias introduced by the words. Half the tokens ending in the ambiguous fricative formed a word if the fricative was interpreted as /s/ but not if it was interpreted as /f/, and the others were the reverse. Listeners exposed only to the /s/-biased tokens categorized more of the /f/-/s/ continuum as /s/, and listeners exposed to /f/-biased tokens categorized more of the continuum as /f/. The ambiguous fricative was associated with either /s/ or /f/ dependent on the bias of the word, which led to an expanded category for that fricative at the expense of the other category.

In addition to lexically-guided perceptual learning, unambiguous visual cues to sound identity can cause perceptual learning as well (referred to as perceptual recalibration in that literature). In Bertelson et al. [3], an auditory continuum from /aba/ to /ada/ was synthesized and paired with a video of a speaker producing

/aba/ and a video of /ada/. Participants first completed a pretest that identified the maximally ambiguous step of the /aba/-/ada/ auditory continuum. In eight blocks, participants were randomly exposed to the ambiguous auditory token paired with video for /aba/ or with the video for /ada/. Following each block, they completed a short categorization test. Participants showed perceptual learning effects, such that they were more likely to respond with /aba/ if they had been exposed to video of /aba/ paired with the ambiguous token in the preceding block, and likewise for /ada/.

Perceptual learning is a well established phenomenon in the psychology and psychophysics literature. Training can improve a participants ability to discriminate in many disparate modalities, such as visual acuity, somatosensory spatial resolution, weight estimation, and discrimination of hue and acoustic pitch [14, for review]. In this literature, perceptual learning is the improvement of a perceiver to judge the physical characteristics of objects in the world through training that assumes attention on the task, but doesn't require reinforcement, correction or reward. This definition of perceptual learning corresponds more to what is termed "selective adaptation" in the speech perception literature rather than what is termed "perceptual learning", "perceptual adaptation" or "perceptual recalibration." In speech perception, selective adaptation is the phenomenon where listeners that are exposed repeatedly to a narrow distribution for a sound category, narrow their own perceptual category, resulting in a change in variance of the category, not of the mean of the category (along some acoustic-phonetic dimension) [10, 36, 46]. Perceptual learning or recalibration in the speech perception literature is a more broad updating of perceptual categories, either in mean or variance [29, 46]. !!Something something differences between objects of perception in psychophysics (”real” objects?) and objects of speech perception (auditory things or what they represent?)!!

van Linden and Vroomen [44] compared the perceptual recalibration effects from the visual lipread paradigm [3] to the standard lexically-guided perceptual learning paradigm [29]. Lipread recalibration and perceptual learning effects had comparable size, lasted equally as long, were enhanced when presented with a contrasting sound, and were both unaffected by periods of silence between exposure and categorization. The effects did not last through prolonged testing in this study, unlike in other studies [12, 20].

Perceptual learning can be captured well in terms of Bayesian belief updating [19] or as part of a predictive coding model of the brain [6]. In Bayesian belief updating, the model categorizes the incoming stimuli based on multimodel cues, and then updates the distribution to reflect that categorization. This updated conditional distribution is then used for future categorizations in an iterative process. Kleinschmidt and Jaeger [19] model the results of the behavioural study in Vroomen et al. [46], with models fit to each participant capturing the perceptual recalibration and selective adaptation shown by the participants over the course of the experiment. A similar, but more broad, framework is that of the predictive brain [6]. This framework uses a hierarchical generative model that aims to minimize prediction error between bottom-up sensory inputs and top-down expectations. Mismatches between the top-down expectations and the bottom-up signals generate error signals that are used to modify future expectations. Perceptual learning then is the result of modifying expectations to match learned input.

As stated previously, the primary questions in the perceptual learning in speech literature have focused on retention of perceptual learning effects and the generalization of perceptual learning to new speakers, contexts or categories. While not the primary focus of this dissertation, these lines of research are briefly summarized in the following sections.

2.1.1 Retention

Kraljic and Samuel [20] looked at the strength of the perceptual learning effect across time in an experimental session with intervening tasks between exposure and testing. Native English listeners were exposed to ambiguous fricatives in between /s/ and /ʃ/ in words that biased interpretation toward either /s/ or /ʃ/ in a lexical decision task either spoken by a female voice or a male voice. Participants that completed an /s/-/ʃ/ categorization task immediately following exposure and also those that performed an unrelated visual task between exposure and categorization showed a large perceptual learning effect. However, participants that performed a task involving auditory input from the same speaker as they were exposed to showed attenuated perceptual learning effects when the speech contained correct versions of the ambiguous fricatives, i.e. typical /s/ tokens when they were exposed to the ambiguous sibilant in all /s/ words in the exposure task. The perceptual learning effect in this condition was almost eliminated. Participants that had an intervening task involving auditory input that did not have any /s/ or /ʃ/ tokens showed perceptual learning effects comparable to those with no intervening task. When the intervening task involved auditory input from a different speaker than exposure, perceptual learning effects were as robust as when there was no intervening task. Percpetual learning was a robust and persisted across non-auditory tasks as well as linguistic ones so long as no new exposure to the particular speaker characteristic was present.

Eisner and McQueen [12] looked at the stability of perceptual learning. Dutch participants first completed a categorization task for a continuum of /s/ to /f/ and then listened to a story that contained ambiguous fricative between /s/ and /f/, with one version having the ambiguous fricative in /s/ contexts and the other having it in /f/ contexts. Immediately following, they completed another /s/ to /f/ categorization task. Finally, 12 hours later, they completed the categorization task once again. Half the participants started at 9 am and completed the final categorization task at 9 pm the same day, and the other half started at 9 pm and completed the final categorization at 9 am the following day. Perceptual learning effects were found in both categorization tasks following exposure, with no significant differences between the two times. The perceptual learning effects found were robust across time and across intervening language exposure, as the participants tested at 9 am and 9 pm likely had many interactions with other people in between.

Perceptual learning effects are robust across time. Given no contradictory evidence for a speaker characteristic, a listener's behaviour for that speaker's speech will remain constant over at least the course of a day. However, the perceptual system remains plastic. If a listener is exposed to a speaker trait in the first interaction, but the trait disappears in later interactions, the perceptual system will attenuate to the newer evidence.

2.1.2 Generalization

Generalizing to new speakers

Kraljic and Samuel [22] looked at different sound contrasts and the ability of participants to generalize across speakers. The first contrast was voicing between /t/ and /d/. When exposed to ambiguous stops between /t/ and /d/ corresponding to /d/ for one speaker, and ambiguous stops correpsonding to /t/ for another, perceptual learning effects corresponded to the most recent exposure, regardless of whether the test voice was the same as that recent exposure voice. The second contrast they used was sibilants of /s/ and /ʃ/. For this contrast, they found the speaker-specificity effect found in the literature, where recency of the exposure did not affect the perceptual learning for a particular voice. They argue that the differences between these two contrasts lies in the relative indexical information carried by the sibilants and the lack of much indexical information carried in the stops. Voicing contrasts in onset position are delimited clearly along the voice-onset time dimension, with variability between native English speakers producing little ambiguity between /t/ and /d/. Sibilant productions can vary dramatically, however. For instance, male speakers of English produce /s/ and /ʃ/ with spectral means lower than female speakers of English, with overlapping distributions between male /s/ productions and female /ʃ/ productions, and continua of synthetic sibilants are categorized differently depending on the gender of the speaker who produced the rest of the word [40].

Eisner and McQueen [11] looked at what manipulations could cause perceptual learning to generalize to additional talkers. Using a Dutch lexical decision task with ambiguous fricatives in between /s/ and /f/, they tested categorization on a contniuum between /s/ and /f/ from two talkers. When exposed to one talker's ambiguous fricative and tested on another speaker's continuum, no perceptual learning effect was found. There were two conditions where the fricatives in the exposure and categorization came from the same speaker, but the speakers of the carrier speech differed. In one, the ambiguous fricative from the categorization speaker's produtions was spliced into the exposure tokens, and in the other, the exposure talker's /s/ to /f/ continuum were spliced with vowels from the categorization talker. In these two conditions, they did find a perceptual learning effect across speakers, despite reports by the participants of hearing different speakers, suggesting a sound-specificity effect in addition (or potentially causing) speaker-specificity effects.

Reinisch et al. [34] looked at perceptual learning of speaker characteristics across languages. When exposed to a native Dutch speaker speaking English with ambiguous fricatives between /s/ and /f/, participants show a perceptual learning effect when categorizing Dutch minimal pairs differing only in whether one sound is an /f/ or /s/ spoken by the same speaker. When exposed to the same native Dutch speaker speaking Dutch words and nonwords with the same ambiguous fricative, native Dutch listeners and L2 Dutch listeners (native German speakers) show comparable perceptual learning effects.

Reinisch and Holt [33] exposed native English listeners to a female Dutch-accented voice speaking words and nonwords, where words ending in /s/ or /f/ instead ended either in a natural token or an ambiguous fricative between /s/ and /f/. Listeners showed a perceptual learning effect for the exposure talker as well as another female Dutch-accented voice, showing cross-speaker generalization. However, when categorizing a continuum from /s/ to /f/ of a male Dutch-accented voice, listeners did not generalize the perceptual learning effect, but there was a slight perceptual learning effect for the first block of categorization tokens for the male voice that disappeared in later blocks. Pretests of the continua revealed that the male voice continuum was heavily biased towards /s/, with steps 1-4 of the continuum consistently heard as /s/. For the exposure female voice, Steps 1-4 were already ambiguous between /s/ and /f/, with the proportion /s/ response less than 60% for all steps. The new female voice was responded to similar to the exposure female voice, but with less ambiguity for the initial step. When the continua for the exposure female voice and the male voice were more closely matched by removing the first four steps of the male voice and removing 4 steps along the continuum of the female voice, generalization of the perceptual learning effects matched those for the new female voice. These findings suggest that the perceptual system leverages known distributions that may not be speaker specific. When new tokens fall outside that known distribution, as in the male voice categorization, perceptual learning for that voice occurred using the relatively abundant unambiguous examples for that speaker to adjust the perceptual system for that talker.

Kraljic and Samuel [20], in addition to the findings reported in in Section 2.1.1, also found an asymmetry in how listeners generalized perceptual learning. Across all of their experiments, categorization of the same voice as exposure produced perceptual learning. When the continuum from /s/ to /ʃ/ from the male voice was categorized following exposure to the female voice, perceptual learning effects were consistently present. When the voice of the exposure and categorization was reversed, the consistency of perceptual learning effects disappeared. They performed an acoustic analysis of the spectral means for the categorization items and the exposure items for each talker. The spectral means of the voices for the continuum steps were well separated, but the exposure items were much closer together. The spectral mean of the ambiguous sibilant for the female voice fell in between the ranges of the female continuum steps and the male continuum steps, but the spectral mean exposure ambiguous sibilant for the male voice was squarely in the range of the male continuum steps. The asymmetry of speaker generalization can then be attributed to the female exposure ambiguous items being acoustically (and therefore perceptually) similar enough to generalize the perceptual learning for the female voice to the male voice.

From these studies, the clearest thread through all of them is the degree of acoustic similarity or perceptual similarity between the exposure stimuli that prompts perceptual learning and whatever continuum the listeners are tested on. Stops and fricative do not actually appear to behave categorically different, per se, but their differences in behaviour can be attributed to the fact that stops are acoustically more similar to each other in general than fricatives are.

Generalizing to other categories and contexts

Kraljic and Samuel [21] looked at two sound contrasts (/d/-/t/ and /b/-/p/) that shared a feature, namely voicing. Participants were exposed to an ambiguous coronal stop in between /d/ and /t/ in English words and then tested on two continua with two different voices. The categorization continuum that was presented first, from /b/ to /p/, showed the stronger perceptual learning effects than the second continuum from /d/ to /t/, even though participants were exposed to ambiguous tokens between /d/ and /t/. Both old voices and new voices for the categorization task produced perceptual learning effects.

Mitterer et al. [28] exposed participants to either words ending with /r/ or /l/ or to words beginning with /r/ or /l/ in Dutch, and tested each group's perceptual learning behaviour on continua from /r/ to /l/ in both initial and final positions. If listeners were exposed to an ambiguous sound between /r/ and /l/ at the ends of words, they showed a perceptual learning effect for the continuum that ended with an /r/ or /l/, but not for the continuum that began with an /r/ or an /l/. The inverse behaviour was observed for the group that was exposed to an ambiguous sound between /r/ and /l/ at the beginnings of words. They argue that the category being affected is not a context-insensitive phoneme, but rather a context sensitive allophone. Jesse and McQueen [16] found that listeners did indeed generalize across positions, but their stimuli were the fricatives /s/ and /f/, and the same physical fricatives were the same across all positions.

Reinisch et al. [35] utilized a visually-guided recalibration paradigm from Bertelson et al. [3] to test whether acoustic cues to place of articulation could be recalibrated with unambiguous visual feedback. In Experiment 1, they trained listeners by exposing one group to the maximally ambiguous token between /aba/ and /ada/ with either a video of /ada/ or /aba/ and another group to the maximally ambiguous token between /ibi/ and /idi/ with either a video of /ibi/ or /idi/. In vowel context of /a/, the consonant portion of the token was silenced so that only formant cues to place of articulation would be available. In the vowel context of /i/, the consonant part was not silenced, but since formant transitions in the /i/ context are the same for labials and dentals, the only cues to place of articulation would be in the consonant itself. Afterwards, when they categorized auditory only continua of /aba/ to /ada/ and /ibi/ to /idi/ with the same silencing of the consonant in the /a/ context. They found a recalibration effect for the continuum participants were exposed to, but no generalization effect to the novel continuum. Experiment 2 followed the same setup as Experiment 1, with the same /aba/ to /ada/ as in Experiment 1, but replaced the /ibi/ to /idi/ continuum with a /ama/ to /ana/ continuum. As in Experiment 1, clear recalibration effects were found for the continuum participants were exposed to, but not for the novel continuum. Experiment 3 followed the same procedure but used a /ubu/ to /udu/ continuum instead of an /ibi/ to /idi/ continuum.

The /u/ context provides formant transition cues to place of articulation, so the consonant was silenced for this continuum as well. As before, there were perceptual recalibration effects for the continuum participants were exposed to, but not to the novel continuum. Across all of these, there is a context specifity effect.

Kraljic et al. [23] exposed participants to ambiguous sibilants between /s/ and /ʃ/ in two different contexts. In one, the ambiguous sibilants were intervocalic, and in the other, they occurred as part of a /str/ cluster. Participants exposed to the ambiguous sound intervocalically showed a perceptual learning effect, while those exposed to the sibilants in /str/ environments did not. The sibilant in /str/ often surfaces closer to [ʃ] in many varieties of English, due to coarticulatory effects from the other consonants in the cluster, but the coarticulatory effects for merging /s/ and /ʃ/ are much weaker in intervocalic position. They argue that the interpretation of the ambiguous sound is done in context of the surrounding sounds, and only when the pronunciation variant is unexplainable from context is the variant learned and attributed to the speaker, see also Kraljic et al. [24]. In addition to a continuum of /asi/ to /aʃi/, they also tested a continuum from /astri/ to /aʃtri/, and found comparable perceptual learning effects across both continua for those exposed to the intervocalic ambiguous sibilants, but no perceptual learning effects on either continua for the other condition, showing a context insentivity absent in other studies.

Continuing the thread of the previous section, perceptual learning tend to extend only to stimuli that is similar to the exposure items. This exposure-specific generalization is widely found in the psychophysics literature as well, where perceptual learning is argued to reside or affect the early sensory pathways, where stimuli are represented with the greatest detail [15]. In a predictive coding model of the brain [6], errors in prediction would not propagate very far from the levels where bottom-up sensory information is integrated. Interestingly, lexically-guided perceptual learning produces much more robust perceptual learning, where test stimuli are either nonword continua [29] or real word minimal pairs [34]. Visually-guided perceptual learning may be more similar to the psychophysics definition of perceptual learning, where participants are better at discriminating the specific stimuli they have been exposed to.

2.2 Attention

In this dissertation, attention is used as a way to reweight the contribution of bottom-up acoustic information and top-down linguistic information. Attention has been found to have a role on perceptual learning in the psychophysics literature. For instance, Ahissar and Hochstein [1] found that in general, attending to global features for detection (i.e., discriminating different orientations of arrays of lines) does not make participants better at using local features for detection (i.e., detection of a singleton that differs in angle in the same arrays of lines), and vice versa. However, there was a small degree of local detection learned from global detection, with the singleton popping out from its field as highly salient.

In the auditory domain, similar asymmetries have been found between global and local processing. In Sussman et al. [43], participants were presented with three types of tones in different orders, with one second stimulus onset asynchrony (SOA). The order of the tones were either random, with tone 1 more frequent than tone 2, which in turn was more than tone 3, or the order of the tones had a general pattern of five tones (1 1 1 1 2). They looked at event-related potentials (ERPs) following tone 2, specifically focusing on the mismatch negativity (MMN) ERP and the N2b ERP, which is evoked when a stimulus is attentively detected as being different from regular stimuli. In addition to the two patterns, there were three attentional conditions. In one, participants were instructed to ignore the auditory stimuli and read a book. In the second, participants were instructed to listen to the tone pitch and press a key when they heard the lowest pitch one (tone 3). In the final condition, participants were told of the five tone pattern and instructed to respond when one of the tones was replaced by the lowest tone. When participants were ignoring the auditory stimuli, there was a MMN response following tone 2. When attending to the pitch of the tones, regardless of the tone pattern, there was both a MMN response and an N2b response following tone 2. When participants attended to the pattern, there was neither a MMN response nor an N2b response after tone 2. These results suggest that auditory representations can be manipulated by attention, resulting in processing differences.

However, attention can only modulate the representation to the degree that the acoustics allow. In other similar studies with different stimulus onset asynchronies, patterns were detected more readily. At a fast presentation rate (100-ms SOA), no MMN was present, even when participants were told to ignore the auditory stimuli [41]. The fast presentation rate is more conducive to chunking the incoming stream into a pattern, whereas the slow presentation rate allows for the participants to process each tone in isolation or as part of a bigger pattern. Similar results were found for varying SOA in an auditory streaming task [41, 42].

Attentional sets are a widely used term in the attention literature. In the visual domain, attentional sets can refer to the strategies that the perceiver uses to perform a task. For instance, in a visual search task, colour, orientation, motion and size are the predominant strategies [47]. Two broad categories of attentional sets are generally used. Focused sets direct attention to components of the sensory input, and diffuse sets direct attention to global properties of the sensory input. In the visual search literature, a focused attentional is the feature search mode, which gives priority to a single feature, such as the colour of the target, and a diffuse attentional set is singleton detection mode, which gives priority to any salient features [2]. In the auditory streaming literature, two attentional sets have been identified as “selective listening”, where the perceiver attempts to hear the components of two streams, and “comprehensive listening”, where the perceiver tries to hear all components as a single stream [45]. Finally, in a lexical decision tasks, the diffuse attentional set is where primary attention is on detecting words from nonwords, and the focused attentional set is where instructions direct participants attention to a potentially misleading sound [30]. Attentional set selection is not necessarily optimal on the part of the perceiver, and it has been shown to be biased based on experience, with the amount of training performed influencing the length of time that perceivers will continue to use non-optimal sets after the task has changed [25].

Attention in perceptual learning in speech perception has not been manipulated in previous work, but some work has been done on how individual differences in attention control can impact perceptual learning. Scharenborg et al. [39] presents a perceptual learning study of older Dutch listeners in the model of Norris et al. [29]. In addition to the exposure and test phases, these older listeners completed three tests for hearing loss, selective attention and attention-switching control. They found no evidence that perceptual learning was influenced by listeners’ hearing loss or selective attention abilities, but they did find a significant relationship between a listener's attention-switching control and their perceptual learning. Listeners with worse attention-switching control showed greater perecptual learning effects, which the authors ascribed to an increased reliance on lexical information. Older listeners had previously been shown to have smaller perceptual learning effects as compared to younger listeners, but the differences were most prominent directly following exposure [38]. Younger listeners initially had a larger perceptual learning effect in the first block of testing, but the effect lessened over the subsequent blocks. Older listeners showed smaller initial perceptual learning effects, but no such decay. Scharenborg and Janse [38] also found that performance in the lexical decision task significantly affected the perceptual learning in the testing phase.

2.3 Lexical bias

Lexical bias is the primary way through which perceptual learning is induced in the experimental literature. Given that ambiguous productions must be associated with a word to induce lexically-guided perceptual learning [29], I predict that differing degrees of lexical bias will lead to differing degrees of perceptual learning. The stronger the lexical bias, the stronger the link will be between the ambiguous sound and the sound category (via the word).

Lexical bias, also known as the Ganong Effect, refers to the tendency for listeners to interpret a speaker's production as a meaningful word rather than a nonsense word. For instance, given a continuum from a nonword like *dask* to word like *task* that differs only in one sound, listeners in general are more likely to interpret any step along the continuum as the word endpoint rather than the nonword endpoint [13]. This bias is exploited in perceptual learning studies to allow for noncanonical, ambiguous productions of a sound to be linked to pre-existing sound categories.

Studies looking at lexical bias use a phoneme categorization task, where participants identify a sound at the beginning or end of a word from two possible options that vary in one dimension. For instance, given a continuum from /t/ to /d/, participants are asked to identify the sound at the beginning or end as either /t/ or /d/. Lexical bias effects are calculated based on two continua, where words are formed at opposite ends. For the /t/ to /d/ continua, one would form a word at the /t/ end, such as *task* and one would form a word at the other end, such as *dash*. Lexical bias effects are then calculated from the different categorization behaviour for these two continua.

Connine and Clifton [9] established different reaction time profiles for perceptual and postperceptual processes in categorizing a continuum. With lexical bias, response times to the end points of a /d/ to /t/ continuum show no difference whether the continuum forms a word at one end point (such as *dice* to *tice*) or at the other (such as *dype* to *type*). However, at the boundary between /d/ and /t/, reaction times are faster when a subject responds consistent to the bias (i.e. interprets an ambiguous word *?ice* as *dice*). For postperceptual processes, in this case a monetary payoff for responding either /d/ or /t/ along a continuum that has nonwords at both ends, the pattern is reversed, where reaction times were faster for responses consistent with the monetary bias at the end points of the continuum, but no such difference was found for the category boundary. Both biases produced similar categorization patterns, such that the participants biased toward /d/, either lexically or monetarily, categorized more of the continuum as /d/, so the principle difference between the two biases was in the reaction time profile.

Lexical bias varies in strength according to several factors. First, the length of the word in syllables has a large effect on lexical bias, with longer words showing stronger lexical bias than shorter words [32]. Continua formed using trisyllabic words, such as *establish* and *malpractice*, were found to show consistently large lexical bias effects than monosyllabic words, such as *kiss* and *fish*. Pitt and Samuel [32] also found that lexical bias from trisyllabic words was robust across experimental conditions, but lexical bias from monosyllabic words was more fragile and condition dependent. They argue that these affects arise from both the greater bottom-up information present in longer words and the greater lexical competition for shorter words.

Pitt and Szostak [30] used a lexical decision task with a continuum of fricatives from /s/ to /ʃ/ embedded in words differing in the position of a sibilant. They found that ambiguous fricatives earlier in the word, such as *serenade* or *chandelier*, lead to greater nonword responses than the same ambiguous fricatives embedded later in a word, such as *establish* or *embarass*. In the experiments and meta-analysis of phoneme identification results presented in Pitt and Samuel [31], they found that, for monosyllabic word frames, token-final targets produce more robust lexical bias effects than token-initial targets.

Pitt and Szostak [30] additionally investigated the role of attention in modulating lexical bias. When listeners were told that the speaker's /s/ and /ʃ/ were ambiguous and to listen carefully to ensure correct responses, they were less tolerant of noncanonical productions across all positions in the word. That is, participants attending to the speaker's sibilants were less likely to accept the modified production as a word than participants given no particular instructions about the sibilants. Given that the task listeners performed was a lexical decision task, the default attentional set for the task, termed "diffuse" by Pitt and Szostak [30], would have attention distributed across both acoustic-phonetic and lexical domains. Listeners given the instructions about the speaker's /s/ productions had a "focused" attentional set, with more weighting on the acoustic-phonetic domain than the "diffuse" attentional set.

Lexical bias is affected by processing conditions. In their first experiment, Mattys and Wiget [27] found that lexical bias has a larger effect when listeners have more cognitive load than when they have no cognitive load from concurrent tasks. In their second experiment, the same cognitive load and non-cognitive load conditions were present, but listeners had to respond to the phoneme identification task within 1500 ms. In this experiment, the lexical bias across cognitive load conditions was identical and similar to the cognitive load condition of experiment 1. In experiment 3, listeners could only respond *after* 1500 ms, and the effect of cognitive load re-emerged with similar magnitude to experiment 1. In the remainder of their experiments, they examined whether cognitive load increased word activation or decreased sensory information, the two primary possible explanations for the pattern of results found in experiment 1. They found that semantic priming was not significantly different across cognitive loads, but fine-grained discrimination suffered under cognitive load conditions. Thus, the effect of cognitive load observed is a function of impoverished fine detail leading to a greater reliance on lexical information. However, the timecourse for the incorporation of these different sources of information is interesting, with lexical information playing a larger role earlier on in processing and sensory signal information being incoporated later on. Earlier responses are more likely to be lexically biased than later responses. The relative weightings of lexical information and acoustic information are malleable in different processing conditions.

2.4 Semantic predictability

Semantic predictability has been shown to have effects on speech production in the same direction as lexical predictability, and the two appear to not interact [37]. No experiments in perceptual learning have used linguistic biases other than lexical ones, but we predict compounding effects for perceptual learning, given the compounding effects in production. Semantic predictability and lexical bias should combine to form a stronger association between a deviant production and the sound category, leading to greater perceptual learning.

Sentences are highly predictable when they contain words prior to the final word that points almost definitively to the identity of the final word. For instance, the sentence fragment *The cow gave birth to the...* from Kalikow et al. [17] is almost guaranteed to be completed with the word *calf*. On the other hand, a fragment like *She is glad Jane called about the...* is far from having a guaranteed completion, other than having the category of noun. Semantic predictability has been found to have effects on both production and perception, which will be discussed in the two following sections

In general, semantic predictability results in acoustically reduced word tokens. In Scarborough [37], words produced in highly predictable frames tend to be shorter in duration and have less dispersed vowel realizations. This semantic predictability effect did not interact with neighbourhood density, a lexical factor that proxies for the amount of lexical competition a word has. Words with many neighbours, and therefore less lexical predictability, had longer durations and more dispersed vowel realizations. For both the lexical and the semantic predictability, high predictability led to less distinct word realizations, and low predictability led to more distinct word realizations, independently of each other.

In a study looking at semantic predictability across dialects, Clopper and Pierrehumbert [7] found that not all dialects realize the effects of semantic predictability the same. For the Southern dialect of American English, the results were much the same as in Scarborough [37], showing temporal and spectral reduction in high predictabilty environments. However, speakers in the Midland dialect showed no such effect, and speakers of the Northern dialect showed more extreme Northen Cities shifting in the the high predictability environment.

Despite the temporal and spectral reduction found in high predictability contexts, high predictability sentences are generally more intelligible. Sentences that form a semantically coherent whole have higher word identification rates across varying signal-to-noise ratios [17]. However, when words at the ends of predictive sentences are excised from their context, they tend to be less intelligible than words excised from non-predictive contexts [26].

Connine [8] and Borsky et al. [4] present conflicting results of the reaction time profile of semantic predictability on a phoneme categorization task. Connine [8] found evidence that semantic predictability operated similar to monetary payoff in Connine and Clifton [9]. Borsky et al. [4] attempted to replicate Connine [8] while removing potential confounds from the methodological design. In contrast to Connine [8], they used only one voicing continuum (from *goat* to *coat*), embedded the acoustic target in the middle of the sentence rather than at the end, and only presented one instance of each sentence to each participant rather than all continuum steps for each sentence to each participant. The reaction time profile in their study more closely aligned to the profile of lexical bias in Connine and Clifton [9].

2.5 Current contribution

Perceptual learning effects require two important aspects to be involved in the exposure phase. There must be some ambiguous acoustic aspect to be learned, and there must be an unambiguous link between the ambiguous acoustics and a sound category. This link can be provided through bottom-up information, such as in the visual domain [3], or it can be top-down information, such as the lexical status of the tokens [29]. Most of the literature within the domain of lexically-guided perceptual learning has been on the presence or absence of perceptual learning in the categorization phases, with manipulations to the categorization phase to test for generalization. The question that I am interested in is in the linking of ambiguous tokens to sound categories. Can manipulations in the exposure phase that reduce the reliability of the linking cause differences in perceptual learning?

In this dissertation, I will induce manipulations of lexical bias and attention in Experiments 1 and 2, and manipulations of sentence predictability and attention in Experiment 3. Lexical bias has been shown to affect phoneme categorization tasks [13], and can be manipulated by position of the ambiguous sound in the word and attention [30]. Sentence predictability, has likewise been found to affect phoneme categorization tasks similar to lexical bias [4], and can be manipulated by the preceding words in the sentence [17]. The interaction of sentence predictability with attention has not been explicitly studied, but the interaction should be similar to lexical bias, given findings that sentence predictability exerts similar effects on phone categorization as lexical bias [4]. In both of these studies, attention will be either diffuse across the word or focused on the speaker's phonetic characteristic to be learned. Attention to the speaker characteristic should lessen the acceptability of these productions as words as in previous work [30], leading to less perceptual learning when comparing these participants to those with a diffuse attentional set.

Chapter 3

Lexical decision

3.1 Motivation

This experiment implements a standard lexically-guided perceptual learning experiment with manipulations to lexical bias and attention.

3.2 Experiment 1

In these two experiments, listeners will be exposed to ambiguous productions of words containing a single instance of /s/, where the /s/ has been modified to sound more like /ʃ/ in a lexical decision task. In one group, the S-Initial group, the critical words will have an /s/ in the onset of the first syllable, like in *cement*, with no /ʃ/ neighbour, like *shement*. In the other group, the S-Final group, the critical words will have an /s/ in the onset of the final syllable, like in *tassel*, with no /ʃ/ neighbour like *tashel*. In addition, half of each group will be given instructions that the speaker has a ambiguous /s/ and to listen carefully, following Pitt and Szostak [30].

Given the difference in word response rates depending on position in the word, we would predict that listeners exposed to ambiguous sounds earlier in words would be less likely to accept these productions as words as compared to listeners exposed to ambiguous sounds later in words. In addition, given the reliance of perceptual learning on lexical scaffolding, this lower acceptance rate for the former

Table 3.1: Mean and standard deviations for frequencies and number of syllables of each item type

Item type	Frequency	Number of syllables
Filler words	1.81 (1.05)	2.4 (0.55)
/s/-initial	1.69 (0.85)	2.4 (0.59)
/s/-final	1.75 (1.11)	2.3 (0.47)
/ʃ/-initial	2.01 (1.17)	2.3 (0.48)
/ʃ/-final	1.60 (1.12)	2.4 (0.69)

group would lead to a smaller perceptual learning effect as compared to the latter group.

3.2.1 Methodology

Participants

One hundred native speakers of English participated in the experiment and were compensated with either $10 CAD or course credit. They were recruited from the UBC student population. Twenty additional native English speakers participated in a pretest to determine the most ambiguous sounds. Twenty five other native speakers of English participated for course credit in a control experiment.

Materials

One hundred and forty English words and 100 nonwords that were phonologically legal in English were used as exposure materials. The set of words consisted of 40 critical items, 20 control items and 60 filler words. Half of the critical items had an /s/ in the onset of the first syllable and half had an /s/ in the onset of the final syllable. All critical tokens formed nonwords if their /s/ was replaced with /ʃ/. Half the control items had an /ʃ/ in the onset of the first syllable and half had an /ʃ/ in the onset of the final syllable. Each critical item and control item contained just the one sibilant, with no other /s z ʃ ʒ ʧ ʤ/. Filler words and nonwords did not contain any sibilants. Frequencies and number of syllables across item types are in Table 3.1

Table 3.2: Frequencies of words used in categorization continua

Continuum	/s/-word frequency	/ʃ/-word frequency
sack-shack	1.11	0.75
sigh-shy	0.53	1.26
sin-shin	1.20	0.48
sock-shock	0.95	1.46

Four monosyllabic minimal pairs of voiceless sibilants were selected as test items for categorization (*sack-shack*, *sigh-shy*, *sin-shin*, and *sock-shock*). Two of the pairs had a higher log frequency per million words (LFPM) from SUBTLEXus [5] for the /s/ word, and two had higher LFPM for the /ʃ/ word, as shown in Table 3.2.

All words and nonwords were recorded by a male Vancouver English speaker in quiet room. Critical words for the exposure phase were recorded in pairs, once normally and once with the sibilant swapped forming a nonword. The speaker was instructed to produce both forms with comparable speech rate, speech style and prosody.

For each critical item, the word and nonword versions were morphed together in an 11-step continuum (0%-100% of the nonword /ʃ/ recording, in steps of 10%) using STRAIGHT [18] in Matlab (The Mathworks, Inc.). Prior to morphing, the word and nonword versions were time aligned based on acoustic landmarks, like stop bursts, onset of F2, nasalization or frication, etc. All control items and filler words were processed and resynthesized by STRAIGHT to ensure a consistent quality across stimulus items.

Pretest

To determine which step of each continua would be used in exposure, a phonetic categorization experiment was conducted. Participants were presented with each step of each exposure word-nonword continuum and each categorization minimal pair continuum, resulting in 495 trials (40 exposure words plus five minimals pairs by 11 steps). The experiment was implemented in E-prime (cite). As half of the critical items had a sibilant in the middle of the word (onset of the final syllable),

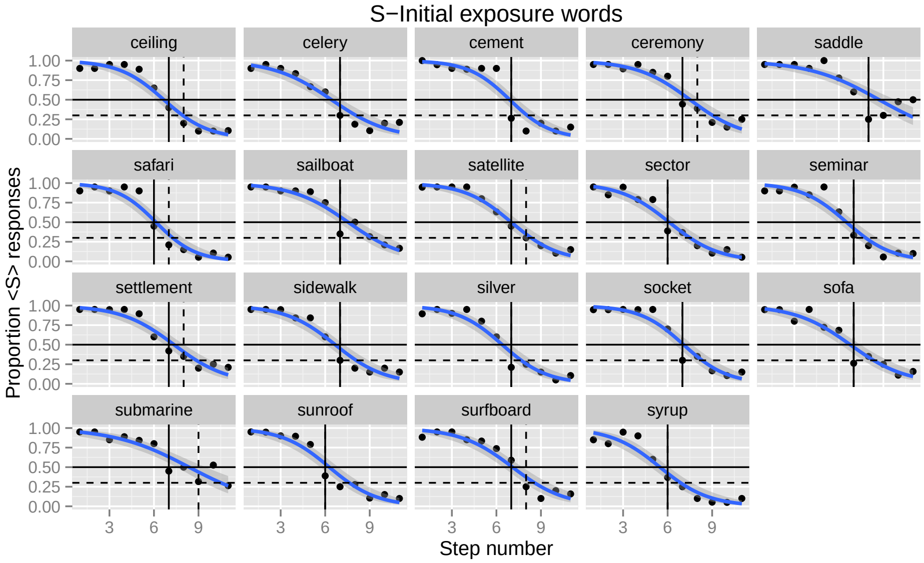


Figure 3.1: Proportion of word-responses for /s/-initial exposure words. Solid lines represent Experiment 1 selection criteria (50% word-response rate) and dashed lines represent Experiment 2 selection criteria (30% word-response rate). Dots are averaged word-response across subjects, and the blue line is a binomial model constructed from the responses.

participants were asked to respond with word or non word rather than asking for the identity of the ambiguous sound, as in previous research [34].

The proportion of s-responses (or word responses for exposure items) at each step of each continuum was calculated and the most ambiguous step chosen. The threshold for the ambiguous step for this experiment was when the percentage of s-response dropped near 50%. A full list of steps chosen for each stimulus item is in the appendix. For the minimal pairs, six steps surrounding the 50% cross over point were selected for use in the phonetic categorization task. Due to experimenter error, the continuum for *seedling* was not included in the stimuli, so the chosen step was the average chosen step for the /s/-initial words. The average step chosen for /s/-initial words was 6.8 ($SD = 0.5$), and for /s/-final words the average step was 7.7 ($SD = 0.8$).

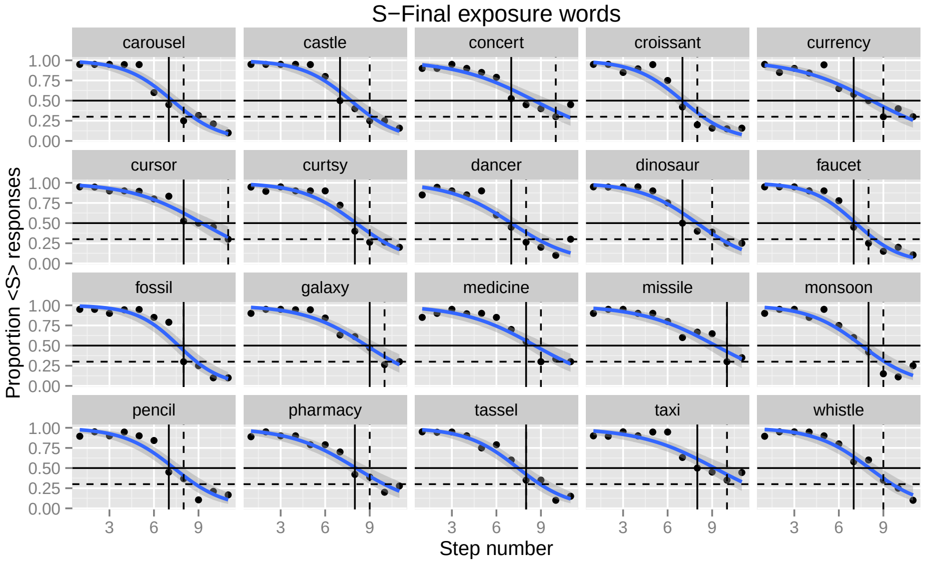


Figure 3.2: Proportion of word-responses for /s/-final exposure words. Solid lines represent Experiment 1 selection criteria (50% word-response rate) and dashed lines represent Experiment 2 selection criteria (30% word-response rate). Dots are averaged word-response across subjects, and the blue line is a binomial model constructed from the responses

Procedure

Participants in the experimental conditions completed two tasks, an exposure task and a categorization task. The exposure task was a lexical decision task, where participants heard auditory stimuli and were instructed to respond with either ”word” if they thought what they heard was a word or ”nonword” if they didn’t think it was a word. The buttons corresponding to ”word” and ”nonword” were counterbalanced across participants. Trial order was pseudorandom, with no critical or control items appearing in the first six trials, and no critical or control trials in a row, but random otherwise, following Reinisch et al. [34].

In the categorization task, participants heard an auditory stimulus and had to categorize it as one of two words, differing only in the onset sibilant (s vs sh). The buttons corresponding to the words were counterbalanced across participants. The six most ambiguous steps of the minimal pair continua were used with seven repetitions each, giving a total of 168 trials. Participants were instructed that there would two tasks in the experiment, and both tasks were explained at the beginning to remove experimenter interaction between exposure and categorization.

Participants were assigned to one of four conditions. Two of the conditions exposed participants to only criticall items that began with /s/, and the other two exposed them to only critical items that had an /s/ in the onset of the final syllable, giving a consistent 200 trials in all exposure phases with control and filler items shared across all participants. Additionally participants in half the conditions received additional instructions that the speaker's ”s” sounds were sometimes ambiguous, and to listen carefully to ensure correct responses in the lexical decision.

3.2.2 Results

Control experiment

Responses with reaction times less than 200 ms or greater than 2500 ms were excluded from analyses. A logistic mixed effects models was fit with Subject and Continua as random effects and Step as a fixed effect with by-Subject and by-Item random slopes for Step. The intercept was not significant ($\beta = 0.43, SE = 0.29, z = 1.5, p = 0.13$), and Step was significant ($\beta = -2.61, SE = 0.28, z = -9.1, p < 0.01$).

Exposure

Trials with nonword stimuli and responses faster than 200 ms or slower than 2500 ms were excluded from analysis. Performance on the exposure task was high overall, with accuracy on filler trials averaging 92%. Word response rates for each of the four conditions did not differ significantly from each other, though S-Final/No Attention participants had a slightly higher average rate of 81% (SD= 17%) than the other conditions (S-Final/Attention: mean = 74%, SD = 18%; S-Initial/No Attention: mean = 74%, SD = 27%; S-Initial/Attention: mean = 76%, SD = 23%). A logistic mixed effects model with accuracy as the dependent variable was fit with fixed effects for trial type (Filler, S, SH), Attention (No Attention, Attention), Exposure Type (S-Initial, S-Final) and their interactions. The random effect structure was as maximally specified as possible with random effects for Subject and Word, and by-Subject random slopes for trial type and by-Word random slopes for Attention. The only fixed effects that were significant were a main effect of trial type for /s/ trials compared to filler trials ($\beta = -1.71, SE = 0.43, z = -3.97, p < 0.01$) and a main effect of Attention ($\beta = 0.76, SE = 0.38, z = 2.02, p = 0.04$). Trials containing an ambiguous /s/ were less likely to be responded to as a word, and participants instructed to pay attention to /s/ were more likely to correctly respond to words in general.

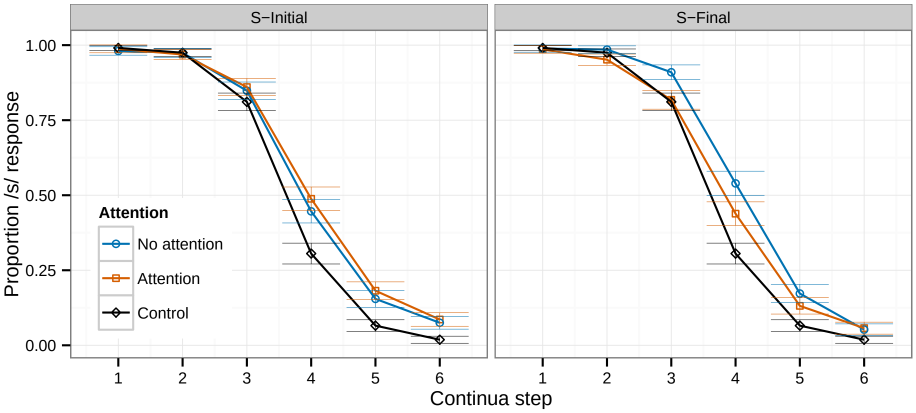
Categorization

Responses with reaction times less than 200 ms or greater than 2500 ms were excluded from analyses. Participants were excluded if their initial estimated cross over point for the continuum lay outside of the 6 steps presented (2 participants). A logistic mixed effects model was constructed with Subject and Continua as random effects and continua Step as random slopes, with 0 coded as a /ʃ/ response and 1 as a /s/ response. Fixed effects for the model were Step, Exposure Type, Attention and their interactions.

There was a significant effect for the intercept ($\beta = 0.83, SE = 0.31, z = 2.6, p < 0.01$), indicating that participants categorized more of the continua as /s/ in general. There was also a significant main effect of Step ($\beta = -2.10, SE = 0.20, z = -10.3, p < 0.01$), and a significant interaction between Exposure Type and Attention ($\beta = -0.93, SE = 0.43, z = -2.14, p = 0.03$). There was a marginal main effect of Exposure Type ($\beta = 0.58, SE = 0.30, z = 1.8, p = 0.06$).

These results are shown in Figure 3.3. The solid lines show the control participants' categorization function across the 6 steps of the continua. The error bars show within-subject 95% confidence intervals at each step. When exposed to ambiguous /s/ tokens in the first syllables of words, participants show a general expansion of the /s/ category, but no differences in behaviour if they are warned about ambiguous /s/ productions. However, when the exposure is to ambiguous /s/ tokens later in the words, we can see differences in behaviour beyond the general /s/ category expansion. Participants not warned of the speaker's ambiguous tokens categorized more of the continua as /s/ than those who were warned of the

Figure 3.3: Proportion /s/ response along the 6 step continua as a function of Exposure Type and Attention in Experiment 1. In the S-Final condition, participants in the Attention condition showed a larger perceptual learning effect than those in the No Attention condition. In the S-Initial condition, there were no differences in perceptual learning between the Attention conditions. Error bars represent 95% confidence intervals.

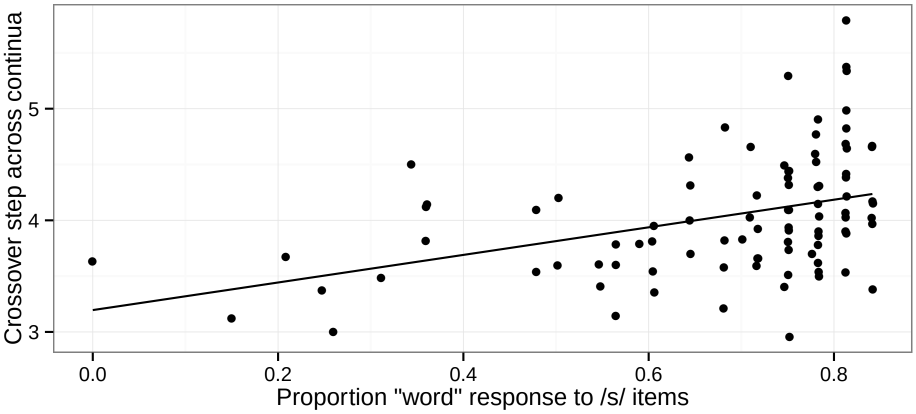


speaker's ambiguous /s/ productions.

As an individual predictor of participants' performance we took the proportion critical word endorsements and compared these values to the estimated crossover points. The crossover point was determined from the Subject random effect in the logistic mixed effects model [**?**]. There was a significant positive correlation between a participant's tolerance for the ambiguous exposure items and their crossover point on the continua ($r = 0.39, t(90) = 4, p < 0.01$), shown in Figure 3.4.

An ANOVA with cross-over point as the independent variable and word endorsement rate, Exposure Type, Attention and their interactions, found only a main effect of word endorsement rate ($F(1,89) = 17.82, p < 0.01$), suggesting that listeners in different conditions were not affected differently from one another.

Figure 3.4: Correlation of crossover point in categorization with the proportion of word responses to critical items containing an ambiguous /s/ token.



3.2.3 Discussion

Perceptual learning effects in this experiment were robust across continua and experimental conditions, indicating the general automaticity of perceptual adaptation, but the degree of adaptation differed across conditions. Differences in attention only had an effect in the S-Final conditions, which replicates earlier findings that the effect of attention increased as the position of the ambiguous sound moved toward the end of the word [30]. The initial sound of a word is already a prominent position and listeners focus on the initial sounds to narrow the set of possible words they might be hearing. Later in a word, expectations for particular words given the preceding phonetic content would be greater, so directed attention on the phonetic detail shows a clear effect. That attention affected perceptual learning at all suggests that the adaptation is not wholly automatic and there is some degree of listener control.

The threshold for stimuli selection differed from that in previous studies. The closest study to this one used 70% of word responses in the pretest as the threshold for selection [34]. In that study, the lowest critical word endorsement rates in the exposure phase were 17 out of 20 (85%). In contrast, this experiment used 50% as the threshold and had correspondingly lower word endorsement rates (mean = 76%, sd = 22%). Interestingly, despite the lower word endorsement rates and the less canonical stimuli used, perceptual learning effects remained robust, which raises the question, can perceptual learning occur from stimuli that are farther from canonical productions than even the ones used in this experiment?

3.3 Experiment 2

Experiment 2 follows up on Experiment 1 by using stimuli that are farther from the canonical productions of the /s/ critical words. If the correlation from Experiment 1 holds, we expect to see lower word endorsement rates and lower (or perhaps non-existent) perceptual learning effects.

3.3.1 Methodology

This experiment followed an identical methodology as experiment 1, except that the step along the /s/-/ʃ/ continua chosen as the ambiguous sound had a different threshold. For this experiment, 30% identification as the /s/ word was used the threshold. The average step chosen for /s/-initial words was 7.3 ($SD = 0.8$), and for /s/-final words the average step was 8.9 ($SD = 0.9$).

3.3.2 Results

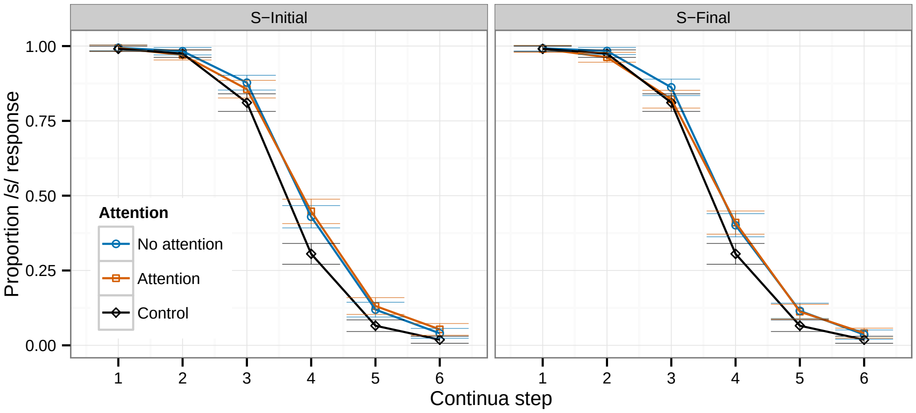
Exposure

Trials with nonword stimuli and responses faster than 200 ms or slower than 2500 ms were excluded from analysis. Performance on the exposure task was high overall, with accuracy on filler trials averaging 92%. An ANOVA of critical word endorsement rates revealed a marginal effect of Exposure Type ($F(1,92) = 3.86, p = 0.05$), with participants in the S-Final conditions having lower word endorsement rates (S-Final/Attention: mean = 56%, sd = 30A logistic mixed effects model with accuracy as the dependent variable was fit with fixed effects for trial type (Filler, S, SH), Attention (No Attention, Attention), Exposure Type (S-Initial, S-Final) and their interactions. The random effect structure was as maximally specified as possible with random effects for Subject and Word, and by-Subject random slopes for trial type and by-Word random slopes for Attention. The only fixed effect that was significant were a main effect of trial type for /s/ trials compared to filler trials ($\beta = -2.51, SE = 0.46, z = -5.35, p < 0.01$).

Categorization

Responses with reaction times less than 200 ms or greater than 2500 ms were excluded from analyses. Participants were excluded if their initial estimated cross over point for the continuum lay outside of the 6 steps presented (2 participants). A logistic mixed effects model was constructed with Subject and Continua as random effects and continua Step as random slopes, with 0 coded as a /ʃ/ response and 1 as a /s/ response. Fixed effects for the model were Step, Exposure Type, Attention and their interactions.

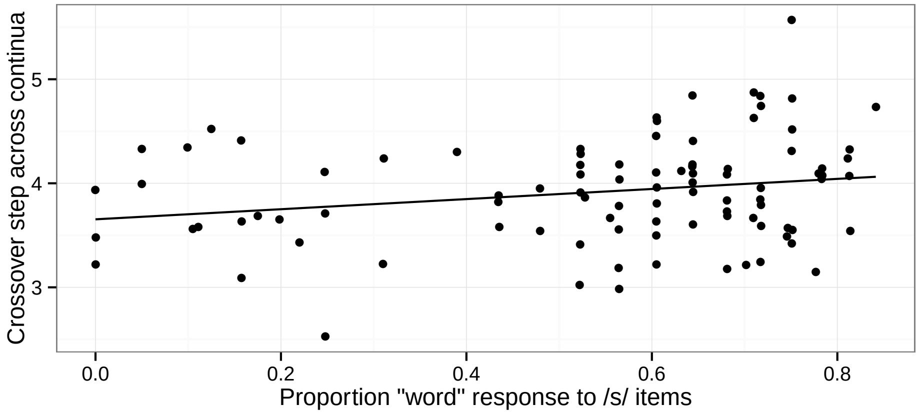
Figure 3.5: Proportion /s/ response along the 6 step continua as a function of Exposure Type and Attention in Experiment 1. In the S-Final condition, participants in the Attention condition showed a larger perceptual learning effect than those in the No Attention condition. In the S-Initial condition, there were no differences in perceptual learning between the Attention conditions. Error bars represent 95% confidence intervals.



There was a significant effect for the Intercept ($\beta = 1.01, SE = 0.38, z = 2.6, p <$

0.01), indicating that participants categorized more of the continua as /s/ in general. There was also a significant main effect of Step ($\beta = -2.67, SE = 0.23, z = -11.2, p < 0.01$). There were no other significant main effects or interactions, though an interaction between Step and Attention trended toward significant ($\beta = 0.35, SE = 0.21, z = 1.6, p = 0.09$).

Figure 3.6: Correlation of crossover point in categorization with the proportion of word responses to critical items containing an ambiguous /s/ token.



As in Experiment 1, the proportion critical word endorsements was calculated for each subject and assessed for correlation with participants' crossover points. There was a significant positive correlation between a participant's tolerance for the ambiguous exposure items and their crossover point on the continua ($r = 0.22, t(92) = 2.25, p = 0.02$), shown in Figure 3.6.

3.4 Groups results across experiments

To see what degree the stimuli used had an effect on perceptual learning, the data from Experiment 1 and Experiment 2 were pooled and analyzed identically as above, but with Experiment and its interactions as fixed effects. In the logistic mixed effects model, there was significant main effects for Intercept ($\beta =$

$1.00, SE = 0.36, z = 2.7, p < 0.01$) and Step ($\beta = -2.64, SE = 0.21, z = -12.1, p < 0.01$), and a significant two-way interaction between Experiment and Step ($\beta = 0.51, SE = 0.20, z = 2.5, p = 0.01$), and a marginal four-way interaction between Step, Exposure Type, Attention and Experiment ($\beta = 0.73, SE = 0.42, z = 1.7, p = 0.08$). These results can be seen in Figure 3.7. The four-way interaction can be seen in S-Final/No Attention conditions across the two experiments, where Experiment 1 has a significant difference between the Attention and No Attention condition, but Experiment 1 does not. The two-way interaction between Experiment and Step and the lack of a main effect for Experiment potentially suggests that while the category boundary was not significantly different across experiments, the slope of the categorization function was.

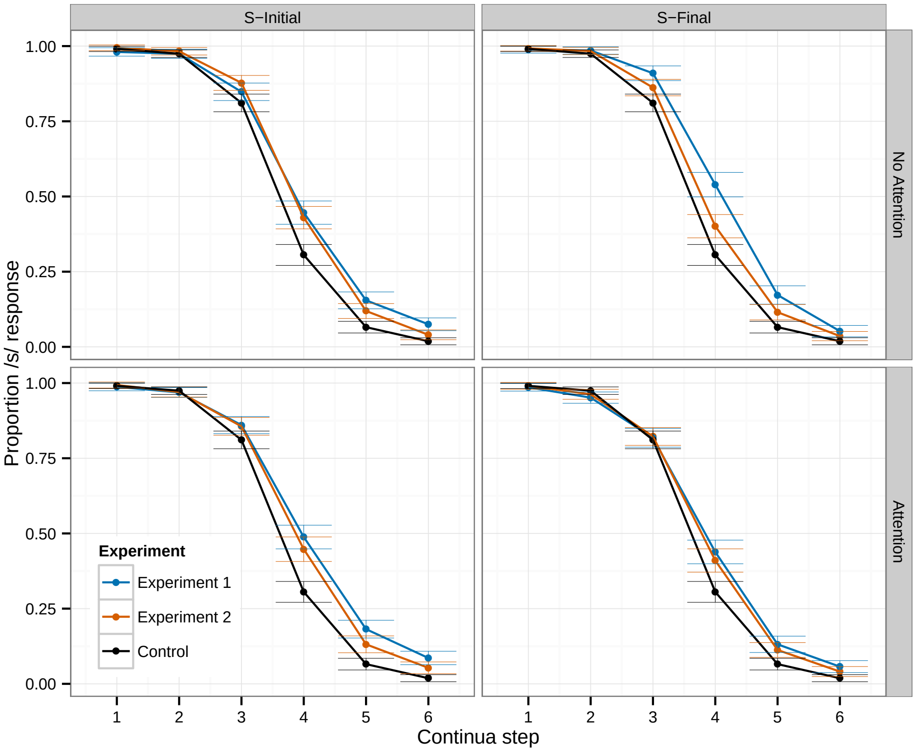
To see if there was a difference with the Experiment 1 in how word endorsement rates affected crossover points, the data was pooled for the two experiments. An ANOVA with cross-over point as the independent variable and word endorsement rate, Exposure Type, Attention, Experiment and their interactions, found a main effect of word endorsement rate ($F(1,185) = 21.82, p < 0.01$) and marginal interaction between word endorsement rates and Experiment ($F(1,185) = 3.11, p = 0.07$).

3.5 General discussion

Perceptual learning was found across all experimental conditions. Attention only had effect on perceptual learning in the S-Final condition of Experiment 1.

Compared to Experiment 1, Experiment 2 had a weaker, yet still significant, correlation between critical word endorsement rates and crossover boundary points, suggesting that although the stimuli used in Experiment 2 were farther from the canonical production, they did not shift the category boundary as much as the stimuli in Experiment 1. While neither attention or position of the ambiguous sound in the word had an effect on the correlation, the distance from the canonical production did. This potentially suggests that the degree to which a category is shifted is inversely related to its distance. Or perhaps more likely, the distance is inversely related to its goodness or plausibility that the ambiguous sound was indeed meant to be an /s/.

Figure 3.7: Proportion /s/ response along the 6 step continua as a function of Exposure Type and Attention in Experiment 1. Error bars represent 95% confidence intervals.



The correlation between word response rate in the exposure phase and the category boundary in categorization phase across both experiments raises two possible explanations. In a causal interpretation between exposure and categorization, as each ambiguous sound is linked to a word and a phonetic category, the distribution for that category (for that particular speaker) is updated. Participants who linked more of the ambiguous sound to the /s/ category updated their perceptual category for /s/ more. This explanation fits within a larger neo-generative model of spoken language processing [**?**]. A non-causal story is also plausible: the correlation may reveal individual differences on the part of the participants, where some participants are more adaptable or tolerant of variability than others, leading to greater degrees of perceptual adaptation. The lack of learning with nonwords [29] makes the latter interpretation particularly appealing.

Chapter 4

Cross-modal word identification

4.1 Motivation

In this experiment, semantic predictability will be used to linguistically bias participants in addition to lexical bias.

4.1.1 Similarity to lexical bias

A key pillar of the motivation underlying this experiment is the notion that semantic predictability is similar to, yet distinct from, lexical bias/lexical predictability. Scarborough [37] found that lexical predictability and semantic predictability did not interact and had the same effect directions, but different effect sizes, with lexical predictability having a larger effect than semantic predictability.

4.2 Methodology

4.2.1 Participants

One hundred native speakers of English (mean age ??, range ??-??) participated in the experiment and were compensated with either $10 CAD or course credit. They were recruited from the UBC student population. Twenty additional native English speakers participated in a pretest to determine sentence predictability, and 10 other native English speakers participated in a picture naming pretest.

Participants were assigned to one of four groups of 25 participants. In the exposure phase, half of the participants were exposed to a modified /s/ sound only in Predictive sentences and half were exposed to it only in Unpredictive sentences. Half of all participants were told that the speaker's production of "s" was somtimes ambiguous, and to listen carefully to ensure correct responses. Participants were native North American English speakers with no reported speech or hearing disorders.

4.2.2 Materials

One hundred and twenty sentences were used as exposure materials. The set of sentences consisted of 40 critical sentences, 20 control sentences and 60 filler sentences. The critical sentences ended in one of 20 of the critical words in Experiments 1 and 2 that had an /s/ in the onset of the final syllable. The 20 control sentences ended in the 20 control items used in Experiments 1 and 2, and the 60 filler sentences ended in the 60 filler words in Experiments 1 and 2. Half of all sentences were written to be predictive of the final word, and the other half were written to be unpredictive of the final word. Unlike previous studies using sentence or semantic predictability [17], Unpredictive sentences were written with the final word in mind with a variety of sentence structures, and the final words were plausible objects of lexical verbs and prepositions. A full list of words and their contexts can be found in the appendix. Aside from the sibilants in the critical and control words, the sentences contained no sibilants (/s z sh zh ch jh/). The same minimal pairs for phonetic categorization as in Experiments 1 and 2 were used.

Sentences were recorded by the same male Vancouver English speaker used in Experiments 1 and 2. Critical sentences were recorded in pairs, with one normal production and then a production of the same sentence with the /s/ in the final word replaced with an /sh/. The speaker was instructed to produce both sentences with comparable speech rate, speech style and prosody.

As in Experiments 1 and 2, the critical items were morphed together into an 11-step continuum using STRAIGHT [18]; however, only the final word in sentence was morphed. For all steps, the preceding words in the sentence were kept as the natural production to minimize artifacts of the morphing algorithm. As in

Experiments 1 and 2, the control and filler items were processed and resynthesized. The ambiguous point selection was based on the pretest performed for Experiment 1 and 2 exposure items. The ambiguous steps of the continua chosen corresponded to the 50% cross over point in Experiment 2.

Pictures of 200 words, with 100 pictures for the final word of the sentences and 100 for distractors, were selected in two steps. First, a research assistant selected five images from a Google image search of the word, and then a single image representing that word was selected from amongst the five by me. To ensure consistent behaviour in E-Prime, pictures were resized to fit within a 400x400 area with a resolution of 72x72 DPI and converted to bitmap format. Additionally, any transparent backgrounds in the pictures were converted to plain white backgrounds.

4.2.3 Pretest

The same twenty participants that completed the lexical decision continua pre-test also completed a sentence predictability task before the phonetic categorization task described in Experiment 1. Participants were compensated with $10 CAD for both tasks, and were native North American English speakers with no reported speech, language or hearing disorders. In this task, participants were presented with sentence fragments that were lacking in the final word. They were instructed to type in the word that came to mind when reading the fragment, and to enter any additional words that came to mind that would also complete the sentence. There was no time limit for entry and participants were shown an example with the fragment “The boat sailed across the...” and the possible completions “bay, ocean, lake, river”. Responses were collected in E-Prime (cite), and were sanitized by removing miscellaneous keystrokes recorded by E-Prime, spell checking, and standardizing variant spellings and plural forms.

The measure used for determining rewriting of sentences was the proportion of participants that included the target word in their responses. For predictive sentences, the mean proportion was 0.49 (range 0-0.95) and for unpredictive sentences, the mean proportion was 0.03 (range 0-0.45). Predictive sentences that had target response proportions of 20% or less were rewritten. The predictive sentences for *auction*, *brochure*, *carousel*, *cashier*, *cockpit*, *concert*, *cowboy*, *currency*, *cursor*, *cushion*, *dryer*, *graffiti*, and *missile* were rewritten to remove any ambiguities.

Five volunteers from the Speech in Context lab participated in another pretest to determine how suitable the pictures were at representing their associated word. All participants were native speakers of North American English, with reported corrected-to-normal vision. Participants were presented with a single image in the middle of the screen. Their task was to type the word that first came to mind, and any other words that described the picture equally well. There was no time limit and presentation of the pictures was self-paced. Responses were sanitized as in the first pretest.

Pictures were replaced if 20% or less of the participants (1 of 5) responded with the target word and the responses were semantically unrelated to the target word. Five pictures were replaced, *toothpick* and *falafel* with clearer pictures and *ukulele*, *earmuff* and *earplug* were replaced with *rollerblader*, *anchor* and *bedroom*. All five replacements were for distractor words.

4.2.4 Procedure

As in Experiments 1 and 2, participants completed two tasks, an exposure task and a categorization task. For the exposure task, participants heard a sentence via headphones for each trial. Immediately following the auditory presentation, they were presented with two pictures on the screen. Their task was to select the picture on the screen that corresponded to the final word in the sentence they heard. As in Experiments 1 and 2, the order was pseudorandom, with the same constraints.

Following the exposure task, participants completed the same categorization task described in Experiments 1 and 2.

4.3 Results

4.4 Discussion

Chapter 5

Conclusions

Stuff I have concluded

Bibliography

[1] M. Ahissar and S. Hochstein. Attentional control of early perceptual learning. *Proceedings of the National Academy of Sciences of the United States of America*, 90(12):5718–22, 1993. ISSN 0027-8424. doi:10.1073/pnas.90.12.5718. URL http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=46793&tool=pmcentrez&rendertype=abstract. → pages 12

[2] W. F. Bacon and H. E. Egeth. Overriding stimulus-driven attentional capture. *Perception & psychophysics*, 55(5):485–496, 1994. ISSN 0031-5117. → pages 13

[3] P. Bertelson, J. Vroomen, and B. De Gelder. Visual Recalibration of Auditory Speech Identification: A McGurk Aftereffect. *Psychological Science*, 14(6):592–597, 2003. → pages 3, 4, 10, 18

[4] S. Borsky, B. Tuller, and L. P. Shapiro. ”How to milk a coat:” the effects of semantic and acoustic information on phoneme categorization. *Journal of the Acoustical Society of America*, 103(5 Pt 1):2670–2676, 1998. URL http://www.ncbi.nlm.nih.gov/pubmed/9604360. → pages 18, 19

[5] M. Brysbaert and B. New. Moving beyond Kucera and Francis: a critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior research methods*, 41(4):977–990, 2009. ISSN 1554-3528. → pages 22

[6] A. Clark. Whatever next? Predictive brains, situated agents, and the future of cognitive science. *The Behavioral and brain sciences*, 36(3):181–204, 2013. ISSN 1469-1825. URL http://www.ncbi.nlm.nih.gov/pubmed/23663408. → pages 5, 11

[7] C. G. Clopper and J. B. Pierrehumbert. Effects of semantic predictability and regional dialect on vowel space reduction. *Journal of the Acoustical*

Society of America, 124(3):1682–1688, Sept. 2008. ISSN 1520-8524. doi:10.1121/1.2953322. URL http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2676620&tool=pmcentrez&rendertype=abstract. → pages 17

[8] C. Connine. Constraints on interactive processes in auditory word recognition: The role of sentence context. *Journal of Memory and Language*, 538:527–538, 1987. URL http://www.sciencedirect.com/science/article/pii/0749596X87901380. → pages 18

[9] C. M. Connine and C. Clifton. Interactive use of lexical information in speech perception. *Journal of experimental psychology. Human perception and performance*, 13(2):291–299, 1987. ISSN 0096-1523. → pages 15, 18

[10] P. D. Eimas, W. E. Cooper, and J. D. Corbit. Some properties of linguistic feature detectors, 1973. ISSN 0031-5117. → pages 4

[11] F. Eisner and J. M. McQueen. The specificity of perceptual learning in speech processing. *Perception & psychophysics*, 67(2):224–238, 2005. → pages 7

[12] F. Eisner and J. M. McQueen. Perceptual learning in speech: Stability over time. *The Journal of the Acoustical Society of America*, 119(4):1950, 2006. ISSN 00014966. doi:10.1121/1.2178721. URL http://scitation.aip.org/content/asa/journal/jasa/119/4/10.1121/1.2178721. → pages 4, 6

[13] W. F. Ganong. Phonetic categorization in auditory word perception. *Journal of Experimental Psychology: Human Perception and Performance*, 6(1): 110–125, 1980. URL http://www.ncbi.nlm.nih.gov/pubmed/6444985. → pages 14, 19

[14] E. J. GIBSON. Improvement in perceptual judgments as a function of controlled practice or training. *Psychological bulletin*, 50(6):401–431, 1953. → pages 4

[15] C. Gilbert, M. Sigman, and R. Crist. The neural basis of perceptual learning. *Neuron*, 31:681–697, 2001. ISSN 0896-6273. doi:10.1016/S0896-6273(01)00424-X. URL http://www.sciencedirect.com/science/article/pii/S089662730100424X. → pages 11

[16] A. Jesse and J. M. McQueen. Positional effects in the lexical retuning of speech perception, 2011. ISSN 1069-9384. → pages 10

[17] D. Kalikow, K. Stevens, and L. Elliott. Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. . . . *Journal of the Acoustical Society of . . .* , 61(5), 1977. URL http://link.aip.org/link/?JASMAN/61/1337/1. → pages 17, 18, 19, 36

[18] H. Kawahara, M. Morise, T. Takahashi, R. Nisimura, T. Irino, and H. Banno. Tandem-straight: A temporally stable power spectral representation for periodic signals and applications to interference-free spectrum, F0, and aperiodicity estimation. In *ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing - Proceedings*, pages 3933–3936, 2008. → pages 22, 36

[19] D. Kleinschmidt and T. F. Jaeger. A Bayesian belief updating model of phonetic recalibration and selective adaptation. *Science*, (June):10–19, 2011. URL http://www.aclweb.org/anthology-new/W/W11/W11-06.pdf#page=20. → pages 5

[20] T. Kraljic and A. G. Samuel. Perceptual learning for speech: Is there a return to normal? *Cognitive psychology*, 51(2):141–78, Sept. 2005. ISSN 0010-0285. doi:10.1016/j.cogpsych.2005.05.001. URL http://www.ncbi.nlm.nih.gov/pubmed/16095588. → pages 4, 5, 9

[21] T. Kraljic and A. G. Samuel. Generalization in perceptual learning for speech. *Psychonomic Bulletin & Review*, 13(2):262–268, Apr. 2006. ISSN 1069-9384. doi:10.3758/BF03193841. URL http://link.springer.com/10.3758/BF03193841. → pages 9

[22] T. Kraljic and A. G. Samuel. Perceptual adjustments to multiple speakers. *Journal of Memory and Language*, 56(1):1–15, Jan. 2007. ISSN 0749596X. doi:10.1016/j.jml.2006.07.010. URL http://linkinghub.elsevier.com/retrieve/pii/S0749596X06000842. → pages 7

[23] T. Kraljic, S. E. Brennan, and A. G. Samuel. Accommodating variation: dialects, idiolects, and speech processing. *Cognition*, 107(1):54–81, Apr. 2008. ISSN 0010-0277. doi:10.1016/j.cognition.2007.07.013. URL http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2375975&tool=pmcentrez&rendertype=abstract. → pages 11

[24] T. Kraljic, A. G. Samuel, and S. E. Brennan. First impressions and last resorts: how listeners adjust to speaker variability. *Psychological science*, 19

(4):332–8, Apr. 2008. ISSN 0956-7976. doi:10.1111/j.1467-9280.2008.02090.x. URL http://www.ncbi.nlm.nih.gov/pubmed/18399885. → pages 11

[25] A. B. Leber and H. E. Egeth. Attention on autopilot: Past experience and attentional set, 2006. ISSN 1350-6285. → pages 13

[26] P. Lieberman. Some Effects of Semantic and Grammatical Context on the Production and Perception of Speech. *Language and Speech*, 6(3):172 –187, 1963. URL http://las.sagepub.com/content/6/3/172.abstract. → pages 18

[27] S. L. Mattys and L. Wiget. Effects of cognitive load on speech recognition. *Journal of Memory and Language*, 65(2):145–160, 2011. → pages 16

[28] H. Mitterer, O. Scharenborg, and J. M. McQueen. Phonological abstraction without phonemes in speech perception. *Cognition*, 129(2):356–361, 2013. → pages 10

[29] D. Norris, J. M. McQueen, and A. Cutler. Perceptual learning in speech, 2003. → pages 3, 4, 11, 13, 14, 18, 34

[30] M. Pitt and C. Szostak. A lexically biased attentional set compensates for variable speech quality caused by pronunciation variation. *Language and Cognitive Processes*, (April 2013):37–41, 2012. URL http://www.tandfonline.com/doi/abs/10.1080/01690965.2011.619370. → pages 13, 15, 16, 19, 20, 28

[31] M. A. Pitt and A. G. Samuel. An empirical and meta-analytic evaluation of the phoneme identification task. *Journal of experimental psychology. Human perception and performance*, 19(4):699–725, 1993. ISSN 0096-1523. → pages 15

[32] M. A. Pitt and A. G. Samuel. Word length and lexical activation: longer is better. *Journal of experimental psychology. Human perception and performance*, 32(5):1120–1135, 2006. ISSN 0096-1523. → pages 15

[33] E. Reinisch and L. L. Holt. Lexically Guided Phonetic Retuning of Foreign-Accented Speech and Its Generalization. *Journal of experimental psychology. Human perception and performance*, 40(2):539–555, 2013. ISSN 1939-1277. URL http://www.ncbi.nlm.nih.gov/pubmed/24059846. → pages 8

[34] E. Reinisch, A. Weber, and H. Mitterer. Listeners retune phoneme categories across languages. *Journal of experimental psychology. Human perception and performance*, 39(1):75–86, Feb. 2013. ISSN 1939-1277. doi:10.1037/a0027979. URL http://www.ncbi.nlm.nih.gov/pubmed/22545600. → pages 8, 11, 23, 24, 28

[35] E. Reinisch, D. R. Wozny, H. Mitterer, and L. L. Holt. Phonetic category recalibration: What are the categories? *Journal of Phonetics*, 45:91–105, 2014. ISSN 00954470. doi:10.1016/j.wocn.2014.04.002. URL http://linkinghub.elsevier.com/retrieve/pii/S009544701400045X. → pages 10

[36] A. G. Samuel. Red herring detectors and speech perception: in defense of selective adaptation. *Cognitive psychology*, 18(4):452–499, 1986. ISSN 00100285. → pages 4

[37] R. Scarborough. Lexical and contextual predictability: Confluent effects on the production of vowels. *Laboratory phonology*, pages 575–604, 2010. URL http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Lexical+and+contextual+predictability:+confluent+effects+on+the+production+of+vowels#0. → pages 17, 35

[38] O. Scharenborg and E. Janse. Comparing lexically guided perceptual learning in younger and older listeners. *Attention, perception & psychophysics*, 75(3):525–36, 2013. ISSN 1943-393X. URL http://www.ncbi.nlm.nih.gov/pubmed/23354594. → pages 14

[39] O. Scharenborg, A. Weber, and E. Janse. The role of attentional abilities in lexically guided perceptual learning by older listeners. *Attention, Perception, & Psychophysics*, pages 1–15, 2014. → pages 13

[40] E. A. Strand and K. Johnson. Gradient and visual speaker normalization in the perception of fricatives. In *KONVENS*, pages 14–26, 1996. → pages 7

[41] E. Sussman, W. Ritter, and H. G. Vaughan. Predictability of stimulus deviance and the mismatch negativity. *Neuroreport*, 9(18):4167–4170, 1998. ISSN 0959-4965. → pages 13

[42] E. Sussman, W. Ritter, and H. G. Vaughan. Attention affects the organization of auditory input associated with the mismatch negativity system. *Brain Research*, 789(1):130–138, 1998. ISSN 00068993. → pages 13

[43] E. Sussman, I. Winkler, M. Huotilainen, W. Ritter, and R. Näätänen. Top-down effects can modify the initially stimulus-driven auditory

organization. *Cognitive Brain Research*, 13(3):393–405, 2002. ISSN 09266410. → pages 12

[44] S. van Linden and J. Vroomen. Recalibration of phonetic categories by lipread speech versus lexical information. *Journal of experimental psychology. Human perception and performance*, 33(6):1483–1494, 2007. ISSN 0096-1523. → pages 4

[45] L. van Noorden and J. F. Schouten. *Temporal Coherence in the Perception of Tone Sequences*. PhD thesis, 1975. → pages 13

[46] J. Vroomen, S. van Linden, B. de Gelder, and P. Bertelson. Visual recalibration and selective adaptation in auditory-visual speech perception: Contrasting build-up courses. *Neuropsychologia*, 45(3):572–577, 2007. → pages 4, 5

[47] J. M. Wolfe and T. S. Horowitz. What attributes guide the deployment of visual attention and how do they do it? *Nature reviews. Neuroscience*, 5(6): 495–501, 2004. → pages 13