Journal of Communication Disorders 52 (2014) 111–133

Contents lists available at ScienceDirect

Journal of Communication Disorders

Perceptual weighting strategies of children with cochlear implants and normal hearing

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ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 12 August 2014
Accepted 1 September 2014
Available online 28 September 2014

Keywords:
Speech perception
Children
Cochlear implants
Perceptual weighting strategies

ABSTRACT

Purpose: This study compared perceptual weighting strategies of children with cochlear implants (CIs) and children with normal hearing (NH), and asked if strategies are explained solely by degraded spectral representations, or if diminished language experience accounts for some of the effect. Relationships between weighting strategies and other language skills were examined.
Method: One hundred 8-year-olds (49 with NH and 51 with CIs) were tested on four measures: (1) labeling of cop–cob and sa–sha stimuli; (2) discrimination of the acoustic cues to the cop–cob decision; (3) phonemic awareness; and (4) word recognition.
Results: No differences in weighting of cues to the cop–cob decision were observed between children with CIs and NH, suggesting that language experience was sufficient for the children with CIs. Differences in weighting of cues to the sa–sha decision were found, but were not entirely explained by auditory sensitivity. Weighting strategies were related to phonemic awareness and word recognition.
Conclusions: More salient cues facilitate stronger weighting of those cues. Nonetheless, individuals differ in how salient cues need to be to capture perceptual attention. Familiarity with stimuli also affects how reliably children attend to acoustic cues. Training should help children with CIs learn to categorize speech sounds with less-salient cues.

Learning outcomes: After reading this article, the learner should be able to: (1) recognize methods and motivations for studying perceptual weighting strategies in speech perception; (2) explain how signal quality and language experience affect the development of weighting strategies for children with cochlear implants and children with normal hearing; and (3) summarize the importance of perceptual weighting strategies for other aspects of language functioning.

1. Introduction

The earliest experiments on human speech perception were conducted to identify the acoustic correlates of phonemic categories. That focus arose from the aims of the work, which in the mid-twentieth century were primarily occupied with trying to translate, in one direction or the other, from a string of alphabetic symbols to what was believed to be a string of acoustic elements isomorphically aligned with those symbols. A chief example of that work was a project designed to build a reading machine for the blind, described by A. Liberman in his book, *Speech: A Special Code* (1996). When that project was

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http://dx.doi.org/10.1016/j.jcomdis.2014.09.003
0021-9924/

initiated in 1944, the goal of identifying invariant acoustic correlates to phonemic categories was considered reasonable and easily within reach. In that work, components of the acoustic signal relevant to phonemic decisions came to be termed cues (Repp, 1982), and the terminology continues to be used today.

Acoustic cues can arise from spectral, temporal, or amplitude structure in the speech signal. Spectral cues can further be described as stable across time (i.e., static) or time varying (i.e., dynamic). An example of a static spectral cue is the broad spectral pattern associated with fricatives (Strevens, 1960). When a fricative is produced, the vocal-tract constriction is held steady for a relatively long time, resulting in spectral structure that is steady for a long time, at least compared to other components of speech signals. However, some spectral patterns arising from briefer articulatory gestures can also create cues that have been termed static, such as the bursts associated with the release of vocal-tract closures (Stevens & Blumstein, 1978). Dynamic spectral cues are the transitions in formant frequencies that arise from movement between consonant constrictions and vowel postures (i.e., formant transitions) (Delattre, Liberman, & Cooper, 1955). The defining characteristic of these cues is that it is precisely the pattern of spectral change that informs the listener.

Temporal cues can involve the duration of single articulatory events or the timing between two articulatory events, such as between the release of a vocal-tract closure and the onset of laryngeal vibration; this is traditionally termed voice onset time (Lisker & Abramson, 1964). Amplitude structure is less likely than spectral or temporal structure to provide cues to phonemic identity. Instead, it more reliably specifies syllable structure, due to the fact that amplitude in speech signals is dependent on the degree of vocal-tract opening, which alternates most closely with syllable structure.

In the early work on acoustic cues, stimuli were constructed such that all components were held constant across the set, except for the specific cue being studied. That cue was manipulated across stimuli, forming a continuum of equal-sized steps. Individual tokens from these continua were presented multiple times to listeners for labeling, and the point along the continuum where responses changed from primarily one category to primarily another category was known as the phoneme boundary; responses on either side of that boundary were consistently and reliably given one label. This pattern of responding was dubbed categorical perception, and was considered a hallmark of human speech perception (Liberman, Harris, Hoffman, & Griffith, 1957). Listeners in those early studies were almost invariably adults with normal hearing (NH) listening to their native language, which suited the goal of identifying acoustic cues defining each phonemic category.

1.1. Trading relations and differences across listeners

It soon became apparent that the paradigm described above was based on a model of speech perception that was overly simplistic. One basis of that conclusion was that more than one cue was found to affect each phonemic decision (e.g., Dorman, Studdert-Kennedy, & Raphael, 1977). Furthermore, there were found to be tradeoffs among cues, such that the setting of one cue affected the labeling of stimuli at each level of the other cue (Best, Morrongiello, & Robson, 1981; Fitch, Halwes, Erickson, & Liberman, 1980; Polka & Strange, 1985). For example, Mann and Repp (1980) showed that the placement of the phoneme boundary along a continuum of fricative noises from /ʃ/ to /s/ was influenced by whether formant transitions in the voiced signal portion were appropriate for an initial /ʃ/ or /s/.

Perhaps more surprising than the discovery of cue trading relations was the finding that weights assigned to cues for specific phonemic decisions varied across listener groups. In particular, adult learners of a second language often have difficulty attending to the cues used in phoneme labeling by native speakers, if those cues conflict with ones used in their first language (e.g., Beddor & Strange, 1982; Cho & Ladefoged, 1999; Gottfried & Beddor, 1988) or if the phonemic contrast does not exist in the first language (e.g., Best, McRoberts, & Sithole, 1988; Crowther & Mann, 1994; Flege & Wang, 1989). This difference in weighting of acoustic cues across languages means that mature perceptual weighting strategies must be learned through experience with a first language, and evidence to that effect has been found: children's weighting strategies differ from those of adults, with modifications occurring across childhood (e.g., Greenlee, 1980; Nittrouer & Studdert-Kennedy, 1987; Wardrip-Fruin & Peach, 1984). Moreover, it has been demonstrated that differences across listener groups in weighting strategies cannot be attributed to differences in sensitivity to the acoustic cues in question, either in the cross-language work (e.g., Miyawaki et al., 1975) or in the developmental work (e.g., Nittrouer, 1996). However, one study found that children growing up in poverty or with histories of frequent otitis media with effusion demonstrated less mature perceptual weighting strategies than children with neither condition (Nittrouer & Burton, 2005). As a result, the authors suggested that the amount of experience a child gets with a first language influences the acquisition of mature weighting strategies. Critical to that interpretation were the assumptions that children growing up in poverty have reduced language input in the home (Hoff & Tian, 2005), and that the temporary conductive hearing loss imposed by otitis media with effusion diminishes opportunities to hear the ambient language. Because the children in neither experimental group had permanent hearing loss, it was concluded that their deficits could not be explained by poor sensitivity to the relevant acoustic cues. Instead, Nittrouer and Burton concluded that the diminished language experience of children in the experimental groups must explain the impediments to their discovering the most efficient weighting strategies for their native language – the strategies used by mature speakers.

1.2. How deaf listeners perceive speech cues

There is, however, a group of listeners for whom that disassociation between sensitivity to acoustic cues and weighting of those cues cannot be presumed. Listeners with hearing loss generally have diminished spectral resolution, making it difficult