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Evaluating the relationship between sublexical and lexical processing in speech perception: Evidence from aphasia

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ABSTRACT

Several studies have reported that aphasic patients may perform substantially better on lexical than sublexical perception tasks (e.g., Miceli et al., 1980). These findings challenge claims made by models of speech perception which assume obligatory sublexical processing (e.g., McClelland and Elman, 1986; Norris, 1994). However, prior studies have not closely matched the phonological similarity of targets and distractors or task demands of the sublexical and lexical perception tasks. The current study addressed shortcomings of these prior studies, testing 13 aphasic patients on sublexical and lexical tasks matched in phonological similarity of stimuli and task demands. When the lexical and sublexical tasks were not matched (Experiment 1a), as in prior studies (e.g., Miceli et al., 1980), several patients with impaired sublexical perception were within the control range on tasks tapping lexical perception. In contrast, when the lexical and sublexical tasks (sublexical: syllable discrimination, auditory-written syllable matching (AWSM); lexical: word discrimination, lexical decision, and picture-word matching (PWM)) were matched on these factors (Experiments 1b and 2), in most instances, patients were impaired on both sublexical and lexical tasks relative to controls and performance on the lexical tasks was not significantly greater than that on the sublexical tasks. For two patients, performance on one lexical task was statistically better than that on one sublexical task, but the advantage was not replicated across other task comparisons. The current study is consistent with models of speech perception which assume obligatory sublexical processing and fails to support models that do not require successful sublexical perception in order to access lexical levels (e.g., Goldinger, 1998; Hickok and Poeppel, 2000).

1. Introduction

Does the perception of lexical information depend on the ability to map acoustic input to abstract, speech-specific sublexical representations, such as phonemes or syllables, or can acoustic information map directly to a lexical or semantic level? Many well known models of speech perception have assumed the former - that is, that speech sounds must pass through a language specific sublexical level in order to access a lexical level (e.g., Cole and Scott, 1974; McClelland and Elman, 1986; Luce et al., 2000; Luce and Pisoni, 1998; Norris, 1994; Norris et al., 2000; Oden and Massaro, 1978). However, other models of speech perception advocate a direct mapping from acoustic to lexical or semantic levels (e.g., Goldinger, 1998; Hickok and Poeppel, 2000; Johnson, 1997; Pierrehumbert, 2001). Below we briefly review models exemplifying the two positions.

TRACE (McClelland and Elman, 1986), Shortlist (and its successor MERGE; Norris, 1994; Norris et al., 2000) and the Neighborhood Activation Model (NAM; Luce and Pisoni, 1998) are among the most influential of models assuming obligatory access to a sublexical level. These models all assume that spectrotemporal analysis parses the auditory signal into abstract, speech-specific, sublexical units of representation, such as phonemes or syllables. These sublexical level representations are subsequently mapped onto a lexical level (Luce and Pisoni, 1998; McClelland and Elman, 1986; Norris, 1994; Norris et al., 2000).

Although these models assume an obligatory sublexical processing stage, other models assume a direct mapping from acoustic to lexical levels. One class of speech perception models, known as exemplar models, allows for holistic processing of acoustic representations of entire words (e.g., Goldinger, 1998; Johnson, 1997; Pierrehumbert, 2001), emphasizing data indicating the influence of specific acoustic features (e.g., pitch of a speaker's voice) on perception. Recently,

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researchers have proposed dual route frameworks for speech perception which claim that a) there are separate sublexical and lexical routes[1] (e.g., Hickok and Poeppel, 2000; Hickok and Poeppel, 2004; Hickok and Poeppel, 2007; Hickok, 2014; Poeppel and Hickok, 2004; Majerus, 2013; Scott and Wise, 2004; Wise et al., 2001) and b) the lexical route does not require access to sublexical representations for lexical perception (e.g., Hickok and Poeppel, 2000). For example, Vaden et al. (2011) state that:

> [sublexical] information is only represented on the motor side of speech processing and…[is] not explicitly extracted or represented as a part of spoken word recognition (p. 2672).

According to this argument, sublexical information, and accordingly the sublexical processing route, is only involved in speech perception when it is necessary for subsequent articulation, as in repeating a word. Further, although these two routes share initial processing of the acoustic features of the speech sounds, they subsequently diverge into two streams that operate largely independently up to the generation of articulatory codes in the dorsal route and accessing meaning in the ventral route. Subsequently, the routes converge and interact. Importantly, access to the lexical level via the ventral route does not necessarily require sublexical processing.[2]

One compelling piece of evidence supporting models with a direct mapping from acoustic to lexical levels is the finding that some brain damaged patients show much better performance on tasks tapping lexical than sublexical speech recognition (Basso et al., 1977; Blumstein et al., 1977; Blumstein, et al., 1977; Miceli et al., 1980). However, there are limitations to these studies which prevent one from drawing strong claims from the findings. For instance, consider the study carried out by Miceli et al. (1980), which is often cited as demonstrating this dissociation between sublexical and lexical perception. Miceli and colleagues had individuals with aphasia perform a sublexical processing task involving CCVC syllable discrimination (e.g., prin-brin; prin-trin) and two lexical processing tasks, involving picture-word matching (with distractor pictures that were semantically related, phonologically related or unrelated), and a sentence comprehension task (where patients acted out sentences such as "Put your hands on the table"). The researchers found that some patients were below the range of controls on CCVC discrimination but not on picture-word matching and sentence comprehension, and vice versa. Miceli et al. (1980) thus concluded that the relationship between the sublexical and lexical levels was more complicated than a simple mapping of phonemes to words. They argued that comprehension of auditorily presented words requires processes different from those involved in perceiving the constituent phonemes.

One means of accommodating such findings would be to argue that while sublexical processing is a necessary step in lexical access, contextual or top-down processes contribute to performance at the lexical but not the sublexical level. This notion is clearly instantiated in interactive speech perception models (e.g., TRACE, McClelland and Elman, 1986) in which information at one level can influence processing at other levels through feedback from higher to lower levels. Such contextual effects are also accommodated by models that do not incorporate feedback, under the assumption that information from different levels is combined in making a decision about perceptual identity (Massaro and Cohen, 1991; Norris et al., 2000). Thus, for example, a patient might perform better on lexical than sublexical tasks because of the activation of semantic information for words (but not sublexical units) that feeds back to the lexical level and stabilizes lexical representations. Further, in more naturalistic tasks like sentence comprehension, meaning coherence or syntactic factors can restrict possible word recognition targets (Tyler and Marslen-Wilson, 1977). In contrast, such top-down contextual factors would play a minimal role in sublexical tasks like syllable discrimination. It seems unlikely, however, that such top-down effects could account for the findings from studies like that of Miceli et al. (1980), as the size of the discrepancy in performance on lexical vs. sublexical tasks was quite large. For example, Basso et al. (1977) note that some patients have "severe" or "very severe" (as defined on p. 91) phoneme identification deficits "in spite of good comprehension" (p. 93). Findings like this (i.e., good comprehension with severe sublexical perception deficits) would be difficult to accommodate purely on the basis of top-down processing. That is, a severe deficit at the phoneme identification level would lead to weak activation of lexical representations with, in turn, weak activation of semantic information. Such weak semantic activation and weak feedback from a semantic level would not be expected to raise lexical perception to a high level. However, if such top-down processes can account for the dissociations observed in prior studies, then we would expect to see substantially better lexical than sublexical processing, even with stimuli that are closely matched in discriminability.

Upon closer inspection, however, it is clear that the tasks from the patient studies used to assess sublexical and lexical processing were not closely matched in terms of task demands or discriminability of the targets and distractors. The sublexical task required the ability to make fine-grained perceptual distinctions, such as discriminating "prin-brin", where the two syllables differed in a single distinctive feature of one phoneme. However, such distinctions were not necessary to understand the commands from the sentence comprehension task (e.g., "Put your hands on the table"). Although their picture-word matching task included phonologically related distractors, the phonological lures differed from the target by one or more phonemes (picture-word matching task described in detail in Gainotti et al. (1975)) and when the difference was only one phoneme, the phoneme might differ by more than one distinctive feature from the target. Thus, poorer performance on the sublexical task may have derived solely from the finer phonetic distinctions that were required.

Other studies that have observed similar dissociations between performance on tasks tapping sublexical and lexical processing suffer from similar limitations. Basso et al. (1977) found that several patients with severe impairments on a sublexical processing task requiring discrimination of consonants differing in voice onset time (VOT) (e.g., /ba/ vs. /pa/, which are both bilabial stop consonants but differ in voicing) were in the normal range on a task of auditory comprehension which required patients to act out commands such as "Point to the green rectangle". Along the same lines, Blumstein et al. (1977b) found no relation between patients' performance on phoneme discrimination and identification tasks using stimuli varied on VOT and performance on the auditory comprehension subtest of the Boston Diagnostic Aphasia Battery (BDAE; Goodglass et al., 1972). Finally, Blumstein et al. (1977a) found a similar effect comparing performance on the discrimination of words differing in a single distinctive feature of one phoneme (e.g., rate, raid) and degree of comprehension impairment on a subset of measures from the BDAE (Goodglass et al., 1972) after excluding Broca's aphasics who performed at ceiling on both. In fact, the patients who had the most severe deficits on the discrimination tasks had only moderate difficulty on the comprehension measure. These research groups concluded that word comprehension can occur independently of phonemic processing.

As with the Miceli et al. (1980) study, the studies by Basso et al. (1977), Blumstein et al. (1977a) and Blumstein et al. (1977b) failed to match perceptual discriminability of targets and distractors. In all three

[1] Further, some researchers have even argued that there are two lexical routes for perception with sublexical information only being processed post-lexically as needed (Gow, 2012). According to this model, patients with sublexical processing deficits would have damage to a post-lexical process, but lexical processing would proceed as normal.

[2] It is important to note that the exact claims regarding sublexical processing vary across papers. Hickok and Poeppel (2004) state that the dorsal and ventral routes share processing up through the sublexical processing stage (pg. 79–80), whereas Hickok and Poeppel (2000) argue for "sound-based representations of speech" (e.g., pg. 131) that are shared between the routes, leaving open the question of whether these sound-based representations correspond to linguistic units.