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Effects of utterance length on lip kinematics in aphasia

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ABSTRACT

Most existing models of language production and speech motor control do not explicitly address how language requirements affect speech motor functions, as these domains are usually treated as separate and independent from one another. This investigation compared lip movements during bilabial closure between five individuals with mild aphasia and five age and gender-matched control speakers when the linguistic characteristics of the stimuli were varied by increasing the number of syllables. Upper and lower lip movement data were collected for mono-, bi- and tri-syllabic nonword sequences using an AG 100 EMMA system. Each task was performed under both normal and fast rate conditions. Single articulator kinematic parameters (peak velocity, amplitude, duration, and cyclic spatio-temporal index) were measured to characterize lip movements. Results revealed that compared to control speakers, individuals with aphasia showed significantly longer movement duration and lower movement stability for longer items (bi- and tri-syllables). Moreover, utterance length affected the lip kinematics, in that the monosyllables had smaller peak velocities, smaller amplitudes and shorter durations compared to bi- and trisyllables, and movement stability was lowest for the trisyllables. In addition, the rate-induced changes (smaller amplitude and shorter duration with increased rate) were most prominent for the short items (i.e., monosyllables). These findings provide further support for the notion that linguistic changes have an impact on the characteristics of speech movements, and that individuals with aphasia are more affected by such changes than control speakers.

1. Introduction

The majority of research on verbal production for normal and communicatively disordered speakers has studied the domains of language (i.e., the set of arbitrary but conventional systems of symbols and cognitive processes) and speech (i.e., the spoken form of language) as separate and independent processes. Although this division has been useful for describing the specific contributions of each to the act of communication, it has limited our understanding of how they may bear upon each other; in particular, how linguistic factors influence the execution of speech movements (c.f. Dromey & Benson, 2003; Kleinow & Smith, 2000, 2006; Smith, 2001; Smith & Goffman, 2004; van Lieshout, Starkweather, Hulstijn, & Peters, 1995). The past decade has seen an increased focus on both theoretical and clinical research aimed at exploring different aspects of this interface between linguistic and speech motor processes in both normal and disordered speakers (Bose, van Lieshout, & Square, 2007; Dromey & Benson, 2003; Howell, Au-Yeung, & Pilgrim, 1999; Kleinow & Smith, 2000, 2006; Silverman & Bernstein Ratner, 1997; Smith, 2001; Smith & Goffman, 2004; van Lieshout, 1998; van Lieshout et al., 1995). For example, in a series of studies involving different subject populations, Smith and colleagues showed that increased linguistic demands (in terms of utterance length and/or syntactic complexity) may lead to increased speech movement variability (Kleinow & Smith, 2000; Maner, Smith, & Grayson 2000; Smith & Goffman, 2004).

Studying the influence of linguistic changes on speech processes has important implications for neurogenic communication disorders, such as aphasia, because in addition to the well-known linguistic processing deficits, speech motor skills and articulatory implementation of speech segments are reported to be compromised to some degree in most types of aphasia (Blumstein, 1998, 2001; Kurowski, Blumstein, Palumbo, Waldstein, & Burton, 2007; Kurowski, Hazen, & Blumstein, 2003; McNeil & Kent, 1990; Square,

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Martin, & Bose, 2001; Vijayan & Gandour, 1995). In order to determine the underlying nature of verbal production deficits in aphasia, it is important that the full gamut of potential contributing factors be investigated. If, as the above studies suggest, speech movement is implicated in putative linguistic impairments, changes in linguistic demands may impact the ability of these individuals to execute the required changes within the limitations of their speech motor system. For this reason, studying speech motor characteristics in relation to linguistic variations in the aphasic population is of critical theoretical and clinical interest. From a clinical perspective, specific information on how linguistic demands change speech motor behaviors in aphasic speakers will enhance our understanding of the relative contribution of language and speech motor processes to the verbal production deficits, and, consequently, may have implications for improving diagnosis and treatment strategies. Despite the importance of this area of investigation, there are currently no systematic studies explaining how linguistic demands in verbal expression are implemented by the articulatory system in individuals with aphasia. The present study attempts to fill this gap by testing whether changes in linguistic demands of verbal stimuli lead to specific changes in speech movements. More concretely, we investigate whether an increase in utterance length induces specific changes in lip kinematics in individuals with aphasia, and we contrast that finding with data from normal control speakers.

A number of studies utilizing acoustic analyses in aphasia have investigated the temporal control of speech production at the segmental level, including changes induced by differences in utterance length (e.g., Baum, 1992; Baum & Boyczuk, 1999; Baum & Ryan, 1993; Gandour, Dechongkit, Ponglorpisit, Khunadorn, & Boongrid, 1993; Haley & Overton, 2001; Kurowski et al., 2003; Strand & McNeil, 1996). In general, these studies have shown group differences in the control of syllable (segment) duration, particularly for larger-sized linguistic units. For example, Baum (1992) demonstrated that individuals with aphasia display the well-known decrease in syllable duration for the root syllable in bi-syllabic words relative to monosyllables, similar to what was found for normal speakers. However, in contrast to normal speakers, aphasic speakers did not exhibit a further decrease in root duration in trisyllabic words. Similarly, abnormal timing patterns for aphasic patients have been reported for speech production at the sentence level of Thai speakers (Gandour et al., 1993). Strand and McNeil (1996) demonstrated that in aphasic–apraxic speakers the acoustic temporal properties of speech were more affected by increased utterance length.

Although these acoustic studies suggest that speech motor skills are compromised in aphasic subjects, they are limited in specifying the nature of this compromise in articulation as acoustic measures fail to reflect adequately the contributions and characteristics of movements from individual articulators (Byrd & Harris, 2007; Hardcastle, 1987; Kent, 1996; Mowrey & MacKay, 1990; van Lieshout & Moussa, 2000). Thus, despite the knowledge that changes in utterance length affect acoustic durations of segments, it remains unclear how such changes affect the spatial and temporal dimensions of single articulator movements of aphasic subjects. The use of detailed kinematic descriptions in both temporal and spatial dimensions of lip movements in the present study will allow us to provide this information. The following section elaborates the theoretical notions regarding the definition of linguistic complexity, and addresses the challenges in selecting aphasic patients for kinematic studies.

Researchers have used various methods and classification schemes to define linguistic complexity. Examples of complexity manipulation from past studies include adding syllables to a root word (Baum & Boyczuk, 1999; Strand & McNeil, 1996; van Lieshout et al., 1995), using different syllabic structures (Sevald, Dell, & Cole, 1995; van Lieshout, Hijl, & Hulstijn, 1999), increasing the length of utterances in a nonsentence condition (Kleinow & Smith, 2000; Strand & McNeil, 1996), increasing the length of utterances in sentence conditions (Baum & Boyczuk, 1999; van Lieshout et al., 1995), and increasing syntactic complexity (Ferreira, 1991; Kleinow & Smith, 2000, 2006).

According to Levelt and colleagues, the length of an utterance is specified at the level of phonological encoding and the processing time for generating a phonological and/or phonetic plan is influenced by the size of units embedded in the plan (Levelt, 1989; Levelt, Roelofs, & Meyer, 1999; Levelt & Wheeldon, 1994; Meyer, 2000). As Levelt (1989) writes, ‘‘the number of syllables in the phonological word will determine the duration of phonetic spell out” (p. 417). This has been confirmed in several studies showing that the number of syllables in a word affects the time it takes to prepare for its execution (e.g., Eriksen, Pollock, & Montague, 1970; Klapp & Erwin, 1976; Levelt, 1989). Similar to changes in word preparation time, the number of syllables for a given unit will also impact the duration of articulation (van Lieshout, Hulstijn, & Peters, 1996). As previously mentioned in the acoustic studies on utterance length, the overall increase in duration is not equally spread across the individual segments and adding syllables will therefore have an impact on the ability of speakers to adjust the durations of individual articulator movements. Other studies have also indicated that such changes are not limited to temporal dimensions. For example, data from lip muscle activity have shown that bilabial consonants in onset positions of longer words (indexed by the number of syllables) were associated with higher electromyographic (EMG) peak amplitudes compared to shorter words (van Lieshout et al., 1995). Typically, stronger EMG signals in this context have been associated with more articulatory effort (higher velocity and greater movement range, McClean & Tasko, 2003). More recently, Bartle, Goozée, and Murdoch (2007) examined the articulatory dynamics of consonant production across different word length conditions in an apraxic–aphasic individual using electromagnetic articulography. When compared to control speakers, the duration and movement range for this patient were significantly greater for consonants in multisyllabic words but not in monosyllabic words. Collectively, these studies indicate that longer utterances impose a greater demand for flexibility in the articulatory system in terms of temporal and spatial aspects of movement control, as evidenced by increases in movement duration, amplitude, and variability.

In the present investigation, the linguistic demands were varied at the phonological level by increasing the number of syllables (i.e., mono-, bi- and tri-syllabic) in nonwords. Nonwords were used to minimize higher order (lexical, syntactic, semantic) influences. Longer items not only have more syllables, but also more gestures (Browman & Goldstein, 1992; van Lieshout et al., 1995). This study focused on the number of bilabial closure gestures, and included items with the same number of bilabial closure gestures but a differing number of syllables (mono vs. bisyllables) and items where both the number of syllables and number of bilabial closure gestures increased (trisyllabic). We expected that the latter category would be the most demanding in terms of motor flexibility, as the same gesture has to be implemented in different positions of the nonword (Byrd, 1996).

The main focus of our investigation was to examine the effects of utterance complexity (indexed by syllable number) on speech movements in individuals with aphasia. Subject selection was restricted to those who did not demonstrate any obvious clinical motor speech disorders, such as dysarthria or apraxia of speech (AOS). Those who claim speech motor involvement in the verbal production of aphasic individuals often face criticism for including aphasic–apraxic subjects in their patient group, because motor problems in the speech production of such