BIOMECHANICAL SIMULATION OF LIP COMPRESSION AND SPREADING

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1 Introduction

Researchers have proposed that human movements exploit regions of biomechanical stability, allowing targets to be reliably achieved in the face of noisy, everyday conditions [1]. Such regions produce quantal biomechanical effects [2], whereby a wide range of muscle activations can generate a similar outcome. Quantal effects have been observed in a number of articulatory regions relevant to speech, including the lips [3, 4], tongue [5], and larynx [6].

Previous biomechanical simulation studies investigating quantal properties of labial speech movements [3, 4] have omitted two cross-linguistically common lip postures. The first is lip compression, or exolabial rounding, where the aperture between the lips is narrowed without or with limited accompanying protrusion [7]. Lip compression frequently accompanies front rounded vowels and some back unrounded vowels. The second is lip spreading, where the corners of the lips are drawn apart. Spreading often accompanies high front vowels such as /i/.

Previous empirical work has attempted to identify the muscle activations used in producing compression and spreading. Spreading is most clearly associated with activation of the buccinator (BUC), risorius (RIS), and zygomaticus (ZYG) muscles, all of which serve to draw back the corners of the mouth [8]. The muscle activations driving lip compression have proven to be more difficult to identify, but orbicularis oris (OO) has been implicated in constricting the lips, while mentalis (MENT), depressor anguli oris (DAO), and BUC have been suggested to help check the constriction generated by OO and produce compression rather than protrusion [9, 10]. A challenge for such studies, however, is that the lip muscles are heavily interdigitated, making measurement of individual muscle activations using techniques such as electromyography difficult [11].

In the current study, we present biomechanical simulation results using a 3D finite-element method face model. With these simulations, we attempt to identify muscle groupings that are sufficient to generate lip compression and spreading and also to examine the biomechanical stability of these two postures.

2 Methods

Simulations of lip compression and spreading were performed using the Artisynth platform [12]. Artisynth is a biomechanical simulation platform that combines finite-element and multibody methods to allow the rigid and deformable structures in the human body to be modeled. For the present simulation we used a model containing the skull, jaw, lips, and face. This model is described in more detail in [4]. Simulations were performed by specifying groupings of muscles and their relative maximum activation stress, then activating them from 0% to 100% of the maximum muscle stress in 1% increments. Lip aperture was measured using the same green-screen technique described in [4], with pixel area measurements converted to mm^2.

Lip spreading was achieved by activating BUC (50 kPa) as the main agonist muscle. Only simulations including BUC were able to generate lip spreading that did not result in complete closure. Simulations that incorporated RIS and ZYG at low levels generated similar postures and are not reported here.

Lip compression was achieved by activating peripheral orbicularis oris (OOP; 70 kPa), DLI (45 kPa), BUC (30 kPa), levator labii superioris (LLS; 30 kPa), and levator labii superioris alaeque nasi (LLSAN; 20 kPa). OOP was activated to reduce lip aperture and induce a certain degree of lip protrusion. The remaining muscles serve to check the constriction generated by OOP: DLI counteracts this for the lower lip, LLS and LLSAN for the upper lip, and BUC along the horizontal dimension. Simulations without these antagonist muscles tended to generate excessive closure.

3 Results

The end-state configurations of the model are shown in Fig. 1. Rest posture and the approximant posture from [4] are included for reference. The postures achieved for spreading and compression align well with expected visual outcomes.

Fig. 2 (left) shows lip aperture as a function of muscle activation for the spreading movement. These results show that the activation of BUC decreases the overall lip opening and induces a consistent lip spreading posture. Furthermore, activation between approximately 50% and 100% results in little change in resulting lip aperture. This quantal region is shaded in Fig. 2.

Fig. 2 (right) shows lip aperture as a function of muscle activation for the compression movement. These results show that activation of the muscles OOP, DLI, BUC, LLSAN, and LLS in the proportions listed in Table 1 is sufficient to produce lip compression. The graph also highlights the existence of a quantal region between approximately 75% and 100% muscle activation, though this region is smaller than that produced by spreading.

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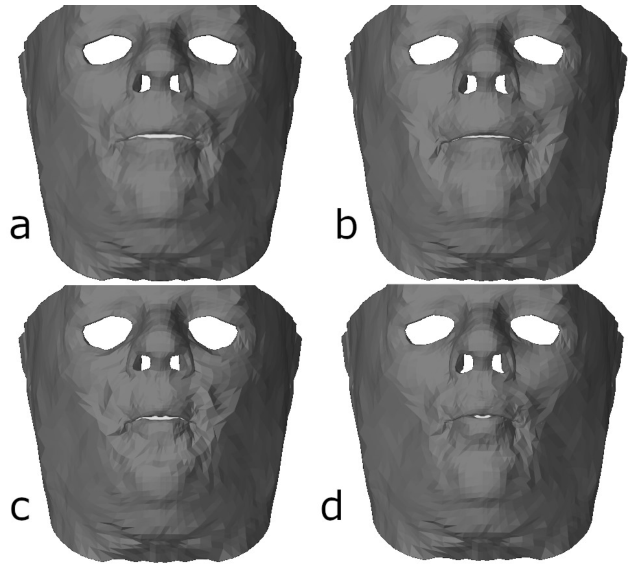

Figure 1: End-state configurations for (a) rest posture; (b) lip spreading; (c) lip compression; and, for reference/comparison, (d) lip rounding.

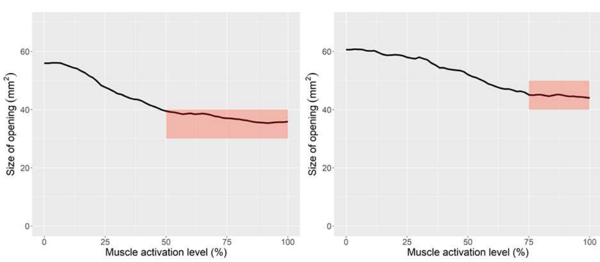

Figure 2: Lip aperture in the simulations of spreading (left) and compression (right). The shaded area marks the quantal region.

4 Discussion

Our results identify groupings of muscles that are sufficient to produce both lip spreading and lip compression. Further, these muscle configurations exhibit quantal properties, indicating that they exploit regions of biomechanical stability that allow targets to be met under a range of different muscle activations.

These results supplement previous work in several ways. Though earlier studies have discussed these two lip postures, they have either focused only on lip aperture without much discussion of muscle activations driving these movements [13, 14], or have reported muscle activation measured using EMG with no corresponding lip opening data [10]. In addition, attributing EMG signals to particular muscles is difficult due to factors described above [11]. The present study uses a 3D biomechanical model to predict muscle groupings that are sufficient to produce lip spreading and rounding, as well as to predict their effect on lip aperture as muscle activation increases.

This study also supports the claim that the functional groupings of muscles that drive the movements used in speech are chosen in part due to their quantal properties: both sets of muscles generate quantal relationships between muscle activation and lip aperture.

It is not the case that the groupings identified in these simulations are the only viable strategies for producing these movements. Further simulation studies should investigate the role of jaw opening in lip compression, as well as other strategies that have been proposed in the literature, such as differential activation of different areas of the OOP [9, 10].

Acknowledgments

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