Postural and muscular effects of upper-limb movements on voicing

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In principle, any muscle that attaches to the rib cage can act on it and thus affect the subglottal pressure that supports voicing. Consequently, there are a lot of *potential* respiratory-vocal muscles. Said muscles would include those around the chest (e.g., pectoralis major), abdomen (rectus abdominus), and back (erector spinae, seratus posterior/anterior). However, in passive breathing and speaking, only a subset of the possible muscles are used. Most notably, the diaphragm and the muscles between the ribs (intercostalis) drive passive speech-supporting respiration (Aliverti, 2016; Seikel, Drumright, & Hudock, 2019). Only on rarer occasions, when coughing, shouting, or breathing deeply, humans recruit other so-called "accessory" respiratory muscles such as the abs and pectoral muscles (Aliverti, 2016; Lasserson et al., 2006; Seikel et al., 2019). From this it is tempting to conclude that there is only a small set of 'primary' respiratory muscles.

Yet, when humans speak or sing it is common to move the upper limbs expressively at the same time — called gesture (Pearson & Pouw, 2022; Wagner, Malisz, & Kopp, 2014). Such upper limb movements will recruit a whole range of upper body muscles, including those involved in maintaining posture (Cordo & Nashner, 1982). Several of these muscles attach to the rib cage (e.g., ab- and pectoral muscles). These muscles are classically listed as accessory to respiratory functioning (Seikel et al., 2019). Given that speaking requires subtle modulations of subglottal pressure (Rubin, LeCover, & Vennard, 1967; Sundberg, Elliot, Gramming, & Nord, 1993; Sundberg, Titze, & Scherer, 1993), co-gesture speaking must be in some way coordinated with the respiratory-and-thus-vocal muscles that are activated during gesturing (for an overview see Pouw & Fuchs, 2022)).

There is now considerable evidence that gestural arm movements affect the voice directly, and is summarized by Pouw & Fuchs, 2022: More extreme peaks in the acceleration of movements with higher (vs. lower) mass upper limb segments relate to more chest-circumference changes (Pouw, Harrison, Esteve-Gibert, & Dixon, 2019), which associated with more extreme acoustic effects on the intensity of vocal sound (through increasing sub-glottal pressure). Furthermore, acoustic effects of upper limb movements are more extreme when subjects are in a more unstable standing versus sitting position (Pouw, Harrison, Esteve-Gibert, et al., 2019). These previous studies assessed continuous voicing, mono-syllable utterances, and fluent speech production (Pouw, de Jonge-Hoekstra, Harrison, Paxton, & Dixon, 2020). This ties in with the idea that a physical impulse (mass x acceleration), impacts posture (especially when standing), recruiting respiratory-related muscles (that change chest circumference), which impacts respiratory-vocal functioning (such that intensity and F0 are affected). Such interactions, between pectoral/upper limb activity and respiratory-vocal states, have been well-studied in non-human animals (Blumberg, 1992; Cooper & Goller, 2004; Lancaster, Henson, & Keating, 1995).

In this study we use surface ElectroMyography to measure muscle activity, and a balanceboard that measures ground-reaction forces to assess center of pressure. Participants (exploratory study N=2, confirmatory study N = 18) performed no movements as well as 4 actions along the sagittal and transversal plane (internal and external) with the elbow flexed at a 90-degree angle. During these movements, they produce a steady-state schwa-like phonation with one egressive flow. As we know that gesture-speech

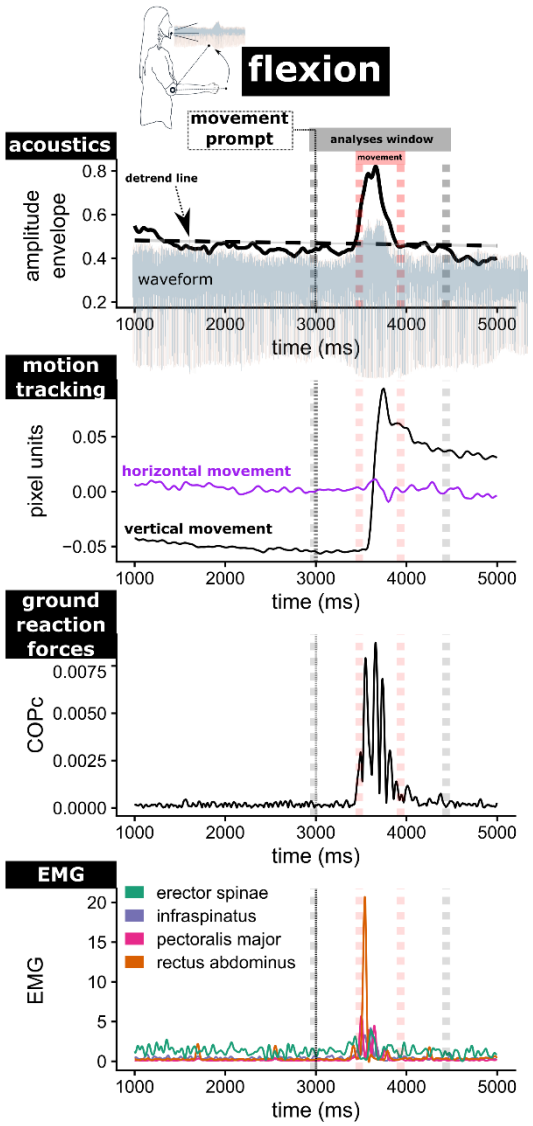
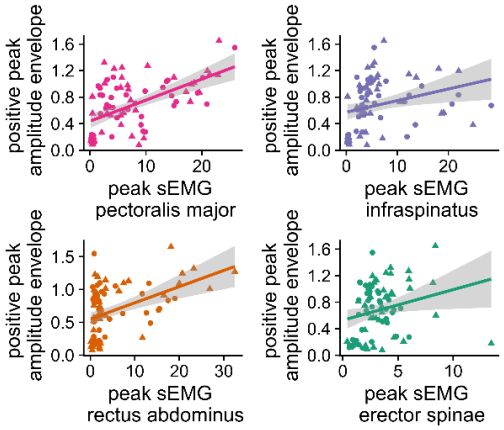


Figure 1. Example time series

biomechanics is modulated by posture (e.g., Pouw, Harrison, & Dixon, 2019)) and some of those postural muscles are well-known as expiratory muscles, we measure two postural related muscles: the rectus abdominus, and the erector spinae in the back. Both the abs and erector spinae directly attach to the rib cage. We also assess focal muscles with and without well-known respiratory effects: We measure an internal rotator muscle on the chest (pectoralis major), and an external rotator muscle on the scapula (infraspinatus). The pectoralis major is associated with respiratory interactions as reviewed above and directly attaches to the rib cage. The infraspinatus is not directly attached to the rib-cage, but it does insert into the scapula which is a dynamic stabilizer for the entire should girdle region (Levin, 1997). Thus, even indirectly it might have a role to play in gesture-speech biomechanics, but most likely, weakly so. See figure 1 for the muscles measured with sEMG in this study.

Results Exploratory Study (all effects reported are statistically reliable at $p < .005$): Movement versus non-movement of the upper limbs yields unintentional positive peaks on the amplitude envelope of vocalization. This can be labeled as 'unintentional' as the task is to produce a stable vocalization output. Further, we show that particular muscle activity is reliably related to positive peaks in the voice's amplitude, especially the rectus abdominus, an expiratory-associated muscle. This muscle and the erector spinae are further also found to be related to postural stability, as the change in the center of pressure reliably positively related to the these postural muscle activations (in contrast to the other focal muscles). These results provide direct evidence that muscle activity (associated with postural control) that relate to moving the upper limbs during vocalization affects the voice in variable and predictable ways, with general implications for the study of gesture and speech in interaction. We will report the full analyses of the confirmatory study at GESPIN2023.

Figure 1: Effects muscle activity on positive peaks in the voice amplitude



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