Experimental approaches in electromagnetic articulography

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Electromagnetic articulography (EMA) is a point-tracking method for the study of speech production, whereby sensors placed on the articulators (including tongue, lips and jaw) are used to track movement in real time in 3D. However, while EMA data has high spatial and temporal resolution, there are limitations to how many sensors can be placed and where (e.g., it is more difficult to place sensors more posteriorly on the tongue) [1, 2, 3]. Consequently, ensuring accurate and durable sensor placement is crucial for EMA experiments. The goal of our study was twofold. First, we wished to review how researchers have previously described EMA data collection procedures, with a focus on sensor placement. Second, we carried out an experiment to evaluate three approaches for attaching sensors to the tongue.

For the first part, we performed a systematic literature review of EMA papers using Google Scholar. We collected journal papers, conference proceeding abstracts and other scientific texts by employing the search terms "electromagnetic articulography" and "electromagnetic midsagittal articulography". We found 627 EMA papers in a period of 30 years, which we believe provides a representative overview of data collection practices. In these 627 papers, we searched for the following parameters: type of EMA device in use, number of participants, population (healthy versus pathological), total number of sensors, number of tongue sensors, placement of sensors, sensor preparation, and adhesive used for sensor placement. Regarding participants, we found that around 80% of studies had 10 participants or fewer (with around 50% of studies having 5 participants or fewer), and that 85% of the studies tested healthy adults. Due to high time demands of the method, a limited number of participants is to be expected, but also highlights the need for comparable and articulatory-driven sensor placement across participants.

Regarding tongue sensor placement, we found that the most frequent choice is to place three sensors (50% of studies), from the tongue apex to the root along the median sulcus. The exact placement strategies differ, however. Some choose to place sensors equidistantly, for example with 1-2 cm between the sensors. Others decide to place the tongue tip sensor 1 cm behind the tongue apex, the tongue back sensor "as far back as comfortable" and the remaining sensor midway between the two. However, it is often unclear how exactly the tongue tip sensor is measured nor is it specified how comfort of participant is determined. The literature review thus demonstrated that experimental designs greatly vary, which in turn impacts how different sounds are being studied and may limit researchers' ability to compare results across studies.

For the second part of our study, we evaluated three approaches for attaching (NDI Wave) EMA sensors with respect to the duration the sensors remain attached to the tongue. Specifically, we adhered out-of-the-box sensors (Fig. 1 left), sensors coated in latex (Fig. 1 centre) and sensors coated in latex with an additional latex flap (Fig. 1 right). All three approaches could be found in our literature review, however while the first two types of sensors are used frequently, the additional latex flap, which increases the adhesion surface, is not mentioned often (notable exceptions, which also increased the sensor surface but using a different approach, include [4, 5, 6]). Latexing sensors increases the sterility and longevity of sensors, as latex can be peeled off after an experimental session and thus the sensor never comes into contact with the participant's saliva directly. However, it is unclear whether the latex offers any other advantages, such as an increase in the time that the sensors stay adhered to the tongue.

We tested ten female participants, aged between 20 and 30, across three separate sessions. We adhered five sensors to the tongue, with the tongue tip sensor placed 1 cm from the tongue apex (measured with an outstretched tongue, using a ruler), the tongue back sensor positioned at the marked place of the

/k/ constriction, and the tongue middle sensor positioned halfway between the two. The tongue lateral sensors were positioned to the left and right of the tongue middle sensor. The participants read out a text for sensor habituation, then proceeded with reading aloud a wordlist and performing a syllable repetition task. The experimental procedure was terminated when all sensors fell off or when the tasks were repeated twice, which took approximately 45 minutes. We built linear mixed-effects models evaluating the effect of sensor position and sensor type on adhesiveness. Our results indicate that there is no significant effect of sensor type on adhesiveness, however there is a medium-sized significant effect of sensor position, as the tongue back sensor adheres to the tongue the least ($p < 0.001$, Cohen's $d = 0.7$; Fig. 2). Additionally, we found a small one-tailed (as the hypothesis was directional) significant effect indicating that the tongue back sensor adheres slightly longer if it is prepared with a latex flap ($p = 0.025$, $d = 0.35$).

Our findings from the literature review and the experiment highlight the need for thoughtful sensor placement and data collection practices.

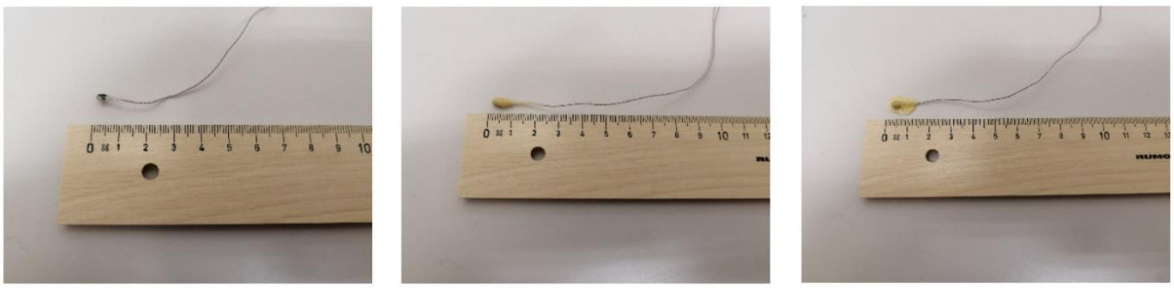

Figure 1: Sensor types (from left to right: out of the box, latexed, latex flap)

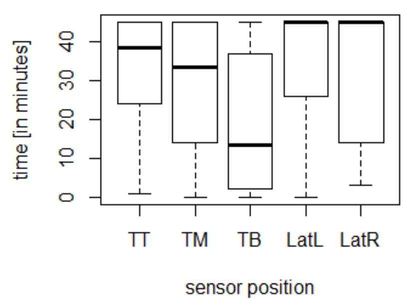

Figure 2: Sensor adhesion times [in minutes] per sensor position on the tongue.

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