TONGUE KINEMATICS IN /kl/ CLUSTERS AND SINGLETON /k/: A COMBINED EMA/EPG STUDY

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ABSTRACT - Results of a combined EPG/EMA study show different movement trajectories of the tongue body for /k/ in clusters and singleton environments. A "looping" trajectory observed during singleton /k/ was abruptly halted during cluster production and seen as a downward vertical movement of the tongue body coinciding with raising of the tongue tip/blade for the /l/. The results point to the advantages of combining EMA with EPG data for investigating lingual dynamics.

INTRODUCTION

The production of the /kl/ cluster in words such as "clip" requires the precise placement and co-ordination of two independently controllable lingual components: the tongue body for the /k/ and the tongue tip/blade for the /l/. The spatial characteristics and timing relationships between the two lingual components in such clusters have been the subject of a number of previous studies using EPG (e.g. Gibbon, Hardcastle and Nicolaidis, 1993; Hardcastle, 1985). In Hardcastle (1985) various syntactic and prosodic constraints on the temporal co-ordination of the /k/ and /l/ were investigated, and in Gibbon, Hardcastle and Nicolaidis (1993) coarticulation during /kl/ clusters was studied in six European languages. In the latter study the articulation of the /k/ and /l/ in /kl/ clusters, which occur in words like "sparkler", was compared to singleton /k/ and /l/ in words like "barker, parlour". One significant finding from this study was that for all languages under investigation, the articulatory placement of the tongue-body (as measured by EPG) was more retracted in the /kl/ cluster compared to the singleton consonant. This was an unexpected finding as it might have been predicted that articulation of the /k/ in the cluster would be more anterior (compared to the singleton) due to the anticipatory coarticulation effect of the upcoming, anteriorly placed, /l/.

It was suggested by Gibbon, Hardcastle and Nicolaidis (1993) that there were language universal constraints between the tip/blade and tongue-body that require specific changes in tongue positioning for cluster production, for example a hollowing of the tongue which would result in a consistently more posterior placement for the /k/ component. It was suggested, furthermore, that this general tendency may interact in interesting ways with language-specific effects. For example it may explain why Catalan (which has a velarised /l/) exhibits closer coupling between tongue tip/blade and tongue-body during /kl/ cluster production thus leading to a closer co-ordination between these two parts of the tongue and a greater tendency towards temporal overlap of the two components of the gesture (Gibbon, Hardcastle and Nicolaidis, 1993).

EPG alone does not provide direct information on tongue configurations so it was decided to carry out an investigation using EPG combined with Electromagnetic Articulography (EMA) to compare lingual trajectories in /kl/ versus /k/ in minimal pairs "kip, clip" and "cap, clap". EPG and EMA provide complementary information on tongue dynamics; EPG measures the location and timing of tongue contacts with the hard palate (Hardcastle, Gibbon and Jones, 1991) and EMA tracks the movement, in the x-y plane, of miniature coils attached to the mid-line of the tongue (Perkell et al 1992; Schönle, 1988). When used in combination, the two techniques can provide a reasonable representation of the overall shape and configuration of the tongue, and its movement (Hoole, 1993; Hoole, 1996).

METHOD

The minimal pairs "kip, clip", "cap, clap" were produced in a carrier phrase "it's a ... again" a total of ten times by a female native English speaker as part of a larger corpus of speech material. Movement trajectories of four miniature coils placed on the mid-line of the subject's tongue, and one on the jaw and one of the lip, were recorded with the Carstens AG100 system (see Figure 1 for placement of the coils). The subject simultaneously recorded tongue-palate contact with the Reading EPG2 system. All recordings were carried out in the Institut für Phonetik und Sprachliche Kommunikation, Universität München, following procedures established by Hoole (Hoole, 1993; Hoole, 1996).

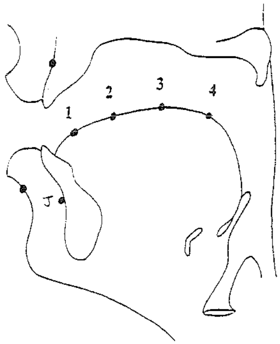

Figure 1.

Approximate positions of the coils used in the EMA recordings. Coil 3 is located roughly opposite the junction between the hard and the soft palate with the tongue at rest, and thus near the most posterior row of EPG electrodes.

Figure 2 shows typical EPG and EMA data from the experiment processed using a set of programs written in the the MATLAB® software package. With this package it is possible to display not only displacement of each coil in the x-y plane but also the velocity and acceleration of each movement (Nguyen, 1996). In Figure 2 for both "clip" and"kip" the tongue body (as represented by coil 3) begins to rise before the onset of the [ə] vowel prior to the /k/ closure at the beginning of the movement. The onset of closure is indicated on the EPG printout by an increase in contacts in the posterior rows of electrodes (see also graph of contact totals). The increase in EPG contacts coincides with the acceleration minimum point. The release is marked by a downward movement of the y3 trace and a simultaneous decrease in the number of EPG contacts in the mid sagittal region of the posterior zones of the palate. The second acceleration minimum occurs just prior to the release. During the /k/ closure for "clip" the tip/blade begins to rise as seen in the y1 trace. The first indications of tongue tip/blade movement on the EPG record are however, not seen until frame 113 (i.e. approximately 25 ms after release). These timing relationships show the importance of considering both EPG and EMA data to gain a detailed insight into lingual trajectories.

The upper part of Figure 2 shows trajectory paths for the four tongue coils in relation to the outline of the palate for the interval from the vowel [ə] to onset of /ɪ/ . For singleton /k/ in "kip" the tongue clearly follows a well defined "looped" trajectory with forward movement during the closure for coils 2, 3 and 4. This "looped" trajectory pattern for velar stops has been noted before by other investigators from x-ray data (Perkell, 1969) and from EMA (Mooshammer, Hoole and Kühnert, 1995). For the /kl/ in "clip" there is minimal forward movement. A similar pattern is seen in "cap", "clap". The minimal forward movement during the cluster appears to be abruptly curtailed by a sharp downward movement coinciding with the onset of the tip/blade rising (marked by arrows in the trajectory path and in the EPG printout). To explore these findings further, measurements were made from the EPG, EMA and acoustic data:

Timing of /l/ gesture

This was measured from the EPG and EMA records as the timing of the onset of the y1 excursion in relation to the beginning of the velar closure defined as the first EPG frame of complete closure in the posterior row of electrodes. The timing of y1 onset was expressed as a percentage of the total duration from V1 to V2 as measured from the acoustic signal.

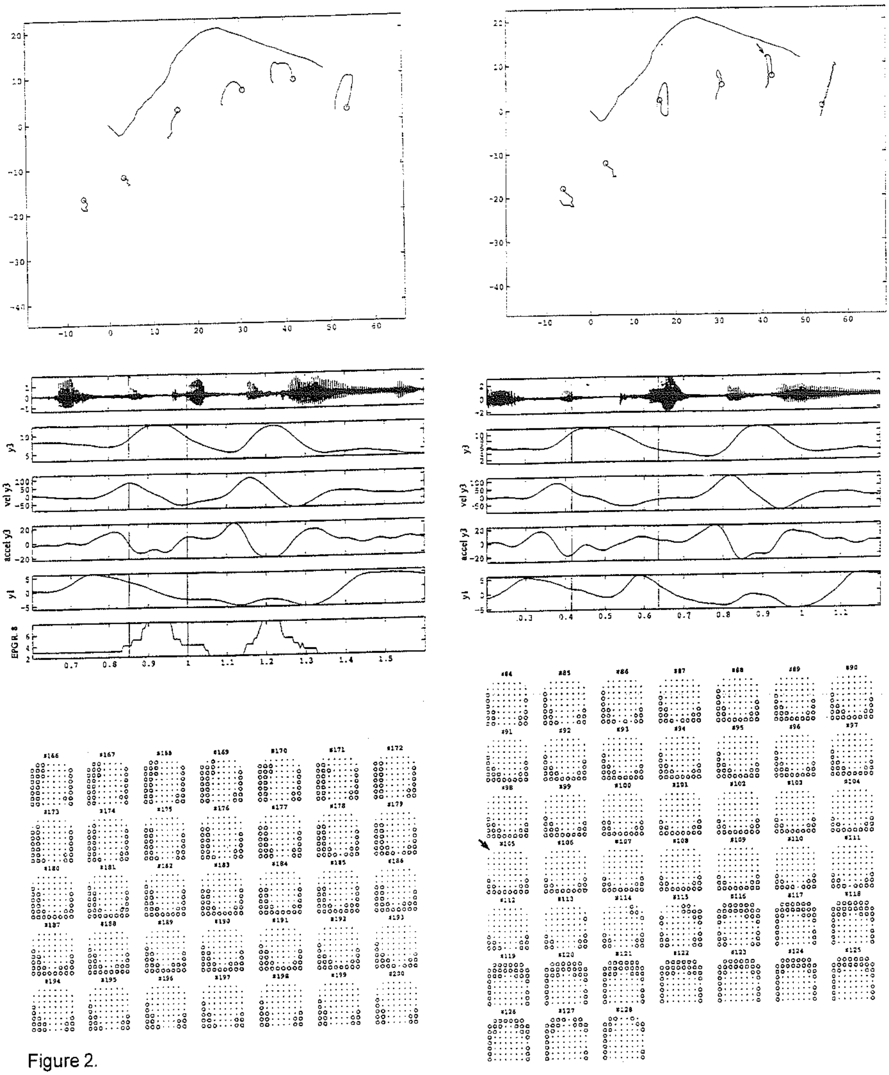

Figure 2.

Printouts of the /k/ (left) and /kl/ sequence (right) in "kip and clip" in the frame "its a - again". The centre display in each printout shows the acoustic signal for the whole utterance and four EMA traces: y3 (vertical up and down movement of coil 3, vel y3 (velocity of vertical movements of coil 3) accel y3 (acceleration of movements of coil 3) and y1 (vertical movement of coil 1). The EPG patterns below are for that part of the utterance demarcated by the two cursors. The top diagram shows trajectory paths for the four lingual coils, the jaw and lip coils during the period between the two cursors. The origin of each trajectory is marked with the symbol o. The arrow in the trajectory display for coil 3 (for "clip") and in the EPG printout shows the point at which the tongue tip/blade begins to rise as indicated by y1. A graph showing the total number of EPG contacts in Row 8 (the most posterior row) is included below the EMA traces for "kip". EPG and EMA sampling rate is 200 Hz.

Forward movement of tongue body

The magnitude of the "looping" in the trajectory paths for /k/ and /kl/ was expressed as the maximum forward excursion of the x3 (i.e. horizontal forward/back) trace from onset of velar closure (first EPG frame of complete contact across the palate) to velar release (last EPG frame of complete contact). The trajectory length ("integrated distance") of the trajectory of coil 3 from the onset to the release of the velar closure for all items was also computed.

RESULTS

Comparisons of EPG patterns in Figure 2 clearly show a more retracted placement during the velar closure in /kl/ (see e.g., the frame just prior to release i.e. frame 109 for /kl/ and frame 192 for /k/. A similar trend was found in the more open vowel environment ("cap" versus "clap"). These observations are fully in accord with the results found previously in (Gibbon, Hardcastle and Nicolaidis, 1993). Results for the timing of the /l/ gesture show a clear tendency in all cases for the onset of the /l/ gesture (as measured from y1 in the EMA record) to occur after the onset of the velar closure (mean 45%, SD 15).

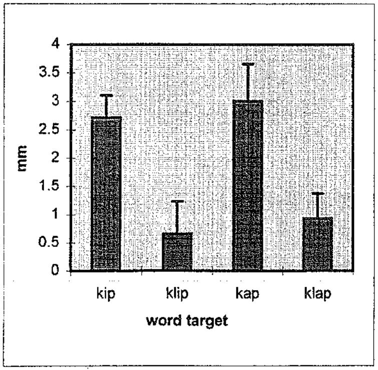

Figure 3.

Means and SD of forward movement of coil 3 during the velar closure for 10 repetitions of the words "kip, clip, cap, clap".

Forward Movement of Tongue Body

Results for the forward movement of the tongue body during the /k/ gesture in all speech items are shown in Figure 3. There is a highly significant ($p < 0.0001$) tendency for the value of x3 (forward movement of coil 3) to be higher in the singleton than the cluster. This confirms the initial observation of the trajectory paths in Figure 2. The length of the trajectory of coil 3 during the velar closure (integrated distance) is shown in Figure 4. As can be seen, the trajectory is about twice as long for /k/s than for /kl/s in both vowel environments.

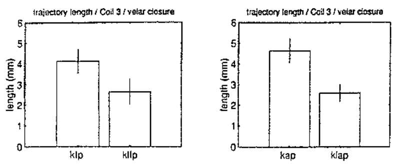

Figure 4.

Trajectory length ("integrated distance") of the trajectory of coil 3 from the onset to release of the velar closure for the four test items.

Timing Relationship Between The Movement of Tongue Body/Tip

In order to determine whether and how the opening gesture for /k/ and the closing gesture for /l/ were synchronised with each other the following annotation points were taken: (a) onset of tongue body raising for /k/ (velocity minimum, y3) (b) onset of tongue body lowering for /k/ (velocity minimum, y3) (c) onset of the tongue tip raising for /l/ (velocity minimum, y1). The onset of the opening gesture for /k/ was taken as an anchor point. The location in time of the events (b) and (c) was determined with respect to this point. The results show that there is a tendency for the movements of the tongue body and tongue tip to be closely co-ordinated in time. The correlation coefficient between the two time intervals is .48. Differences emerged however depending on the following vowel. For /klip/ the tongue tip starts to move upward before the onset of the tongue body lowering. For /klap/ it is the opposite.

Position of Onset of Velar Closure

These results raised the question of whether the tongue had the same position at the onset of the velar closure for single /k/s and /kl/s, i.e. did the tongue start from the same position in the vocal tract. To check this, the position of the EMA coils at the first EPG frame of complete contact across the palate for /k/ was taken. The position of the tongue was very similar at the onset of the velar closure for /kl/s and single /k/s regardless of the following vowel (Figure 5). Thus it seems unlikely that difference in the trajectory of the third coil during the velar closure for /k/ and /kl/s could results from the fact that the starting position is different in these two cases.

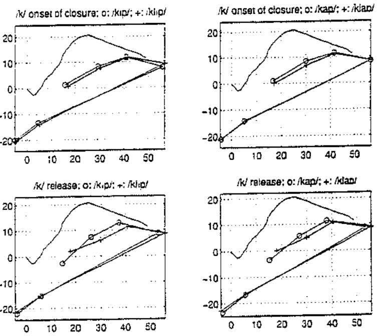

Figure 5.

Average position of the coils at two instances in time: onset of velar closure and release of velar closure.

Co-ordination of Mandible with Tongue

It was possible that the sudden change in direction of the tongue body seen on the EMA trace was due to jaw movement for the /l/. To examine the movement of the mandible, particularly at the point where there is an apparent radical alteration in the looping trajectory of the tongue body, the position of the EMA coils at the point of last EPG frame of complete contact for /k/ was taken (see Figure 5). The mandibular position was identical at the release of the closure for /k/s and /kl/s indicating that the reduction in the forward movement of the tongue body in /kl/s cannot be due simply to a conflicting gesture of the mandibule.

Shape of the Tongue

In the Gibbon, Hardcastle and Nicolaidis (1993) paper, some specific predictions were made about the shape of the tongue during the production of /kl/ sequences. These predictions were largely confirmed by the EMA data. On average, the anterior part of the tongue appears to have a convex form at the release of velar closure for /k/s and a slightly concave form for the /kl/s. This inhibits forward movement of the tongue body, and this in turn gives an apparently (from EPG records) more posterior placement for the velar in /kl/s than singleton /k/.

DISCUSSION

The results revealed details of tongue kinematics which were not obtainable from EPG alone. Approximately mid-way during the velar closure in the /kl/ cluster the tongue tip/blade begins to rise for the /l/. This raising of the tongue is not necessarily seen on the EPG trace but is clearly visible as an upward excursion of the y1 parameter in the EMA record. The peak velocity of the y1 parameter is achieved after release of the velar closure (Figure 2). It seems that this tip/blade raising for the /l/ may inhibit the forward looped trajectory of the tongue body which is seen clearly in the trace for the /k/ produced as a singleton.

It appears therefore that the posterior placement of the tongue (noted previously in Gibbon, Hardcastle and Nicolaidis, 1993) should rather be interpreted as an inhibition of the characteristic tendency of the velar stop towards a looped forward trajectory. The production of a tip/blade gesture for /l/ may be incompatible with the characteristic velar trajectory. It would be interesting to examine whether the tendency occurs for other velar/alveolar sequences such as /kt/ in "tractor" or whether the kinematic effects noted in this study are a special feature of lateral articulation. Alveolar articulations in general certainly do seem to have a blocking effect on the forward looping movement for the velar (see for example Kühnert, 1996 for alveolar/velar sequences such as /tk/).

Another possible explanation for the lack of forward movement of the tongue body is that in /kl/ sequences there is a kind of blending process taking place since the tongue body is often quite retracted for /l/. This hypothesis will be tested by comparing the trajectories for /l/ and /t/ in this and a number of other speakers.

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