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Reliability of electromagnetic articulography recording during speaking sequences

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SUMMARY For the development of malocclusions and speech disorders, major aetiological significance is attributed to orofacial malfunctions, especially of the tongue. The position of the tongue to the alveolar arch and teeth, particularly within the area of the tip of the tongue, is of special interest for orthodontists. Electromagnetic articulography is a new technique used to examine tongue function and to record its movement in the midsagittal plane. The aim of the study was to determine whether this procedure offers suitable and reliable results.

Thirty-one subjects aged 14.3–37.3 years had to repeat speaking sequences five times. The German syllables they had to repeat were /asa/, /ascha/, /ata/, /ala/, /ana/, /aka/. The tongue movements were registered with an 'Articulograph AG 100®'. Distances, angles and encircled planes were evaluated, and the proportion of intra-individual to overall variability was calculated in order to check the reliability of the courses of movement. Angles and distances especially showed, depending on the position of the receiver coils, strong reliability during speaking sequences, whereas area produced unfavourable results. The analysis of long trajectories and angles appeared favourable in order to describe the courses of movement. This required, however, a systematic assessment of functional movement with electromagnetic articulography.

Introduction

For the development of malocclusions and speech disorders, major aetiological significance is attributed to orofacial malfunctions, especially of the tongue (Tränkmann, 1982, 1985; Adrianopoulos and Hanson, 1987; Straub, 1960, 1961). To date, it has neither been clear to what extent malfunctions of the orofacial area result in a pathological shaping of the anatomical structures nor to what extent malocclusions lead to malfunction (Hahn, 1988; Steegmayer, 1991; Tränkmann, 1988). Of special interest for orthodontists is the position of the tongue to the alveolar arch and teeth, especially within the area of the tip of the tongue.

It has been difficult to examine sufficiently tongue movements within the oral cavity due to difficulty of access. In addition to clinical examinations, palatographical and radiological procedures as well as sonography have been used (Wein *et al.*, 1988, 1991; Engelke *et al.*, 1989, 1990; Böckler *et al.*, 1990; Engelke and Schönle, 1991; Müßig, 1992).

Radiological procedures such as high-speed X-ray cinematography have the disadvantage of radiation exposure, and sonography offers because of physical reasons, only limited information as to the movements of defined points on the surface of the tongue in relation to the palate. One disadvantage is the missing representation of the palatal outline when air is accumulated between tongue and palate. Another disadvantage is that the tip of the tongue cannot be portrayed in certain types of malocclusions, and sometimes because of the shadow caused by the mandibular bone (Stone and Shawker, 1986; Engelke *et al.*, 1989; Engelke and Schönle, 1991; Fuhrmann and Diedrich, 1993).

With a new procedure called electromagnetic articulography (EMA) the possibility exists to examine functions of the tongue and to record its

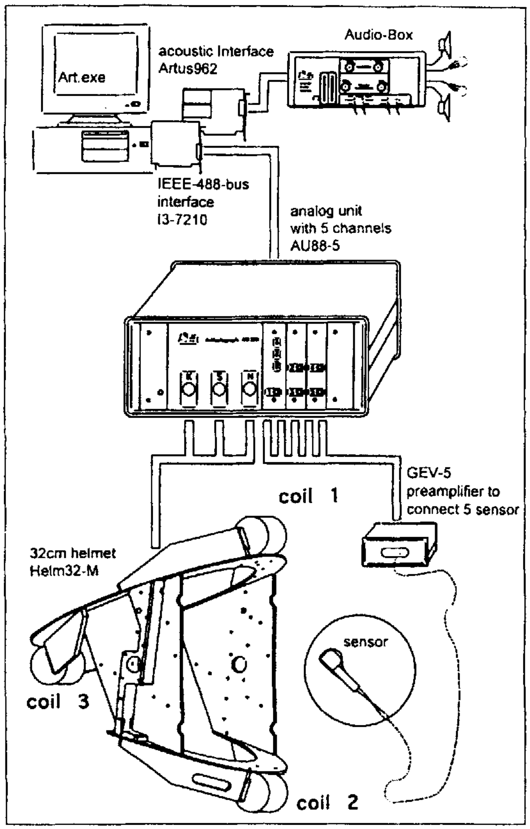

Figure 1 Articulograph AG 100®: three coils transmit radial-symmetric magnetic fields at different frequencies. The transmitting coils are attached to a helmet, one to the forehead (coil 1), one to the chin (coil 2) and one to the nape of the neck (coil 3).

movement within the midsagittal plane. The question as to whether this procedure offers suitable and reliable results was investigated in this study.

Subjects and method

The registration of the tongue movements was undertaken with an Articulograph AG 100®, Carstens Medizinelektronik, Göttingen, Germany. The system works according to the principle of measuring distances via induction. Three coils transmit radial-symmetric magnetic fields at different frequencies. These three transmitting coils were attached to a helmet at the following positions: forehead (coil 1), chin (coil 2) and nape of the neck (coil 3) (Figure 1).

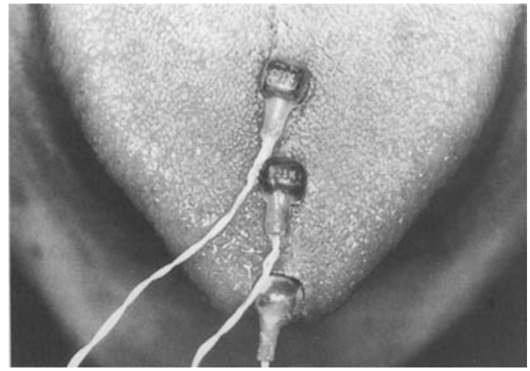

Figure 2 On the surface of the tongue, in the area of the sulcus medianus, one miniature receiver coil was fixed to the tip of the tongue and two others were fixed at a distance of 10 and 20 mm, respectively, dorsal of the first position using physiologic glue.

On the tongue surface, in the area of the sulcus medianus, three miniature receiver coils were fixed with physiologic glue Histoacryl® blau (B. Braun Melsungen AG, Melsungen, Germany). One was placed on the tip of the tongue, and the other two at 10 and 20 mm distance dorsal to it (Figure 2). Additionally, a coil was fixed to the gingival fringe of the upper jaw in the midsagittal plane for reference, and in the same way in the lower jaw for registration of opening.

For calculation of the position of the receiver coils an alternating voltage, depending on the distance, was induced in them by the transmitter coils. The alternating voltage was converted into direct voltage by synchronous demodulator switching and then further processed in an analogue-to-digital converter. A computer classified the distances of receiver and sender coils two-dimensionally into an X-Y co-ordinate system which was then available for further evaluation. The registration frequency of this measuring system was 100 Hz.

Thirty-one subjects (14 male, 17 female) aged 14.3–37.3 years with an average age of 26.5 ± 4.1 years were examined. The German syllables /asa/, /ascha/, /ata/, /ala/, /ana/, /aka/, which are sequences of vowel–consonant–vowel (VCV-sequences), were repeated five times in sequence. Additionally, a reference plane corresponding to the occlusal plane was registered.

Prior to the measurements, a plastic splint with a channel for the coil on the tip of the

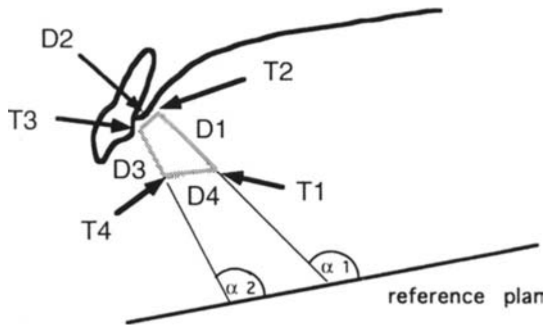

Figure 3 The following positions T1, T2, T3, T4, the distances D1, D2, D3, D4, and the angles Alpha1, Alpha2 were used for further analysis.

tongue was made. This splint was manufactured on a mandibular plaster model and aligned with its channel on the median sagittal plane and on the occlusal plane. Kerr® Impression Compound (Kerr USA, Romulus, MI, USA), was used for fixation in the region of the anterior teeth and molars. With the cooled Kerr® material, it was possible to fix the splint to an intra-oral reproducible position, and by moving the tip of the tongue coil along the channel to assess a contour of reference.

The choice of speaking sequences was made following the study by Engelke *et al.* (1991).

The courses of movement of the three tongue coils were evaluated (Figure 3):

T1 The most caudal position when building the first vowel of the VCV-sequence

T2 Contact point of palate (e.g. 't' in ata), the first cranial position of the tongue (e.g. 's' in asa), i.e. the beginning of the production of consonants

T3 Removal point of the palate or the last cranial position of the tongue when ending the consonant production

T4 Most caudal position when building the second vowel of the VCV-sequence

In order to record the course of movements with a parameter and to assess them with regard to their intra- and inter-individual variability, it was decided to calculate the area of the following triangles:

A1 T1, T2, T4
A2 T2, T3, T4

For further analysis, the distances between the following points were calculated:

D1 distance T1–T2
D2 distance T2–T3
D3 distance T3–T4
D4 distance T1–T4

Additionally, the following angles were determined:

Alpha1 between distance D1 and the corresponding reference plane
Alpha2 between distance D3 and the corresponding reference plane

To determine the reliability of the observations, the variability of data within one individual subject was compared with the variability between the subjects. In order to express the correlation statistically and objectively, the intra-class correlation coefficient (ICC) was used which mirrors the portion of variability between the single units observed with respect to the overall variability. Thus an ICC of >0.5 indicates greater variability between than within individual subjects.

According to the index developed by Sachs (1992) the following divisions were used and an ICC of >0.60 was chosen as a limit for sufficient reliability:

Index:	<0.10	none
	0.10–0.40	low
	0.41–0.60	clear
	0.61–0.80	high
	0.81–1.00	almost complete reliability

Additionally, clinical results as well as a functional status were ascertained in order to record and differentiate orofacial malfunctions.

Results

The results of the clinical examination and of the functional status were: five subjects were oral breathers, one had a sigmatism and a further 16

Table 1 ICC values and corresponding 95 per cent confidence intervals of the distance D1.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.66	0.77	0.87
asa	Coil 2	0.46	0.61	0.75
asa	Coil 3	0.57	0.7	0.82
ascha	Coil 1	0.63	0.75	0.85
ascha	Coil 2	0.54	0.68	0.81
ascha	Coil 3	0.69	0.79	0.88
ata	Coil 1	0.57	0.7	0.82
ata	Coil 2	0.5	0.64	0.78
ata	Coil 3	0.55	0.68	0.81
aka	Coil 1	0.82	0.89	0.94
aka	Coil 2	0.53	0.67	0.8
aka	Coil 3	0.66	0.77	0.87
ala	Coil 1	6.66	0.77	0.87
ala	Coil 2	0.64	0.76	0.86
ala	Coil 3	0.71	0.81	0.89
ana	Coil 1	0.65	0.76	0.86
ana	Coil 2	0.7	0.8	0.89
ana	Coil 3	0.64	0.76	0.86

Table 2 ICC values and corresponding 95 per cent confidence intervals of the distance D2.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.62	0.74	0.85
asa	Coil 2	0.25	0.41	0.6
asa	Coil 3	0.36	0.52	0.69
ascha	Coil 1	−0.03	0.08	0.25
ascha	Coil 2	0.32	0.48	0.66
ascha	Coil 3	0.59	0.72	0.83
ata	Coil 1	0.57	0.7	0.82
ata	Coil 2	0.19	0.35	0.54
ata	Coil 3	0.25	0.41	0.59
aka	Coil 1	–	–	–
aka	Coil 2	0.45	0.6	0.75
aka	Coil 3	0.59	0.72	0.83
ala	Coil 1	0.6	0.72	0.83
ala	Coil 2	0.61	0.74	0.84
ala	Coil 3	0.54	0.68	0.81
ana	Coil 1	0.49	0.64	0.78
ana	Coil 2	0.32	0.49	0.66
ana	Coil 3	0.42	0.58	0.74

Table 3 ICC values and corresponding 95 per cent confidence intervals of the distance D3.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.77	0.85	0.91
asa	Coil 2	0.71	0.81	0.89
asa	Coil 3	0.69	0.79	0.88
ascha	Coil 1	0.8	0.87	0.93
ascha	Coil 2	0.77	0.85	0.92
ascha	Coil 3	0.78	0.86	0.92
ata	Coil 1	0.66	0.77	0.87
ata	Coil 2	0.68	0.79	0.88
ata	Coil 3	0.7	0.81	0.89
aka	Coil 1	0.81	0.88	0.93
aka	Coil 2	0.75	0.84	0.91
aka	Coil 3	0.76	0.85	0.91
ala	Coil 1	0.67	0.78	0.87
ala	Coil 2	0.74	0.83	0.9
ala	Coil 3	0.69	0.8	0.88
ana	Coil 1	0.79	0.87	0.93
ana	Coil 2	0.85	0.9	0.95
ana	Coil 3	0.8	0.87	0.93

Table 4 ICC values and corresponding 95 per cent confidence intervals of the distance D4.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.4	0.56	0.72
asa	Coil 2	0.4	0.56	0.72
asa	Coil 3	0.47	0.62	0.76
ascha	Coil 1	0.57	0.7	0.82
ascha	Coil 2	0.7	0.81	0.89
ascha	Coil 3	0.6	0.73	0.84
ata	Coil 1	0.19	0.35	0.54
ata	Coil 2	0.3	0.46	0.64
ata	Coil 3	0.47	0.62	0.76
aka	Coil 1	0.03	0.16	0.35
aka	Coil 2	0.28	0.44	0.62
aka	Coil 3	0.4	0.55	0.71
ala	Coil 1	0.46	0.61	0.76
ala	Coil 2	0.47	0.62	0.77
ala	Coil 3	0.47	0.62	0.77
ana	Coil 1	0.48	0.63	0.77
ana	Coil 2	0.45	0.61	0.76
ana	Coil 3	0.46	0.61	0.76

Table 5 ICC values and corresponding 95 per cent confidence intervals of the angle Alpha1.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.86	0.91	0.95
asa	Coil 2	0.89	0.93	0.96
asa	Coil 3	9.45	0.6	0.75
ascha	Coil 1	0.85	0.91	0.95
ascha	Coil 2	0.85	0.91	0.95
ascha	Coil 3	0.86	0.91	0.95
ata	Coil 1	0.78	0.86	0.92
ata	Coil 2	0.81	0.88	0.93
ata	Coil 3	0.23	0.39	0.58
aka	Coil 1	0.14	0.3	0.49
aka	Coil 2	0.68	0.79	0.88
aka	Coil 3	0.75	0.84	0.91
ala	Coil 1	0.26	0.42	0.61
ala	Coil 2	0.81	0.88	0.93
ala	Coil 3	0.68	0.79	0.88
ana	Coil 1	0.17	0.32	0.51
ana	Coil 2	0.46	0.61	0.75
ana	Coil 3	0.4	0.56	0.72

Table 6 ICC values and corresponding 95 per cent confidence intervals of the angle Alpha2.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.69	0.79	0.88
asa	Coil 2	0.88	0.93	0.96
asa	Coil 3	0.66	0.77	0.87
ascha	Coil 1	0.89	0.93	0.96
ascha	Coil 2	0.86	0.91	0.95
ascha	Coil 3	0.7	0.8	0.89
ata	Coil 1	0.81	0.88	0.93
ata	Coil 2	0.86	0.91	0.95
ata	Coil 3	0.26	0.42	0.6
aka	Coil 1	0.41	0.57	0.72
aka	Coil 2	0.79	0.87	0.93
aka	Coil 3	0.81	0.88	0.93
ala	Coil 1	0.43	0.59	0.74
ala	Coil 2	0.18	0.34	0.53
ala	Coil 3	0.4	0.55	0.71
ana	Coil 1	0.76	0.84	0.91
ana	Coil 2	0.81	0.88	0.93
ana	Coil 3	0.22	0.38	0.57

Table 7 ICC values and corresponding 95 per cent confidence intervals of the area A1.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.44	0.59	0.74
asa	Coil 2	0.59	0.72	0.83
asa	Coil 3	0.5	0.64	0.78
ascha	Coil 1	0.67	0.78	0.87
ascha	Coil 2	0.72	0.82	0.9
ascha	Coil 3	0.71	0.81	0.89
ata	Coil 1	0.48	0.63	0.77
ata	Coil 2	0.45	0.6	0.75
ata	Coil 3	0.54	0.68	0.8
aka	Coil 1	0.27	0.44	0.62
aka	Coil 2	0.43	0.58	0.73
aka	Coil 3	0.46	0.61	0.76
ala	Coil 1	0.68	0.79	0.88
ala	Coil 2	0.56	0.7	0.82
ala	Coil 3	0.8	0.87	0.93
ana	Coil 1	0.4	0.56	0.72
ana	Coil 2	0.46	0.62	0.76
ana	Coil 3	0.52	0.66	0.8

Table 8 ICC values and corresponding 95 per cent confidence intervals of the area A2.

Function	Coil	0.95 Left confidence limit ICC	ICC	0.95 Right confidence limit ICC
asa	Coil 1	0.57	0.71	0.82
asa	Coil 2	0.31	0.47	0.65
asa	Coil 3	0.27	0.44	0.62
ascha	Coil 1	–0.05	0.05	0.21
ascha	Coil 2	0.36	0.52	0.69
ascha	Coil 3	0.64	0.76	0.86
ata	Coil 1	0.54	0.68	0.81
ata	Coil 2	0.17	0.32	0.52
ata	Coil 3	0.19	0.34	0.53
aka	Coil 1	–	–	–
aka	Coil 2	0.37	0.53	0.7
aka	Coil 3	0.43	0.58	0.73
ala	Coil 1	0.71	0.81	0.89
ala	Coil 2	0.6	0.73	0.84
ala	Coil 3	0.47	0.62	0.77
ana	Coil 1	0.65	0.77	0.86
ana	Coil 2	0.47	0.62	0.77
ana	Coil 3	0.43	0.58	0.74

showed hyperactivity of the orofacial muscles when swallowing. With regard to malocclusion, six subjects had a distal occlusion and one a mesial occlusion. In the vertical direction, two subjects had an open bite and three a deep bite. At the time of examination, seven subjects were undergoing orthodontic treatment, and 19 had been treated previously. Two had undergone speech therapy.

Individual movements of function in the following results are indicated in combination with the relevant position of the coils (e.g. /asa/ at coil 1 = /asa/1).

Calculation of distances

The analysis of distance D1 showed that all ICCs of 0.61–0.89 produced good to very good values and were within the range of high to almost complete reliability (Table 1).

The distance D2 showed a non-uniform picture (Table 2). The tip of the tongue showed best values during the syllables /asa/, /ata/ and /ana/. /Ala/ showed highly reproducible values in all areas with ICCs between 0.68 and 0.74, especially within the range of coil 2, while at /ascha/ and /aka/ only coil 3 produced acceptable values. All other positions were marked by an increased intra-individual variability.

Similar to the variable D1, the ICCs for the variable D3 of 0.77–0.9 produced high to almost complete reliability without exception; the confidence intervals were very favourable as well at 0.10–0.21 (Table 3). Therefore, this indicates that adequate reliability exists for all functions and coils.

Concerning the distance D4, the syllable /ascha/ clearly dominated with values of 0.7–0.81, while the syllables /ala/ and /ana/ hardly exceeded the limit for sufficient reliability (Table 4). Only the third coil offered sufficiently reliable values for the syllables /asa/ and /ata/. /Aka/ also showed a high variability within subjects.

Calculation of angles

The analysis of the angle Alpha1 between the distance D1 and the corresponding plane showed good ICC values (Table 5). With 0.91, /ascha/ showed the best values at all coils. /Asa/ and /ata/ were about the same, but at the third coil there was a clear decrease as they are dentoalveolar sounds. /Aka/, however, was poorly reproducible within the area of the tip of the tongue and showed the strongest reproducibility within the range of coil 3. Similarly, /ala/ and /ana/ performed particularly badly at the tip of the tongue and showed their best values at coil 2, whereas only /ala/ possessed reproducible values at the second and third position, and /ana/ possessed one reproducible value at the second coil.

The analysis of the angle Alpha2 between the distance D3 and the corresponding plane again showed high to almost complete reliability of /ascha/, whereas the quality of the third coil decreased in comparison with the angle Alpha1 (Table 6). /Asa/ and /ata/ again produced the least reliable results at coil 3, whereas /ata/3 was far beyond the limit of sufficient reliability. Again /aka/ reproduced the tip of the tongue poorly, while /ala/ did not show any reliability at any position. /Ana/, however, showed almost totally reliable values at the first two coils.

Calculation of area

The evaluation of the area A1 produced especially favourable values for the function /ascha/ within the range of all three coils with ICC values of 0.78–0.82 and is, therefore, within the range of high to almost complete reliability (Table 7). Lower values were recorded for the syllables /asa/ and /ata/, whereas /asa/1 and /ata/2 were slightly below the previously determined limit of sufficient reliability. The highest values were shown by /asa/2 and /ata/3 with ICC values of 0.72 and 0.68, respectively. The evaluation of /aka/ and /ana/ showed ICCs with values of 0.44–0.66, which were all lower than those of /ala/. With 0.7–0.87, this syllable achieved high to almost complete reliability. /Aka/, /ala/ and /ana/ reached their maximum at coil 3. Using confidence intervals, /ala/ had a distinctly better range, 0.13–0.26, compared with /aka/ and /ana/ (0.28–0.35). Coil 3 also showed adequate values.

The results of plane A1 varied compared with those of plane A2 (Table 8). The best values were found either within the range of the first coil (/asa/, /ata/, /ala/, /ana/) or within the range of the third coil (/ascha/, /aka/). The values then decreased with increasing distance from this coil. For statistical reasons, /aka/ could not be evaluated at coil 1. Sufficiently reliable values were found with the syllables /asa/1, /ascha/3, /ata/1, /ala/1 to 3 as well as with /ana/1 and 2.

Discussion

The aim of the present examination was to analyse the patterns of movement of the tip of the tongue by means of EMA when performing certain functional movements with regard to reliability. Examinations of the spatial and temporal co-ordination of tongue, jaw and soft palate at different functional movements have previously been carried out (Schönle *et al.*, 1983, 1989; Engelke *et al.*, 1989, 1991; Engelke and Schönle, 1991; Schwestka-Polly *et al.*, 1992).

Engelke *et al.* (1989) overlapped the courses of movements when repeating the speaking sequences and deduced, in a purely descriptive way, high reliability from the similarity of the courses of movement, in agreement with Schönle (1988) for electromagnetic findings.

In this evaluation the statistical reliability of the courses of movements was investigated. This was carried out independently of the subjective assessment of the examiner by means of pure mathematical evaluation of geometric data and the comparison of the variability of the individual subjects with the overall variability of the courses of movement.

Distances

The distances D1 and D3 produced high to almost complete variability with all VCV-sequences. As a result of the selection of the vowel /a/ and the resulting deep position of the tongue, long trajectories of movement were necessary to cross the distance to the palatal location used for consonant building. For geometrical reasons, relative sensitivity was small with regard to disruptive factors, and thus the variability was low (Schwestka-Polly *et al.*, 1992).

For mathematical reasons, the different locations used for the building of vowels and consonants in a sagittal direction had only a minimal effect on the length of the distances. Different ICC values can be explained by the unfavourable combination of function and position of the coils, as well as by variations in the building locations of vowels and consonants. Thus, at D1 building of the consonants /s/ and /t/ required the most sensitive motorical differentiation since articulation was located close to the alveolus at the tip of the tongue, represented by coil 1 (Habermann, 1986). Possibly the less favourable results of the second and third coil positions reflect the minor importance of tongue movement when producing these consonants, which corresponds with the results of Hoole *et al.* (1990). On the other hand, for building of the consonants /l/, /sch/ and /n/, the back of the tongue or the entire tongue seems to be responsible.

The different positions of consonant building might be another factor for the variability of the distances D1 and D3. In 1990, Hoole *et al.* found higher variances in the range of the tip of the tongue compared with the dorsal part of the tongue during the building of /a/ at VCV-sequences for vowel 1. Opposite conditions were true for vowel 2 (Hoole *et al.*, 1990). The higher reliability of the downward movement of D3 compared with D1 is striking. A more stable course of movement in the vertical direction is to be expected after consonant building, but this presupposes a more variable first vowel building, possibly depending on the starting position of the tongue at rest.

These results contradict the statement of Hoole *et al.* (1990) who found a greater variability for vowel 2. Almost all syllables showed lower ICC values at the second coil concerning the distance D1. In this connection, these lower values might be explained by the associations discussed above. It is still unclear to what extent the tip and back of the tongue take control of the course of movement or to what extent the range in between allows a certain degree of freedom.

The distance D2 with a more sagittal direction along the palate proved to be unsatisfactory, as only a few function–coil combinations exceeded the given limits. Minute disruptive dimensional factors such as the size of coils or variation of movement had an adverse effect in relation to the overall distance. However, the favourable values for /asa/1, /ata/1, /ala/1 to 3 or /aka/3 confirm the high motorical demand on the tip and back of the tongue necessary for the building of the corresponding consonant (Hoole *et al.*, 1990). Unfortunately, a comparison with the results of Engelke *et al.* (1989, 1991) and Schwestka-Polly *et al.* (1992) is not possible as these authors do not take the component of movement into consideration.

Likewise, the rather unfavourable values of D4 can be explained from the comparison of the variability of the second vowel building position to the first observed from a sagittal direction (Hoole *et al.*, 1990; Engelke *et al.*, 1991). The extremely favourable values for /ascha/ are striking. Engelke *et al.* (1991) attributed a clearly greater distance to the dorsal building of the consonants /sch/ at /ascha/ in comparison with /s/ at /asa/ (Engelke *et al.*, 1991). These co-articulatory correlations between consonant and vowel (Hoole *et al.*, 1990) are expected to bring about a greater distance between the first and second vowel point due to the greater distance, and consequently are thought to bring about less susceptibility to variabilities.

Angles

The angles Alpha1 and Alpha2 are marked by high reproducibility in most function-coil combinations, similar to the distances D1 and D3. Lower results at the third coil at /asa/ and /ata/ proved again the high motorical demands for the tip of the tongue, while /ascha/ requested more involvement from the entire tongue, at least during upward movements. /Aka/, however, reached its lowest variability in the dorsal area as expression of a velar sound (Hoole *et al.*, 1990). Thus, this result is in agreement with those of other authors who attribute a selective possibility of innervation to the different areas of the tongue and therefore different patterns of movement (Hoole *et al.*, 1990; Gröne *et al.*, 1992; Schwestka-Polly *et al.*, 1992). Highest reproducibility was found at /l/ and /n/ and mostly at coil 2, which confirms the results of Hoole *et al.* (1990), who observed an increased variability of these sounds in the dorsal area.

Areas

Areas can be seen as an expression of both the variable distances and angles associated with the summation of the disruptive factors. This could also be the reason for the overall low ICC values, especially at A2, which is influenced by the disruption-sensitive distance of D2. This combination effect could also be the reason why the results of the areas only partly showed the importance of the tip of the tongue for the sounds /s/ and /t/, and of the back of the tongue for the sound /k/, as this was shown with the other variables. Therefore, analysis of the area seems rather unsuitable for the registration of complex patterns of movement.

Conclusion

It has been established that primarily for the comparison of different subjects their functional movements should be assessed, which might show a slight intra-individual variability in comparison with the overall variability and, thus, draw attention to possible pathological components of movement. It has to be taken into consideration that different speaking sequences show variability depending on coil position, due to the varying motorical demands of the individual parts of the tongue during articulation of vowels and consonants. The analysis of long distances or directions of movement seems especially favourable for description of the courses of movement. This, however, requires the systematic assessment of those functional movements, which appear to be favourable and show a high reliability for investigations using EMA.

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