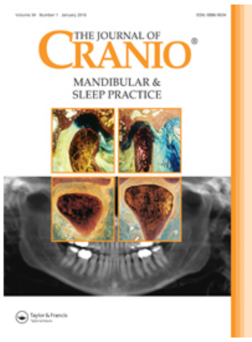

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Clinical Practice

Mandibular movement during speech of two related Latin languages

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Objectives/hypothesis: This study assessed the kinesiographic recordings of jaw movements during reading a text in Galician and Spanish language.
Study design: Cross-sectional blind study.
Methods: A homogeneous healthy group of 25 normal stomatognathic system and native Galician participants was studied. Frontal and parasagittal plane recordings of the intraborder lateral jaw movements and during reading Galician and Spanish texts were recorded using a calibrated jaw-tracking device kinesiograph.
Results: Although movements were similar in both languages, a greater retrusion of the jaw in the Spanish language was shown; moreover, a tendency exists for a left side motion envelope in this right-handedness preference sample.
Conclusions: This study supports the hypothesis that speech is controlled by the central nervous system rather than by peripheral factors, and that the hemispheric dominance influences the asymmetry of the speech envelope.

Keywords: Speech, Jaw motion, Kinesiography, Spanish, Galician

Introduction

Language is a product of the human mind, and it is also 'a mode of action'.[1] Language is organized around simple structures and proto-words, which require the co-occurrence of intra-syllabic (consonant-vowel) and inter-syllabic (labial consonant-vowel-crown consonant sequences) structures.[2]

The production of speech is linked to a group of processes that are closely coordinated by the central nervous system, such as breathing, phonation, articulation and resonance. These processes are associated with a feedback mechanism between sensory and auditory information.[3] Specific zones of the oral cavity are required to produce each phoneme. Three patterns exist (Fig. 1): the anterior, labial ('pa') which is also necessary to initiate nasal consonants ('ma'); the intermediate, where the tongue is applied against the hard palate ('tal'); and the posterior, which is used to pronounce dorsal consonants ('gota') which involve closure of the soft palate.[2]

The acquisition and evolution of language resulted from an interactive and self-organizing biomechanical process. Limitations in complex movements and culturally mediated cognitive systems constrained these processes.[2]

Speech requires the participation of the interconnected nervous, muscular and skeletal systems. The nervous system controls and regulates muscular activity.[4] The muscular system specializes in speed and strength, and specifies the coordination of sequences of movement by showing clear structural and functional differences between skeletal muscles. The skeletal system provides the two temporomandibular joints by which complex hinge movements are combined with displacement motions. The precision of speech is in part due to the freedom of jaw movement that permits the temporomandibular joints to vary their position according to the sound emitted. This precision requires differentiation, integration, and refinement.[5]

Neurocommunication between the cerebral cortex and muscles is necessary for the control of speech;

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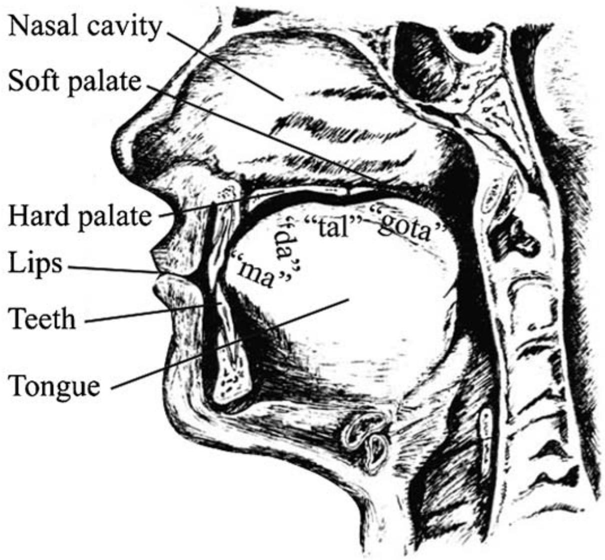

Figure 1 Main anatomical structures involved in speech production.

human language has a very finely differentiated motor rhythmicity (at 2–3 Hz) between speech patterns.[6] The influence of jaw dynamics in voice production has been reported. Nevertheless, few studies have been carried out on jaw dynamics in speech.[3,7–10] The jaw requires less opening when pronouncing in a low voice but more opening when pronouncing in a Louder voice.[11] Electroglottographic studies have shown that larynx adduction increases to the degree that jaw opening does.[12] Furthermore, the production of sibilant sounds appears to require a reduced vertical dimension of occlusion[13] in subjects with dental wear, when compared to those with a normal occlusion.[14]

Mandibular movements may be analyzed by direct observation, radiography, lightweight head-mounted cephalostat with a strain gauge,[11] and through computerized kinesiography.[10,15–21]

A kinesiograph consists of a group of magnetometers that read the magnetic field generated by a magnet fixed to the buccal side of the mandibular incisors. Computer processing calculates the speed of displacement and provides Graphics recordings.[8] Howell[9] reported mean magnitudes of 8.3 mm vertically, 4.2 anteroposteriorly, and 1.6 mm laterally in the envelope of speech.[9]

There are few studies in which jaw behavior has been evaluated during speech of two different languages. It has been shown that sibilant sounds produce the closest speaking space, and that the mean and the variability of the closest speaking space in Cantonese speakers is smaller than that in English speakers.[22] The differences in mandibular movement between two related languages have never been studied, in particular two Latin languages such as Galician and Spanish.

Galician is a language descended from Latin and developed within the westernmost territory of the Roman expansion through Europe. It is now spoken in the Autonomous Community of Galicia, which approximately occupies the Northwest corner of the Iberian Peninsula. Galician and Portuguese have the same origin and development. Galician began with poetic texts in the twelfth century, and was consolidated with prose writings in the second decade of the thirteenth century. Both Galician and Spanish are currently spoken in Galicia.

The Spanish language evolved in a similar way to Galician. The first evidence of which may be the 'Cartularies of Valpuesta', where texts from the ninth to the thirteenth centuries are compiled. Although written in Latin, they reveal the presence of a romance Spanish in the language structure and in certain terms used. The oldest conserved literary work, the 'Poem of the Cid' ('Cantar de mio Cid') has been dated to between 1195 and 1207.

This study aims to determine whether there are differences in jaw movement in the speech of two languages of a common root: Spanish and Galician. The following null hypothesis is considered (H0): there are no differences in kinesiographic recordings of jaw movement between Galician and Spanish speech.

Method

The Ethics Committee of the University of Santiago de Compostela approved this observational study. All participants signed an informed consent form. The study was carried out between January 2010 and July 2013.

Twenty-five adult students (20 women and 5 men) from the undergraduate dental degree of the University of Santiago de Compostela were included in the study. The average age was 19 years (1.50), with a range of 18 to 23.

Criteria for inclusion: Participants with a functionally normal, anatomical stomatognathic system and native, habitual use of both the Galician and Spanish languages.

Criteria for exclusion: Current or prior alterations in phonation, fixed or removable intraoral retainer devices, signs or symptoms of dysfunction in the masticatory structures, prior speech-language therapy, and neurological or cognitive deficits.

Handedness preference (assuming contralateral hemispheric dominance) was assessed according to the Edinburgh inventory; positive values were considered

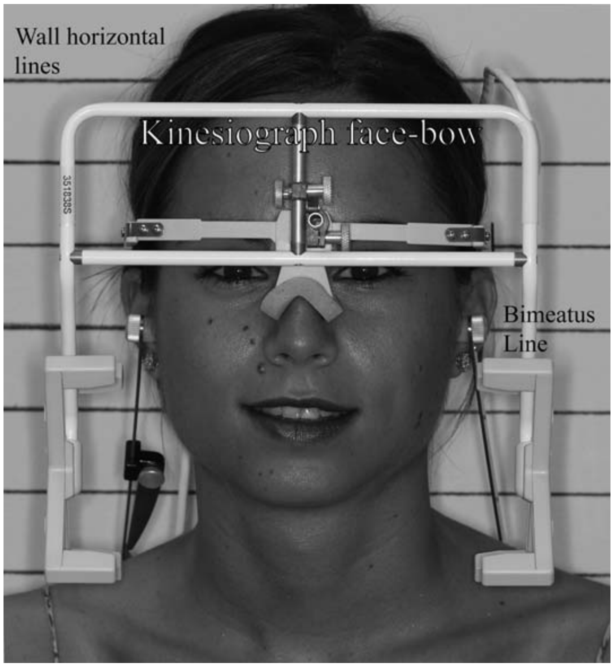

Figure 2 Kinesiograph face-bow placed on a participant's head, parallel to the bimeatal and Frankfort lines.

right-hand preference and negative values were considered left-hand preference.[23]

Kinesiography

To evaluate the possible influence of peripheral factors in jaw dynamics, recordings of the lateral guidance (LG) angles were made. Jaw motion was recorded during the successive reading of Spanish and Galician texts of 8 seconds mean duration. A calibrated Model K7 (Myotronics Inc., Kent, WA, USA) diagnostic system was used for the recordings (Fig. 2). The frontal plane lateral anterior guidance formed a tracing from which a line was drawn between the midsagittal starting point and a point 2.00 mm away along its pathway.[24] The angle formed between this line and the horizontal Frankfort line was measured with ImageJ software.[25] Two different examiners assisted in performing each series of three tests. The tests were conducted in a double-blind manner. Participants were unaware of the objectives of the assessment, and the clinicians were unaware of the participants' condition.

The index of asymmetry of the LG angles (AsymLG) was established using the following non-dimensional equation

$$\text{AsymLG} = (\text{rightLG} - \text{leftLG})/(\text{RLG} + \text{LLG}) \times 100$$

The AsymLG varies between -100 and 100. Positive values indicate that the right LG is higher.

The kinesiograph was 'Zeroed' before initiating each test using the maximum intercuspation point as a reference point, coinciding with '0' on the ordinate axis.

The kinesiograph takes recordings of the jaw movement along the indicated planes and also in time sequence. In scan 1 mode the intra-border lateral jaw movements were recorded (within which the path of common oral functions are physically inscribed), while scan 3 mode was used to record the velocity of jaw movements in the horizontal plane (incisal zone). The recordings obtained were evaluated, and two experienced examiners verified their quality. Recordings with noise were rejected until accurate records were obtained, insuring that the jaw position at the end of each recording coincided with the initial position, and repeating the test when it ended in a different position. This method has been shown to be reproducible between sessions.[16,26] The recordings were exported as images in a tagged format (Tagged Image File Format – TIFF) and processed using ImageJ digital analysis software to carry out the measurement of distances and angles of the variables.[25] Figure 3 shows the points of reference between which the distances were measured, and from which the variables were constructed. Variables V1, distance between MIP and the most cranial jaw-position; V3, distance between sagittal plane and the most cranial jaw position; V6, distance between sagittal plane and the most caudal jaw-position; and V7f, vertical magnitude of jaw-displacement between the most cranial and the most caudal jaw-positions, were measured in the frontal plane recordings (Fig. 3A). Variables V2, horizontal displacement with respect to the MIP (anterior displacements were considered positive values and posterior displacements were considered negative values), V4 was defined as vertical jaw-displacement between MIP and the most caudal jaw-position; V5, horizontal distance between MIP and the most caudal jaw-position (because the mandible always moves distally, all values were considered positives); and V7s, distance between most cranial and most caudal jaw-position, were measured in the sagittal plane (Fig. 3B). Variable V8, time-domain recording with time as the x-axis (Fig. 3C).

Experimentation/tasks

The jaw movements were recorded during the reading of two short texts, one in Galician and its equivalent in Spanish (see Appendix). The Spanish and Galician recordings were made by the same subject without re-positioning the Kinesiograph face-bow. Although the texts were not grammatically perfect, it was possible to maintain equal expressiveness. Twenty-four recordings were obtained per participant.

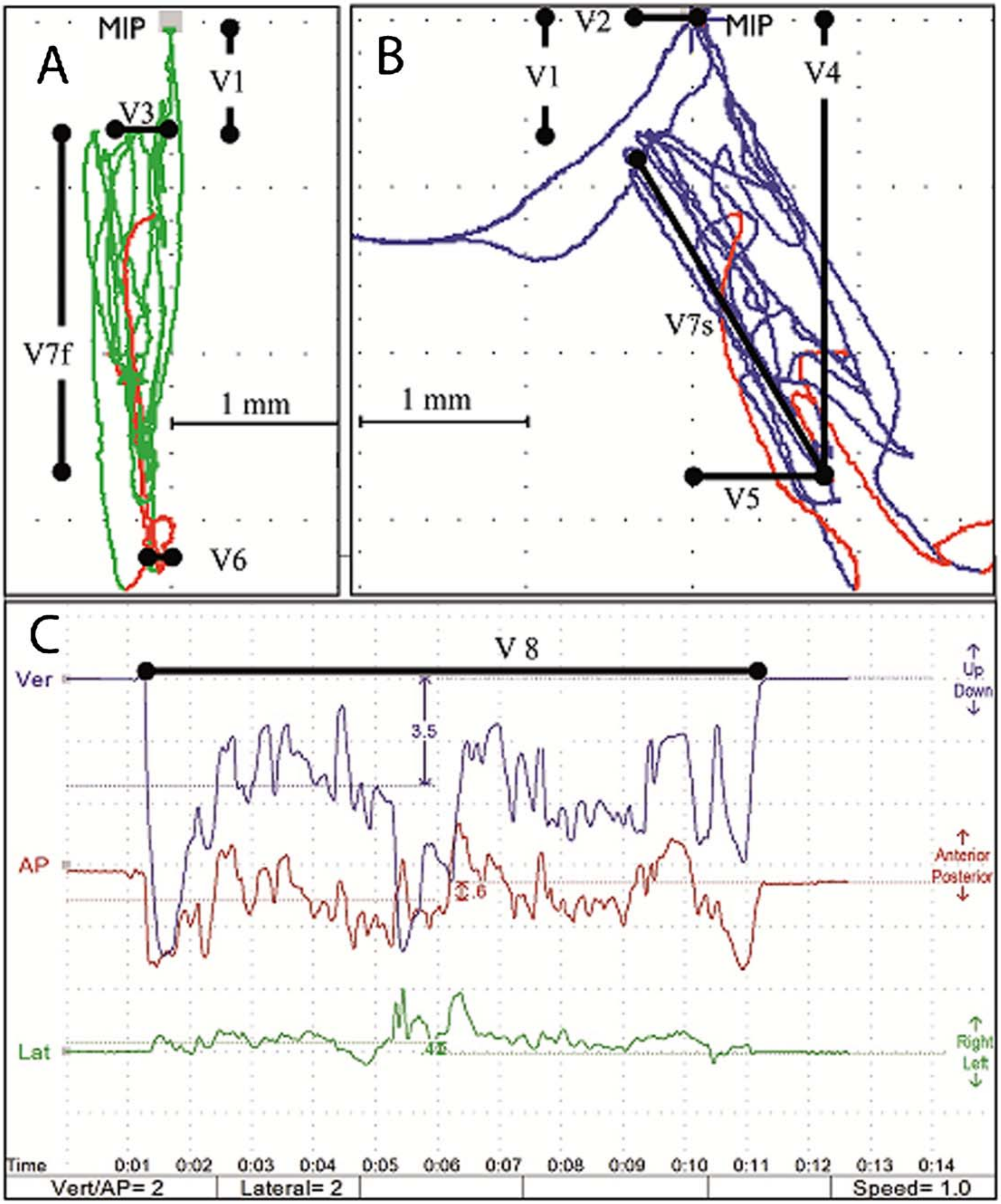

Figure 3 Graphic recording of a typical speech envelope showing points measured from that specific movement. The task recordings were successively performed for A, frontal and B, sagittal plane (in scan 1 mode); and (in scan 3 mode) C, time-domain recording with time as the x axis.

Statistical analysis

Reliability of measurements between two observers was assessed by the intraclass correlation coefficient (ICC). The values of the variables are shown as an average (SD). The normality of the continuous variables was evaluated using the Kolmogorov–Smirnov test. The variables for which the normality hypothesis was not rejected were compared using the two-tailed independent Student *t* test. Using the Pearson correlation test, the correlations between

Table 1 Mean (SD) values of lateral guidance angles (LG)

Lateral guidance and condylar path angle measurements and intra-individual differences					
Factor	Mean (SD)	Min.	Max.	Difference (95% CI)	*P*
LG global	37 (12.87)	5	70		
RightLG	38.44 (12.18)	13.50	57	2.88 (−3.30 to 9.06)	0.346
LeftLG	35.56 (13.62)	5	70		
AsymLG	4.71 (24.34)	−44.33	76.74		
Gender differences, mean (SD)					
	Women	Men			
RightLG	37.25 (13.30)	43.20 (3.83)	5.95 (−1.17 to 13.07)	0.097	
LeftLG	35.38 (12.96)	36.30 (17.75)	0.92 (−13.46 to 15.31)	0.895	
AsymLG	1.96 (21.50)	15.72 (34.21)	13.76 (−11.26 to 38.79)	0.267	

AsymLG, asymmetry index of lateral guidance angles.

the variables were evaluated. Dichotomous variables were compared using the Fisher exact test, level $a=0.05$. The software used was PASW Statistics 20 (SPSS, Chicago, IL, USA). The proportion of participants using right or left speech envelope was assessed by the 'prop.test' package (R version 2.15.0; http://www.R-project.org).[27]

Results

All participants were right-handed.

The measurements from two observers were closely repeatable for the LG outcomes (ICC=0.94; 95%CI: 0.880 to 0.966; $P<0.001$); variables related with the speech envelope showed an ICC between 0.84 (95%CI: 0.623 to 0.944; $P<0.001$) and 0.92 (95%CI: 0.789 to 0.959; $P<0.001$).

Table 1 shows the frontal plane lateral guidance and intra- and inter-individual comparisons. The mean value of the LG was 37 (12.87) degrees, with no differences amongst gender or side (Table 2).

Table 3 shows the average values (SD) of the magnitude of jaw displacement (in mm, variables 1 to 7) and temporal displacement (in seconds, variable 8).

Movements were similar in both languages. Nevertheless, variable 5 indicated a greater retrusion of the jaw in the Spanish language: 3.11 (1.60) mm vs 2.43 (1.33) mm; 95% CI: 0.325 to 1.035; $P=0.001$.

Jaw displacement was greater during the pronunciation of Galician than during the pronunciation of Spanish for both measurements in the sagittal (variable 7s, Table 3) and frontal planes (variable 7f, Table 3).

Table 2 Gender differences within variables. Mean (SD). Same variables and units as Table 1

Spanish				
	Gender Mean (SD)			
Variable	Male	Female	Difference (95%CI)	*P*
1	1.36 (1.08)	1.80 (1.25)	−0.442 (−1.701 to 0.822)	0.477
2	0.73 (0.53)	1.02 (0.81)	−0.287 (−1.080 to 0.506)	0.461
3	0.72 (0.55)	0.38 (0.31)	0.341 (−0.040 to 0.721)	0.077
4	4.52 (0.82)	4.84 (1.85)	−0.324 (−2.096 to 1.448)	0.709
5	3.29 (2.13)	3.06 (1.51)	0.215 (−1.475 to 1.905)	0.795
6	0.60 (0.74)	0.67 (0.54)	−0.068 (−0.667 to 0.532)	0.818
7saggital	2.14 (1.12)	2.35 (0.96)	−0.208 (−1.236 to 0.820)	0.679
7frontal	1.46 (0.43)	1.89 (0.72)	−0.430 (−1.131 to 0.270)	0.217
8	9.63 (0.77)	9.38 (1.76)	0.251 (−1.441 to 1.942)	0.762
Galician				
1	1.72 (1.51)	1.75 (1.17)	−0.028 (−1.311 to 1.255)	0.964
2	0.76 (0.80)	0.98 (0.78)	−0.218 (−1.028 to 0.592)	0.583
3	0.78 (0.65)	0.40 (0.35)	0.376 (−0.056 to 0.809)	0.086
4	4.06 (0.60)	4.57 (1.65)	−0.514 (−2.088 to 1.061)	0.506
5	2.40 (1.48)	2.43 (1.33)	−0.035 (−1.442 to 1.372)	0.959
6	0.70 (0.76)	0.83 (0.53)	−0.132 (−0.726 to 0.462)	0.650
7saggital	3.02 (1.91)	3.80 (1.44)	−0.785 (−2.369 to 0.798)	0.316
7frontal	2.22 (0.94)	2.90 (1.08)	−0.665 (−1.763 to 0.433)	0.223
8	10.38 (1.20)	9.20 (1.52)	1.181 (−0.342 to 2.704)	0.122

There was a statistically significant negative correlation with respect to the jaw displacement during pronunciation in Galician. The distance between the origin of the movement (MIP) and the front-most jaw position tends to diminish when the distance increases between the posterior and anterior limits during speech; see Fig. 3B variable 1 vs variable 7s and Fig. 4. This correlation was significant (two-tailed Pearson correlation −0.403, P=0.046). The correlation of these variables in the Spanish language was not significant (0.110; P=0.910).

The qualitative analysis of the frontal plane (Fig. 3A) showed lateral jaw displacement during speech in 20 (80%) participants. More participants deviated the jaw to the left (n=15; 60%) than to the right (n=5; 20%) when speaking in either language (P=0.002). Five participants showed jaw symmetry during speech.

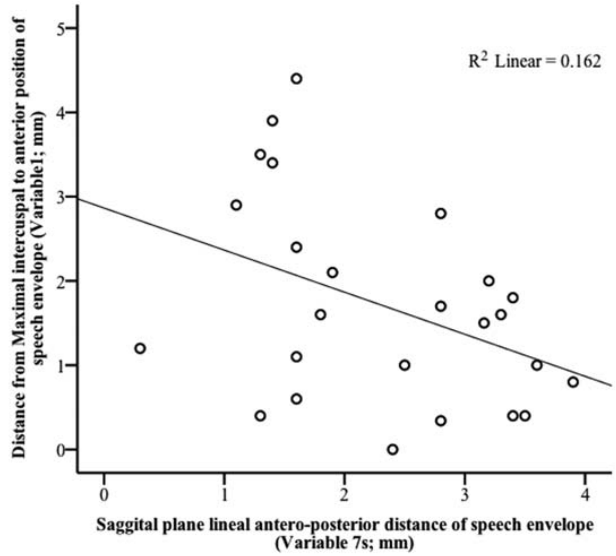

Figure 4 Plot of distances: from Maximum Intercuspal Position to the upper jaw position during speech (Variable 1), and from the anterior to the posterior jaw position during speech (Variable 7s). The speech envelope decreased when the free way increased.

Discussion

The results of this study may support a rejection of the null hypothesis. The pronunciation of Galician, in particular the sentences selected, requires a range of jaw movements that is greater than in Spanish; furthermore, the jaw is positioned further back in Galician speech.

Methods

The study group was very homogeneous in terms of age, social background, dental status, and other psycho-biological factors. All the participants regularly used both languages. This criterion for random selection before the participants were enrolled was intended to favor the internal validity of the study. The Spanish and Galician recordings were made by the same subject without re-positioning the Kinesiograph face-bow in an attempt to increase the reliability of all variables, especially V5 and V7.

Although Galician shows its own morphological executions and syntactic constructions distinct from Spanish, the sentences were selected by a professor who is a specialist in linguistics and were designed to cover diverging, Essentials phonetics. The sentences were translated from Galician to Spanish. The translation was not made to standard use of Spanish but the syntactic use as spoken in Galicia. Verbal tense form was varied equally in both versions being practical for recording and authentic linguistically. A previous study design insured that the selected sentence (of 7 seconds average duration) provided sufficient data.

Significance of the study

The reproducibility of the records and measurements of all variables was excellent (ICC>0.9) as reported by previous studies.[16,26] Therefore, it is suggested that the method employed is satisfactory for the evaluation of jaw dynamics and supports the findings previously reported.[3,10]

The jaw was placed further back with respect to the reference point (maximal intercuspal position) in the pronunciation of Spanish as opposed to Galician. Spanish requires a greater range of movements than

Table 3 Magnitude of jaw movements (mm) during speech in the Spanish and Galician languages. Mean (SD); units: all variables are expressed in mm, except for V8, which is expressed in seconds

Variable	Spanish	Galician	Difference (95% IC)	*P*
1	1.71 (1.21)	1.74 (1.21)	0.029 (−0.2751 to 0.2175)	0.81
2	0.96 (0.76)	0.93 (0.77)	0.025 (−0.2380 to 0.2884)	0.845
3	0.45 (0.39)	0.48 (0.44)	−0.032 (−0.2074 to 0.1434)	0.71
4	4.78 (1.68)	4.47 (1.50)	0.308 (−0.2745 to 0.8905)	0.29
5	3.11 (1.60)	2.43 (1.33)	0.680 (0.3253 to 1.0347)	0.001
6	0.65 (0.57)	0.80 (0.56)	−0.152 (−0.3233 to 0.0201)	0.081
7s	2.30 (0.98)	3.65 (1.53)	−1.342 (−2.0328 to −0.6504)	0.001
7f	1.80 (0.68)	2.75 (1.07)	−0.948 (−1.4301 to −0.4659)	<0.001
8	9.43 (1.60)	9.43 (1.52)	0.0004 (−0.8233 to 0.8241)	0.99

Galician (Table 3). This posterior position that the jaw adopts during speech, independently of the language, could explain the onset or worsening of orofacial pain in patients who suffer TMD during speech. However, difference in jaw position during speech of both languages is probably a consequence of the guttural sound of Galician, which requires the use of different positions of the epiglottis[12] that are less necessary in Spanish.

An aspect studied here was the analysis of the influence of lateral guidance. Although it may appear logical to think that speech is produced with some drift towards the side which the jaw moves most easily, and towards which the jaw moves more horizontally, this study did not find any association. This finding suggests that the coordination of speech is principally directed by the central nervous system, and that LG angles do not influence it.

The Pearson correlation coefficient showed a negative association (Fig. 4) between jaw displacement from the position of dental contact to the upper limit of the movements during speech (variable 1) and the magnitude of the displacement (variable 7s) when speaking Galician, but not when speaking Spanish language. The wider the subject opens their jaw to place the jaw in the speaking zone, the smaller the resulting magnitude of jaw displacement during speech, and its correlation is influenced by the language phonemes. Therefore, there is a flow limit that is determined by phonetic necessity and/or the efficiency or limitations of the structures involved. Nevertheless, the positions from which movements are initiated during phonation vary with each individual.

The negative correlation of variables 1 and 7s in Spanish was not found in Galician pronunciation, due probably to Galician requiring a larger envelope than Spanish.

The analysis of the registers in the horizontal plane revealed a tendency for the jaw to deviate toward the left side. Speech was generated with a lateral movement in 84.6% of the observations; 58% did so toward the left and 23% to the right. This tendency has previously been reported, although not explained.[20] In the authors' opinion, this tendency toward the left argues in favor of the use of the side with hemispheric dominance, an aspect which has not been cited in the literature; the most plausible explanation for this deviation is the characteristic that all participants in the study were right-handed; to assesses whether hemispheric dominance influence exists, however, a new study on left-handers should be carried out.

As there were no significant differences in the most closed position of the jaw between the two languages, this study suggests that reading either language spoken in this study can be used to determine the vertical dimension of occlusion and free interoclusal space in oral rehabilitation, supporting previous reports.[13]

Comparison with other research

To the authors' knowledge, this is the first study that evaluates the possible differences in jaw dynamics during speech in two languages with a common root. Many authors have analyzed jaw movement in one language, amongst them Spanish[10] and Brazilian Portuguese.[3] These studies have been directed towards evaluating if antagonistic dental contacts exist,[10] while others have researched dynamic aspects, such as the range of motion, and jaw movement velocity in the incisal zone.[3] The current study intends to evaluate if the phonemes of two different languages of common origin require different jaw movements.

This study showed significant differences in the range of jaw displacement (Variables 7s and 7f, Table 3) between both languages, and also in the extreme but repeated positions that the jaw adopts (Variable 5, Table 3, Fig. 3). One plausible explanation is the use of more closed phonemes in the Galician language that appear to require a specific movement of the phonatory structures,[11,12] probably due to the position of the tongue and bottom of the mouth appearing to require a greater descent in Galician pronunciation.

The position of greatest opening during the speech in the present study showed a lesser displacement of flow than in Bianchini's study[3] (Variable 4, Table 3 and Fig. 3). The recordings for the present study, in Spanish and Galician, respectively showed 4.78 (1.68) mm and 4.47 (1.50) mm, while other authors reported a descent of a little more than 11.0 mm.[15]

It is difficult to establish precise comparisons with other studies, as they each used different sentences of differing lengths[14] or used pictures[3] of a common object, e.g. a clock, pencil, etc., for the subject to name. These differences from the present study could be due to the use of the point of greatest flow that was repeated along various tracings. In other studies, the limit route was used. Nevertheless, it seems logical to use the position that is adopted repeatedly and not only the limit route, since this position could be influenced by inadvertent movements of the arch and is probably less reproducible than the area more commonly used for phonation. Moreover, both positions may be recorded in future studies. Another difference is that other studies used the isolated and successive recognition of objects, whereas the present study used the reading of a sentence of approximately 7 seconds' duration. The need to reinitiate the term may demand a new opening each time speech is interrupted, whereas, in continued speech, it can require more consistent movements in a more limited area.

This study has various limitations. While a homogeneous study population increases the internal validity of a study, it may reduce the possibility of extrapolation to other population groups. Therefore, future studies could include groups of participants with different characteristics, including patients who complain of pain when speaking. This study included only five males; thus, although no difference between genders (Tables 1 and 2) was found, and the alternative hypothesis cannot be accepted, the assumption of the null hypothesis should be cautiously interpreted, and the possibility of a type II or beta error is possible. A more extensive study will need to be carried out in order to assess whether gender differences exist or not.

Furthermore, this study only analyzed jaw movement, but speech is a complex mechanism involving structures and their neurological, sensory, and motor coordination. Future studies could investigate differences in the movements of intraoral and pharyngeal structures, particularly the movement of the tongue and soft palate. Moreover, because it has been shown that experimental alteration of the palatal vault influences jaw dynamics during speech,[21] palatal vault morphology should be evaluated in future research in order to homogenize/stratify the samples and thus increase the study validity.

The analysis of a selected sentence could offer different characteristics of specific phonemes that are also used in both the languages studied. Further studies could attempt to identify whether jaw dynamics differ with certain phonemes.

Additionally, the environmental conditions were different from those in which habitual and natural speech is conducted. Recording a long period of speech with continuous recording of movement could show differences in common speech, although this could introduce other confounding factors that are difficult to control and evaluate.

This study suggests the influence of central factors, with LG having no influence in healthy subjects. Future studies are recommended to clarify if the hemispheric dominance factor remains in left-handed subjects and also to establish jaw dynamics in symptomatic patients during speech.

Conclusions

This study suggests a predominance of central influence in the asymmetry of jaw movements during speech. Both the Galician and Spanish languages, although similar, appear to require different patterns in the movement of the integral structures of the stomatognathic system.

Disclaimer Statements

Contributors None

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Conflicts of interest None.

Ethics approval None.

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Appendix

The sentence read in Galician was the following:
'Era un home que desexaba ir ó estranxeiro, pero nunca fora nun avión; o home dicía que sempre xusto cando ía chamar para coller o billete, tiña tanto susto que non o facía'.
The sentence, translated to Spanish, was:
'Era un hombre que deseaba ir al extranjero, pero nunca fuera en avión; el hombre decía que siempre justo cuando iba a llamar para coger el billete, tenía tanto susto que no lo hacía'.

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