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ORIGINAL ARTICLE

Phonetic Alterations Caused by Different Lingual Appliances

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ABSTRACT
Objective: To evaluate the differences in phonetic alterations caused by three different lingual appliances, all bonded in sequence on the same patients. **Material and Methods:** Lingual brackets (STb, Incognito and Harmony) were bonded from 1.3 to 2.3 with a 0.013 CuNiTi archwire. The text was formulated to evaluate the phonetic variations in a controlled context (logatomi) and more casual sentences. The recording of the text was performed at time t0 (before positioning the brackets), t1 (after positioning the brackets) and t2 (60 minutes after positioning the brackets). An ANOVA-type analysis was performed. **Results:** A significant correlation was confirmed between the effects of all the linguistic methods used compared to the absence of the same. The most influenced acoustic variables were the center of gravity of the acoustic spectrum of the analyzed sounds (CoG) and the number of zero crossings of the instantaneous amplitude curve of the considered signal. **Conclusion:** The effects deriving from the positioning of the various brackets were relatively contained: in some cases, for some subjects, for some consonants and in specific contexts, some brackets may occasionally be less invasive than others. However, no lingual system was systematically better than others regarding phonetic alterations.

Keywords: Orthodontics; Phonetics; Orthodontic Appliances; Orthodontic Brackets.

Introduction

The number of adult patients requiring orthodontic treatment is increasing. These patients usually have some multidisciplinary criticism [1-3] and high aesthetic requests. Given the poor compliance of patients with removable appliances, lingual orthodontics is sometimes the only possible solution [4]. It has been demonstrated that lingual orthodontics has some biomechanical advantages [5-9] and some side effects. Even if lips are not in contact with fixed appliance [10] and not articular problem are described [11], lingual orthodontic patients can have phonetic problems affecting the patient's relational life. Multiple studies have tried to quantify the presence of distortions and / or the absolute absence of phonetic sounds caused by lingual attacks and how long it takes to recover normal pronunciation.

Already from the first studies conducted by Fujita [12], it emerged that: in the group of sample patients (Japanese language), to whom the vestibular brackets adapted to the lingual side were applied, the greatest difficulties, even if of limited duration, were recorded in the pronunciation of dental consonants and Th [12].

The first comparative study that assessed the influences on the phonetics of different lingual appliances was published almost 20 years ago. This study found that any type of lingual appliance causes phonetic distortions and discomfort for the patient, but these factors vary according to size: the smaller the appliance, the less influences it induces on the production of sounds [13].

Further confirmation of how much the size of lingual brackets plays an important role in phonetic problems is given by a recent German study in which 7th generation Ormco-Kurz brackets were compared with custom-made brackets. The group treated with customized brackets and in which the lingual space was less restricted had fewer problems with phonetics and lingual lesions, and therefore all resulted in better comfort for the patient [14].

It has been reported in the literature that retrognathic patients have greater difficulty in adapting to lingual appliances [15]. Considering that the assessment of phono-articulatory difficulties has been ascertained varies according to the idiom considered, a study evaluated the phono-articulatory difficulties in Arabic-speaking patients [16]. According to the Likert scale, assessment of oral discomfort was determined using standardized questionnaires comprising five questions with four possible response points. Patients were asked to express their subjective opinions regarding discomfort, difficulty speaking, and chewing at t0, t1, t2. A reduction in complaints occurred during the first three months following the insertion of the brackets and most patients were satisfied in the third evaluation period.

Slater analyzed what could be done to help the patient overcome phonation problems [17] and concluded that it is necessary to warn the patient of the probable onset of the phonetic problem and that it is necessary to choose equipment that determines the smallest possible footprint.

Therefore, this study aimed to evaluate the differences in phonetic alterations caused by three different lingual appliances, all three bonded in sequence on the same patients.

Material and Methods

Study Design and Sample

In this prospective study, three different lingual orthodontic appliances were bonded to the same patient on six different patients. The minimum sample size was not reached due to the complexity of bonding three customized appliances on the same patient.

The following inclusion criteria were adopted: 1) Italian mother-tongue; 2) Permanent and complete dentition; 3) Molar Class I; and 4) Good general health. As inclusion criteria were established: 1) Presence of open bite or cross-bite; 2) Presence of infantile swallowing; and 3) Presence of pre-existing language difficulties (articulatory defects).

Clinical Protocol

For each patient and each type of appliance tested, the protocol was as follows: taking the alginate impressions, developing the plaster model, making the Kommon base, positioning the lingual brackets from 1.3 to 2.3 with a 0.013 CuNiTi archwire [18]. The lingual brackets tested were:

- Harmony (American Orthodontics, Sheboygan, WI, USA);
- Incognito (TOP - Service für Lingualtechnik GmbH, 3M Unitek Corporation, Bad Essen, Germany);
- STb (Ormco Corporation, Orange, CA, USA).

A text was formulated to evaluate the phonetic variations in a controlled context (logatomi) and more casual sentences. The recording of the text was performed at time: t0 (before positioning the brackets), t1 (after positioning the brackets) and t2 (60 minutes after positioning the brackets).

In these experimental conditions, various measurements of acoustic variables were performed, which allowed evaluating the effects of the presence of the different brackets on a selection of alveo-dental sounds in different vowel contexts. For each condition, recordings were made with the help of means, equipment and personnel available at the A. Genre Laboratory of Experimental Phonetics in Turin (LFSAG). The data was collected thanks to a DigiDesign Mbox2 professional recording system (Avid Technology Inc., Burlington, MA, USA) and a Shure SM58 microphone (Prase Engineering S.p.A., Noventa di Piave, Venice, Italy) with (partially) noise reduction obtained in the soundproofed environment ensured by a modular silent booth (Amplifon S.p.A., Milan, Italy) model G2x1 (-42 / -45 dB between 1 and 4kHz). The signal-to-noise ratio averaged +40 dB.

The distance of the microphone from the speaker's lips was variable, between 15 and 20 cm checked with a ruler, as was its orientation: according to the height of the observed subject. In all the recordings, we tried to obtain an excellent alignment between the axis of the microphone and the speaker's vocal duct.

The software used was PRAAT (version 5.3.02, Praat, Amsterdam, Netherlands), created by Paul Boersma and David Weenink of the Institute of Phonetical Sciences of the University of Amsterdam. PRAAT is a program specifically dedicated to speech analysis and is currently considered the complete software for experimental phonetics (www.fon.hum.uva.nl/praat).

For each condition (corresponding to a separate sound file, in .wav mono PCM format at 16bit and 44.1 kHz), eight variables were measured:

1) Dur - i.e., the duration of the sound analyzed;
2) Intensity - i.e., the energy (SPL0 / 1) of the analyzed sound;
3) Cog - i.e., the center of 'gravity' of the acoustic spectrum (0 ÷ 22050 Hz) of sound analyzed;
4) Sd - i.e., the standard deviation for the center of 'gravity' of the density acoustics of the analyzed sound spectrum;
5) Skew - i.e., the asymmetry of the center of 'gravity' of the acoustic spectrum of the sound analyzed concerning an equiprobable Gaussian;
6) Kurtosis - i.e., the flattening of the acoustic spectrum of the analyzed sound with respect to an equiprobable Gaussian;

7) Zc = the number of zero crossings (positive and negative) of the curve of instantaneous amplitude of the analyzed sound.
8) To these was added a derived variable, zc_norm, obtained dividing zc by dur (zc / dur), i.e., the number of zero crossings in the unit of time (s).

Statistical Analysis

The analyzed data was extracted from PRAAT, using the AcuFric Script at the University of Warwick, starting from a set of Text Grid label files prepared for each file (48 labels). The statistical analysis was conducted on 13923 sounds. The occurrences of the sounds were measured using the "Ime 4" (IME Group, Varese, Italy) package (software standard R for mixed-effect models) [19,20]. For each occurrence, seven variables were considered.

To obtain statistical significance values, repeated measures ANOVA-type analyses were performed under the mixed-effects framework. This draft dates back to Chambers et al. [21]. The statistical analyzes derived from this method were previously discussed with the staff of the LFSAG of the University of Turin.

The analyses performed with the mixed effect model have a series of figures by subject, condition, sound, and context. A post-hoc power calculation was performed using the G*Power software (Heinrich-Heine-Universität Düsseldorf, Germany). The post-hoc calculation yielded a minimum detectable effect size of f=0.36 between the medium and large thresholds.

Ethical Clearance

The study design was reviewed and approved by the Ethics Committee of Postgraduate School of Orthodontics (Protocol No. 9/2017).

Results

The graphic inspection of the values assumed by some variables allowed to identify some conditions in which the acoustic consequences of the positioning of the heels generate statistically significant deviations from the physiological conditions. In particular, a significant correlation was confirmed between the effects of all the linguistic methods used compared to the absence of the same. Significant effects were recorded in the case of the creations of / s / and / ts / and, in particular, for some subjects (those who prefer dental articulation places), in the context / u_u / (Tables 1 to 3 and Figures 1 to 3).

The most influenced acoustic variables were the center of gravity of the acoustic spectrum of the analyzed sounds (CoG) and the number of zero crossings of the signal's instantaneous amplitude curve (this variable was correlated to the previous one). Another variable subject to greater dispersion of values in the presence of lingual attachments is the standard deviation of the spectrum (also characterized by a correlation with the statistical variable kurtosis).

No significant changes were observed between t1 and t2; presumably, the explanation for this data is due to the fact that it is a very short time compared to those taken into consideration in other studies reported in the literature.

Table 1. Recorded effect on Harmony group.

Time	Intensity	Cog	Sd	Skew	Kurtosis	Zc_norm	Dur
T0	60.73 ± 0.82	5817.96 ± 220.30	1696.82 ± 75.40	0.19 ± 0.12	2.92 ± 0.31	5.94 ± 0.27	111.56 ± 8.30
T1	54.15 ± 0.90	5032.64 ± 198.01	1954.86 ± 74.90	0.68 ± 0.18	2.77 ± 0.36	5.31 ± 0.38	129.76 ± 7.52
T2	56.33 ± 0.79	4986.77 ± 212.52	1969.51 ± 67.87	0.59 ± 0.20	2.91 ± 0.39	5.31 ± 0.37	135.78 ± 7.34

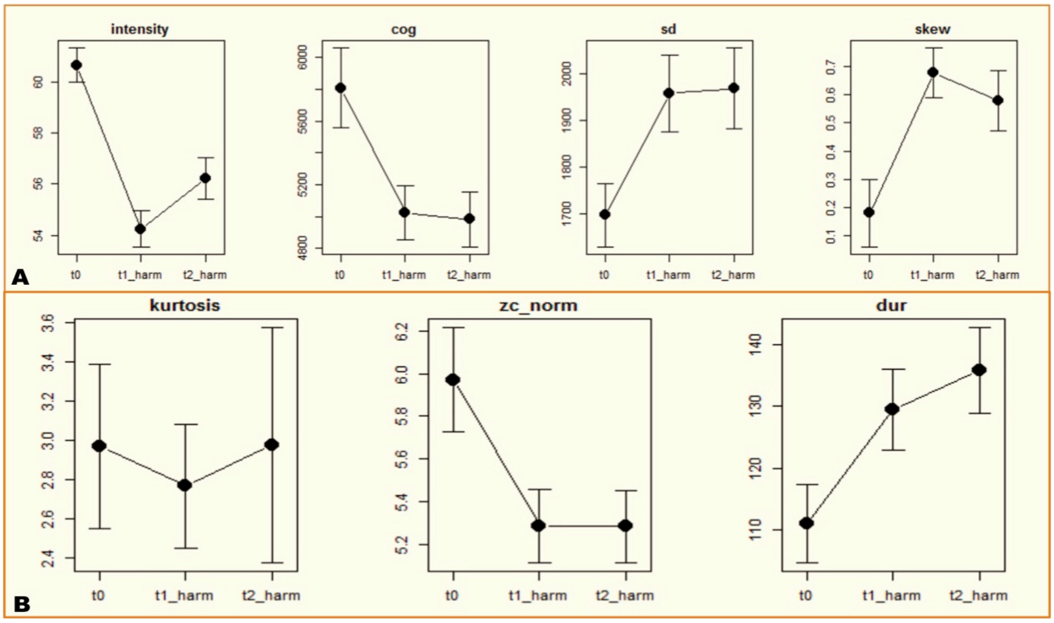

Figure 1. Overall parameters of Harmony brackets.

Table 2. Recorded effect on Incognito group.

Time	Intensity	Cog	Sd	Skew	Kurtosis	Zc_norm	Dur
T0	60.73 ± 0.82	5817.96 ± 220.30	1696.82 ± 75.40	0.19 ± 0.12	2.92 ± 0.31	5.94 ± 0.27	111.56 ± 8.30
T1	56.05 ± 0.78	5038.59 ± 194.30	1896.00 ± 63.70	0.54 ± 0.16	3.21 ± 0.37	5.26 ± 0.42	126.03 ± 7.20
T2	53.88 ± 0.73	4983.32 ± 201.13	1904.21 ± 37.84	0.49 ± 0.09	2.78 ± 0.45	5.21 ± 0.77	121.48 ± 7.22

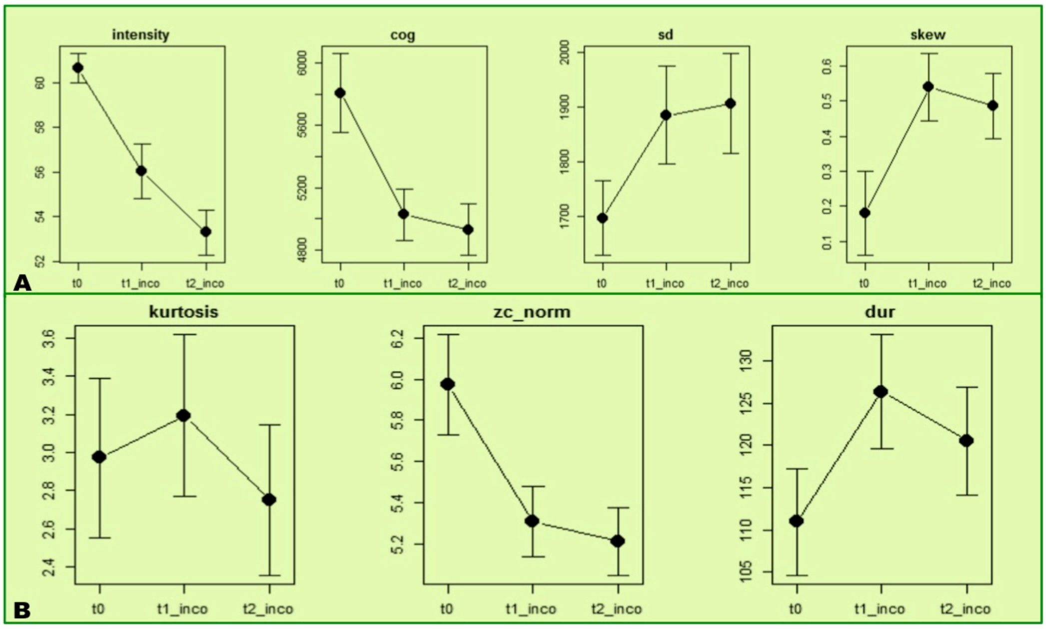

Figure 2. Overall parameters of Incognito brackets.

Table 3. Recorded effect on STb group.

Time	Intensity	Cog	Sd	Skew	Kurtosis	Zc_norm	Dur
T0	60.73 ± 0.82	5817.96 ± 220.30	1696.82 ± 75.40	0.19 ± 0.12	2.92 ± 0.31	5.94 ± 0.27	111.56 ± 8.30
T1	57.04 ± 0.73	5266.12 ± 181.00	1904.20 ± 43.90	0.45 ± 0.10	2.50 ± 0.23	5.53 ± 0.22	124.13 ± 7.47
T2	57.55 ± 0.72	5283.32 ± 167.23	1954.61 ± 42.74	0.39 ± 0.09	2.61 ± 0.42	5.47 ± 0.52	122.78 ± 5.14

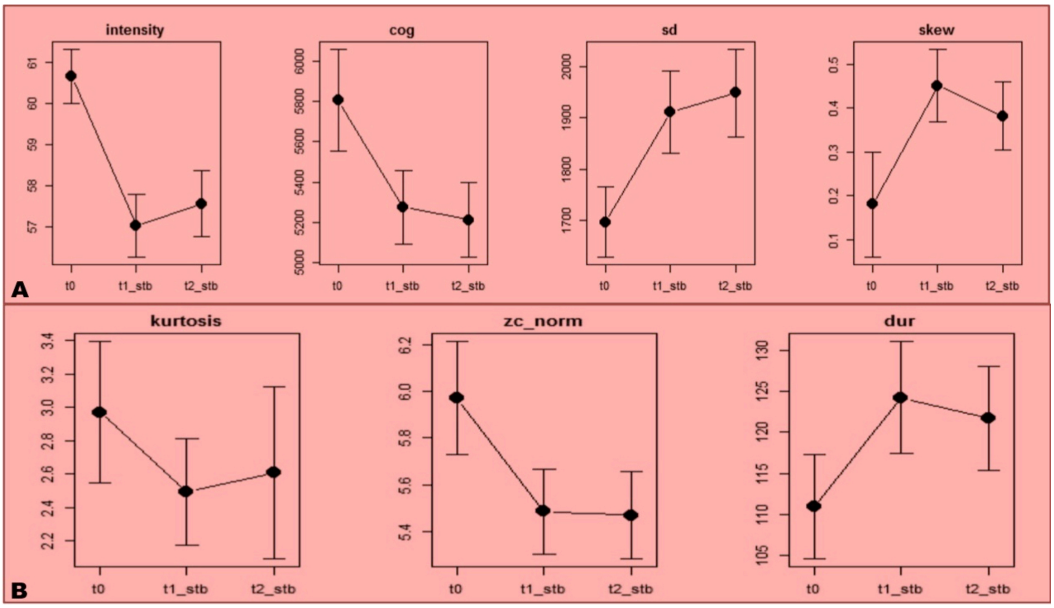

Figure 3. Overall parameters of STb brackets.

Discussion

Due to general characteristics of production (generally subject to variability even in placebo conditions), we did not focus on those of intensity and duration. However, we observed how the intensity was overall reduced for all correction conditions: the inter-speaker variability confirmed statistical significance.

The same is true for the duration, which generally occurred longer for the correction conditions (the articulation of sounds generally requires more effort in these conditions), but, above all, the observed subjects seemed disposed to a slower articulation speed. There were no significant variations between the two observations under correction conditions (t1 and t2), but in two cases (Incognito and STb), the condition at time t2 was less significantly from that t0. Also, the values assumed by the zc_norm variability were not commented on, considering that they were correlated with those of CoG.

Curtosis (kurtosis) and asymmetry (skew) were, finally, neglected because the first rarely indicated significant variations (in some conditions, it even goes against the trend in the comparison t0-t1-t2 for the different appliances) and the second because useless for discrimination between their performances.

We, therefore, focused on reading the two CoG and Sd graphs, evaluating their values deriving from the positioning of the different types of lingual equipment. The interpretation of the data in the CoG and sd graphs for the Harmony appliance was as follows. The Harmony 6 subjects at T1 and T2 observed a significantly lowering the CoG (usually lower sounds) and equally significantly raising the sd (acoustic dispersion of energy over a broader spectrum of fricative phases observe). However, the average values of sd are closer to that measured on average at t0 than in other devices.

As for the Incognito device, the figures of CoG and sd showed similar trends, but the variation of sd was more contained at t1 and t2 and was on average closer (although not significantly) to that of t0.

Finally, as for STb, CoG and sd showed values generally similar to those of Harmony. However, the average values of CoG at t1 and t2 were, in this case, more similar, compared to those measured for the other appliances, to those of the condition t0.

Although occasionally some acoustic variables may be less disturbed in the case of some appliances (sd for Harmony and CoG for STb), no appliance generally seems to be preferable to others. According to the previous studies, all the tested brackets produce significant statistical deviations from the conditions defined by time t0, according to the previous studies [13,16,17].

It should be pointed out better the various effects of lingual appliances on oral function. Together with acoustic-phonetic alterations tested in the present report, lingual multibracket appliances have been demonstrated to have many other effects on the oral environment, such as enamel decalcifications, microbiological alterations, and temporary restriction of tongue space [22-24]. All these variables should be discussed with the patients before treatment to improve self-awareness.

Certain malocclusions show a relationship with speech defects and this does not appear to correlate with the severity of the condition. There is no direct cause-and-effect relationship. Similarly, no guarantees of improvement can be given to patients undergoing orthodontic or orthognathic correction of malocclusion [25].

Unlike what happens for lingual appliances, the insertion of fixed labial appliances affects speech sound production. In that cases, sibilant and stopped sounds are affected, with /s/ being affected most often; furthermore, accommodation to fixed appliances depends on the severity of malocclusion [26]. These authors performed the analysis on 23 patients, unlike the present study, which analyzed six patients. The sample size certainly represents a limit for this study, and future analysis with larger sample sizes will be able to clarify even better the phonetic alterations caused by lingual appliances. Furthermore, longer residence times of the various lingual appliances on patients could deepen and expand the effects analyzed in this study.

Conclusion

The effects deriving from the positioning of the various brackets were relatively contained: in some cases, for some subjects, for some consonants, and in certain contexts, some brackets may occasionally be less invasive than others. However, no lingual system was systematically better than others regarding phonetic alterations.

Authors' Contributions

PA		https://orcid.org/0000-0002-4020-5065	Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Original Draft, Writing - Review and Editing.
LG		---	Writing - Review and Editing.
FC		https://orcid.org/0000-0002-4641-2196	Conceptualization and Writing - Review and Editing.
MP		https://orcid.org/0000-0001-6198-3053	Conceptualization and Writing - Review and Editing.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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