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Articulatory Distortions when using Different Types of Mouthguard

(Pengherot-berotan Artikulasi apabila Menggunakan Jenis Pelindung Mulut yang Berbeza)

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ABSTRACT

A non-randomised controlled trial was conducted to compare the articulatory distortions of plosive sounds when using different types of mouthguards. Female national rugby players aged 18 and above were recruited, all of whom were native speakers of Malay without speech or hearing impairment. Boil-and-bite and custom-fitted mouthguards were provided for each participant. The articulation of phonemes with plosive sounds (/p/, /b/, /d/ and /t/) was recorded in a quiet room for the following conditions in a predetermined sequence: not using a mouthguard, using a boil-and-bite mouthguard, and using a custom-fitted mouthguard. A washout interval of one hour was implemented among the conditions. The recorded speech waveforms were digitised and transcribed into the Praat software version 6.0.39 for spectrographic analysis. The mean voice onset time (VOT) for all phonemes was measured in milliseconds. Friedman test was used as the omnibus test with a level of significance set at $\alpha = 0.05$, while Bonferroni-corrected Wilcoxon signed-rank test was used for pairwise comparisons. A total of 25 participants completed the follow-up. A statistically significant difference was found in the articulation of all plosive sounds among control, boil-and-bite mouthguard and custom-fitted mouthguard ($P < .001$). All pairwise comparisons were statistically significant ($P < .001$). Although the articulation of plosive sounds was distorted when boil-and-bite and custom-fitted mouthguards were used, distortions were more notable in the boil-and-bite mouthguard.

Keywords: Dental trauma; mouthguard; rugby; speech

ABSTRAK

Kajian terkawal bukan rawak dijalankan untuk membandingkan gangguan artikulasi bunyi plosif apabila menggunakan pelbagai jenis pelindung mulut. Pemain ragbi kebangsaan wanita yang berusia 18 tahun ke atas dipilih sebagai peserta kajian dan kesemuanya merupakan penutur asli Bahasa Melayu dan tidak mempunyai sebarang gangguan ucapan atau pendengaran. Pelindung mulut 'boil-and-bite' dan pelindung mulut yang dipadan khusus disediakan untuk setiap peserta. Artikulasi fonem dengan bunyi plosif (/p/, /b/, /d/, dan /t/) direkodkan di dalam bilik yang senyap dalam urutan yang telah ditetapkan seperti keadaan berikut: tidak menggunakan pelindung mulut, menggunakan pelindung mulut 'boil-and-bite' dan menggunakan pelindung mulut yang dipadan khusus. Selang waktu antara keadaan ialah selama satu jam. Bentuk gelombang ucapan yang dirakam telah didigitalkan dan disalin ke dalam perisian versi Praat 6.0.39 untuk analisis spektrografik. Minimum masa permulaan suara bagi semua fonem diukur dalam milisaat. Ujian Friedman digunakan sebagai ujian keseluruhan dengan tahap signifikan yang ditetapkan adalah pada $\alpha = 0.05$, manakala ujian pangkat-tanda Wilcoxon pelarasan-Bonferroni digunakan untuk perbandingan pasangan. Seramai 25 peserta telah menjalani susulan lengkap. Terdapat perbezaan yang ketara dalam artikulasi semua bunyi plosif antara kawalan, pelindung mulut 'boil-and-bite' dan pelindung mulut yang dipadan khusus ($P < .001$). Semua perbandingan sepadan adalah ketara secara statistik ($P < .001$). Walaupun artikulasi bunyi plosif terjejas dengan penggunaan kedua-dua pelindung mulut 'boil-and-bite' dan pelindung mulut yang dipadan khusus, perubahan adalah lebih ketara dengan pelindung mulut 'boil-and-bite'.

Kata kunci: Pelindung mulut; pertuturan; ragbi; trauma gigi

INTRODUCTION

Traumatic dental injuries (TDI) are highly prevalent globally (Petti et al. 2018). Contact sports increase the risk of sustaining TDI because of the high impact of contact among participants (Sane & Ylipaavalniemi 1998). The prevalence of orofacial trauma among rugby players range from 6.7 to 71.9%, with the lower prevalence reported among females and schoolchildren than the elite male players (Kumamoto & Maeda 2004). The risk of injuries increases with increasing player age, especially among

players who undergo long hours of training and who compete professionally (Muller-Bolla et al. 2003). TDI often involves injuries to the tooth structure, periodontal tissue, oral mucosa, and temporomandibular joints. The vulnerable site is the upper jaw, particularly the upper incisors (Feliciano & Calda 2006). These injuries often affect a person's appearance, thereby leading to psychological stress (Glendor 2008). Furthermore, TDI would require challenging, time-consuming and costly treatment (Berger et al. 2009; Glendor et al. 2001).

The use of mouthguards is associated with a lower prevalence of sports-related injuries (Fernandes et al. 2018). Wearing a mouthguard while playing a sport can reduce the occurrence and severity of dental trauma (Yeşil & Gungor 2009) perhaps because it acts as an impact-absorption device that dissipates the energy of a traumatic blow, thereby diverting the forces away from oral structures (Hoffman et al. 1999). The ability to protect the mouth is dependent on the capability of the mouthguard to absorb shock and dissipate impact (Craig & Godwin 2002).

Mouthguards are typically composed of a thermoplastic copolymer that fits over the occlusal surfaces of the maxillary teeth and extends near the vestibular reflection. Basically, three types of mouthguards are available in the market, namely, stock, boil-and-bite, and custom-fitted mouthguards (ASTM International 2016). Stock mouthguards are sold to the public in several sizes and are used with minimal modification. Boil-and-bite mouthguards are the most commonly used ones and represent 90% of all mouthguards worn (Padilla et al. 1996). This type is made of a thermoplastic material, which is softened in hot water and then moulded to the dental arch by the user. Custom-fitted mouthguards are formed by taking an impression of the dental arches, making a mould and then fabricating a mouthguard on the mould in the laboratory. However, limited availability and higher cost hinder the widespread use of custom-fitted mouthguards (Patrick et al. 2005).

The common problems with mouthguard use include difficulty in breathing, oral dryness, altered tastes, nausea, discomfort, and speech interference. The association of these problems with the type of mouthguard was assessed using a self-reported questionnaire (Duarte-Pereira et al. 2008; Gawlak et al. 2016) and a visual analogue scale (Brionnet 2001). When mouthguard type-specific speech difficulties were assessed exclusively, a semi-subjective measure, such as speech sound assessment conducted by a speech language pathologist, was utilised (Morrow et al. 1984).

Plosive sounds are created by developing an airstream in the oral cavity and suddenly releasing it (Shriberg et al. 1995). The /p, b/ and /t, d/ differ in the way they are formed. The former is produced by altering the lips, whereas the latter is presented by moving the tongue on the palatal surfaces of the alveolar or dental structure. The presence of an intra-oral appliance such as a mouthguard can reduce the palato-lingual dimensions for tongue movement or the bucco-labial dimensions for lips movement, thereby distorting the plosive sounds.

Considering the lack of objective assessment of articulatory distortion, this research aimed to evaluate the impact of wearing boil-and-bite and custom-fitted mouthguards on the articulatory distortions by spectrographic analysis. The specific objective was to compare the mean VOT of plosive sounds when using the different types of mouthguards.

Methods

A non-randomised controlled trial was performed. All players in the national female rugby team were invited to participate.

Their medical history was obtained, and a dental examination was performed to determine the players' eligibility to participate in the study. The inclusion criteria were: an adult female aged 18 years old and older, currently representing the nation and participating actively in rugby, and a native speaker of Malay (national language). The exclusion criteria were: did not play rugby within the last six months; has edentulism; has used a mouthguard, an orthodontic appliance or a removable prosthodontics appliance within the last six months; has a known history of allergy to polymers; and has medical problems (ASA classification 3 and above). Ethics approval was obtained from the Research Ethics Committee. Informed consent was provided by all participants in written form. Participation was voluntary, and data confidentiality was maintained.

The sample size required was determined using the G*Power software. The assumptions were an effect size of 0.25 with 5% margin of error and 80% power. Correlation among measures was set at 0.5. This yielded a minimal sample size of 28. A dropout rate of 10% was expected between the first visit and the fitting visit. Thus, the total sample size was adjusted to 32.

For each participant, the dental impression of the maxilla was obtained using an alginate impression material and a rigid perforated stainless-steel tray. On-site infection control was implemented by rinsing impressions under running tap water and spraying with disinfectant before transporting in sealed and labelled Ziploc bags. The impressions were cast within the same day using type II dental stone. After about 45 min, the dental models hardened. The highest margins of the vestibular border were marked, and the excess stone was trimmed off.

The custom-fitted mouthguards were constructed using the dual laminated technique with the thermo-pressure machine (Erkopress 300 Tp by Erkodent, Germany). A layer of white ethylene-vinyl acetate (EVA)

thermoplastic sheets of 3 mm in thickness with 125 mm diameter (Dentsply International Raintree Essix, Court East Sarasota, USA) was secured in the ring, and the model was placed in the form pot. These were heated together in the pressure machine. Afterward, the first layer and the model were taken out and cooled at room temperature for 10 to 15 min. Excess EVA material was removed so that the labial borders of the mouthguard were within 2 mm of the vestibular reflection. The palatal margins were limited to the cervical area of the palatal surface of the upper teeth. The distal ends enclosed the distal surface of the first molars. A second layer was adapted with the black EVA sheet. The trimming process was repeated. Finally, the mouthguard produced was adjusted to an even thickness of 4 mm. Iwanson spring wax calipers crown gauge measuring 1-10 mm calibrated scale was used to ascertain uniform thickness at the occlusal, buccal and palatal surfaces. All the borders of the mouthguard were smoothened.

During the fitting, each participant was given a boil-and-bite mouthguard and a custom-fitted mouthguard. The boil-and-bite mouthguard is composed of double-layered EVA. Following its manufacturer's instructions (KHZ058 Bicolor Mouth Guard, Shenzhen Kanghao Industrial Co. Ltd, China), the mouthguard was immersed in a bowl of hot water (about 80 °C). After 50 s, the softened sheet was fitted on the maxillary arch of the participant. The participant then bit down to ensure the mouthguard stayed firmly on the maxilla. The mouthguard was removed and immersed in cold water to retain its shape. For the custom-fitted mouthguards, the adaptation, stability and retention of the mouthguards were checked at fitting. Adjustments and smoothing were performed where necessary. The participants were instructed on mouthguard use and care.

Three recordings were made in a quiet room for each of the following conditions: not using mouthguard, immediately after fitting of a boil-and-bite mouthguard, and immediately after fitting of a custom-fitted mouthguard. For each participant, the three recordings were done one hour apart to minimise a carryover effect. The recorder (Sony IC Recorder, ICD-SX700/SX800, San Diego, USA) was placed 15 cm away from the participant's lips. The participant read out loud the four selected Malay words displayed on the laptop screen, one after another. The selected words with plosive sounds were *paku* for phoneme /p/, *bola* for phoneme /b/, *dadu* for phoneme /d/ and *tatu* for phoneme /t/.

All the recordings were digitised (at a sampling rate of 22 kHz and 32-bit resolution) into the computer and transcribed into the Praat software version 6.0.39 (Boersma & Weenink 2018). The acoustic characteristics of a sound sample were studied by viewing and measuring its waveform and spectrogram. The following standard setup was used to create the spectrogram display: A frequency range of 0-5,000 Hz, a window length of 0.005 s and a dynamic range of 50 dB. The mean VOT was measured from the spectrograms for phonemes /p, b, d, t/ in a millisecond. Triplications were done for the recording, and the average of the three readings was the mean VOT.

Statistical analysis was performed using SPSS version 22.0. Demographic data were summarised using descriptive statistics. The normality assumption of VOT was violated (Shapiro-Wilk test, $P < .05$). Hence, Friedman test was conducted to test the null hypothesis that no differences exist among the conditions. Statistical significance was set at $\alpha = .05$. The post hoc Wilcoxon signed-rank test was executed for pairwise comparisons. Bonferroni adjustment was accomplished to correct for multiple testing.

RESULTS

A total of 31 rugby players attended the first visit for the impression-taking session. However, six of them did not return to the fitting visit because of other commitments. Hence, only 25 participants completed the follow-up sessions. The participants were aged between 18 and 32 years old, with a mean age of 21 years old. Most participants had less than two years of rugby playing experience (n = 16, 64%). None of the participants previously used a mouthguard.

Table 1 shows the median of VOT, interquartile range and *p*-values for all /p, b, d, t/ plosive sounds. Statistically significant differences were evident among the conditions for all plosive sounds (Friedman test, $P < .001$). For each plosive sound tested, the post hoc analysis using the Wilcoxon signed-rank test revealed significant differences between no mouthguard and boil-and-bite mouthguard ($P < .001$), between boil-and-bite mouthguard and custom-fitted mouthguard ($P < .001$) and between no mouthguard and the custom-fitted mouthguard ($P < .001$). Distortion was most marked for the boil-and-bite mouthguard.

DISCUSSION

This study compared the articulatory distortion when using boil-and-bite and custom-fitted mouthguards. The mean VOT of the /p, b, d, t/ plosive sounds were significantly different from the use of mouthguards. Distortion was the greatest when using boil-and-bite mouthguards, followed by custom-fitted mouthguards. This is crucial in team sports that require communication, such as rugby.

The current study demonstrated that articulatory distortion is inevitable when using a mouthguard. Similar to intra-oral appliances, placement of the foreign body in the mouth reduces the dimensions of the oral cavity, thereby restricting the movement of the

tongue during articulation and distorting various sounds. However, the mechanism of speech disturbance differs slightly between orthodontic appliances and sports mouthguards because of the space occupied intra-orally. Chen et al. (2018) reviewed on various orthodontic appliances and concluded that labial fixed appliances increase contact between the labial brackets and the lips besides contributing to tongue protrusion, hence resulting in notable changes for the articulation of /s/ sound. In contrast, lingual fixed appliances restrict tongue movement, cause tongue soreness, alter the morphologies of palatal surfaces of anterior teeth and render the air seal ineffective for the pronunciation of /i/, /a/, /o/, /s/, /l/, /t/ and /d/. When using upper Hawley retainers, VOT changes were noted for /d/ (Atik et al. 2017). The discrepancy between appliances elucidated the critical influence of lingual/palatal coverage and vertical dimension in the distortion of plosive sounds. Sports mouthguards require palatal coverage for retention and vertical thickness for protection of teeth; however, these features affect the articulation of plosive sounds.

The custom-fitted mouthguard resulted in less articulatory distortion when compared with the boil-and-bite mouthguard. The custom-fitted mouthguard was specifically designed and fabricated according to the working model constructed from the individual's impression. Therefore, the fit and retention in the mouth was superior to that of boil-and-bite mouthguard. The boil-and-bite mouthguard is often unstable (Duarte-Pereira et al. 2008). Similar to dentures, the tongue of the wearer of a loose mouthguard has two functions, that is, participate in speech articulation and control the appliance. When the appliance is loose, there is a greater demand for the latter function, thereby resulting in the deterioration in the quality of speech (Laurina & Soboleva 2006).

Apart from retention and stability, the oral appliance's thickness can also affect speech. For instance, in patients with bonded lingual appliances, the smaller lingual appliances are associated with less pronounced speech impairment (Hohoff et al. 2003). In fact, irregularity in the material distribution in boil-and-bite mouthguard is one of the major drawbacks (Duarte-Pereira et al. 2008). A uniform thickness of 4 mm was ascertained in the custom-fitted mouthguards, whereas the thickness of the boil-and-bite mouthguards could not be controlled. This reflects the real-life situation in which custom-fitted mouthguards are made in the dental laboratory, whereas boil-and-bite mouthguards are softened and moulded by the consumers. We observed that some of the boil-and-bite mouthguards are thick at the anterior midline portion but become thinner at the posterior region after fitting. Predictably, the plosive sounds are distorted because the movement of the tongue and lips are restricted.

The extension of the palatal margin of the mouthguard affects the pronunciation of certain sounds. When the assessment was conducted using the aeroacoustic method, a significant distortion of fricative sound was found as the palatal margin was set 4 mm away from the gingival line (Nozaki et al. 2013). The palatal margins of the custom-fitted mouthguards were limited to the cervical area of the palatal surface of the upper teeth. In contrast, the palatal margin of the boil-and-bite mouthguard was inconsistent and was generally farther away from the cervical area of the palatal surface of the upper teeth. This might affect the alveolar-dental plosive sounds (/t, d/).

LIMITATIONS

Although randomisation was planned, unfortunately, a mix-up of mouthguards and models occurred during delivery; therefore, the code was broken to fit the mouthguards to the appropriate owners. This could introduce the 'order effect'. The order of intervention could affect the outcome. For instance, speech adaptation could occur after fitting the first mouthguard (boil-and-bite); hence, the speech was less distorted when using the second mouthguard (custom-fitted). Nonetheless, the short wearing time and speech recording period and a washout interval of one hour should be sufficient to counteract this.

The participants were asked to pronounce single words instead of phrases or sentences. Furthermore, only plosive sounds were assessed. Hence, the findings could not be extrapolated to the overall speech quality of mouthguard users.

Speech was immediately recorded after fitting of a mouthguard; thus, the participants did not have adequate time to adapt fully to the newly prescribed mouthguard. Whether the magnitude of the articulatory distortion is dependent on the duration between the placement of the mouthguard intra-orally and the speech assessment is unclear. Adaptability was shown in a study testing the use of orthodontic retainers, where articulatory distortion was reduced significantly after seven days of use (Haydar et al. 1996). It is also unclear whether users of boil-and-bite mouthguards and custom-fitted mouthguards differed in adaptability over time. Further research in this matter would provide valuable knowledge in advocating the use of sports mouthguards.

CLINICAL IMPLICATIONS

Compliance of mouthguard use depends on the users' ability to breathe and speak while wearing a mouthguard (Çetinbaş & Sönmez 2006). Malaysian university rugby players who mostly used boil-and-bite mouthguards discontinued using them after complaining of general discomfort and speech disturbance (Liew et al. 2014). In contrast, custom-fitted mouthguards are preferable

because these maintain oral moistness and improve adaptation, thereby causing less interference with respiration and speech (Duarte-Pereira et al. 2008). The present study provides a rationale for dentists to objectively recommend and counsel the patients who are involved in contact sports on how to use a mouthguard. Initial articulatory distortion is unavoidable; nevertheless, these patients can choose to use a custom-fitted mouthguard instead of a boil-and-bite mouthguard to minimise sound distortion.

TABLE 1. Median and interquartile range (IQR) of mean voice onset time (millisecond) for /p, b, d, t/

Plosive sounds	No MG	BB MG	CF MG	No MG vs BB MG vs CF MG	No MG vs BB MG	BB MG vs CF MG	No MG vs CF MG
	Median (IQR)	Median (IQR)	Median (IQR)	*P*-value	*P*-value	*P*-value	*P*-value
/p/	11.60 (1.92)	27.52 (1.91)	21.85 (1.97)	<.001*	<.001**	<.001**	<0.001**
/b/	42.80 (2.56)	57.62 (1.14)	49.81 (1.24)	<.001*	<.001**	<.001**	<0.001**
/d/	41.59 (2.07)	56.31 (1.59)	50.29 (1.76)	<.001*	<.001**	<.001**	<0.001**
/t/	17.73 (2.36)	56.68 (2.16)	51.33 (1.63)	<.001*	<.001**	<.001**	<0.001**

* indicates statistical significance of Friedman test ($P < .05$). ** indicates statistical significance of the Wilcoxon signed-rank test with Bonferroni correction ($P < .017$).
Abbreviation: MG – mouthguard, BB – 'boil and bite', CF – custom-fitted

CONCLUSION

Although articulation of plosive sounds was distorted when boil-and-bite and custom-fitted mouthguards were used, it was more notable in the boil-and-bite mouthguards.

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