Original Article

Modification of cognitive function induced by a functional orthodontic device

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Abstract

Chewing is one of the most important orofacial functions. Over the last twenty years, a number of authors have examined the correlation between an efficient chewing function and different aspects of body functions: implementation of cognitive functions, reduction of nociceptive impulse propagation, reduced levels of stress, reduced risk of developing atherosclerosis and desaturation, limitation of eating disorders and constipation. Starting from the above considerations, this study aims at investigating the correlation between occlusal balance – without which there would be no proper mastication – and fundamental aspects as cognitive function, stress, arousal and concentration. For this purpose, we used specific tools and software to observe the electrical activity of the brain in 10 healthy volunteers. All the measurements for each participant have been carried out in three different phases: a first phase in which all the individuals were in a condition of initial occlusion; a second phase in which the occlusion was modified using a functional orthodontic device; and a third phase, in which individuals removed the device. The variations between three phases have been evaluated by using the Student's t-test, and we considered them significant for p<0.05. The results have highlighted a significant variation in terms of stress, arousal and concentration among the three phases.

Keywords: cognitive function 1; elastodontic appliances 2; chewing 3

Introduction

Chewing is essential for the appropriate nutrition of every person, for both physical and mental well-being. However, chewing is guaranteed only by the presence of most or all dental elements, by a balanced intercuspation and proper intraoral and extraoral muscular function.

In the field of functional orthodontics, mastication can activate specific muscular groups, influencing trophism of the bone segment which these muscles are inserted in [1] or originate from [2].

Furthermore, several theories suggest that the stomatognathic apparatus can be meant as an "access door" to the whole body. The lack of occlusal balance might have negative repercussions on different body locations, and one may presume that recovering a proper masticatory function seems to be associated to the resolution of numerous pathologies and diseases.

In the last two decades, literature has sought to examine the correlation between an impaired mastication and structural alterations of all those cerebral areas that are involved during chewing. Masticatory performance could be linked in a relationship of direct proportionality to cerebral blood flow [3,4], to cerebral oxygenation, to gray volume matter (GMV) and to the number of interconnections between different cerebral areas [5]. In elderly individuals, with an inadequate number of dental elements, the cerebellar and motor cortex GMV undergoes a significant reduction, as well as a dorsolateral prefrontal cortex (DLPFC), which is physiologically involved in cognitive processes and in the expression of personality. Based on findings, it is not difficult to understand how advancing age is, in most cases, associated with a loss of the cognitive function [6,7].

The use of functional connectivity magnetic resonance imaging (fcMRI) allows to highlight the brain areas mainly involved during chewing. In particular, there seems to be a connection between the motor cortex and the post-central gyrus, the cingulate and precuneus cortex, as well as the cerebellum, with the bilateral sensory-motor cortex, the superior temporal gyrus and the superior cingulate left cortex. Deficient chewing can suppress the proliferation of dentate gyrus cells [8] and trigger hippocampal degeneration [9], resulting in impaired spatial memory [10]. A limited number of dental elements seems to be linked to worsened cognitive-attentive functions in patients affected by Alzheimer's disease [11]; it also seems to be connected with impaired learning ability, related to degeneration of periodontal mechanoreceptors, with a consequential suppression of sensory feedback, which becomes rather insufficient and can cause central atrophy [8]. Moreover, because of human connectome, there might be a correlation between the Broca praxic language area and the area of the motor mastication and swallowing control in brain cortex; hence, language skills and feeding quality could be interconnected [12].

In addition to cognitive functions, several studies have highlighted the interdependence between higher levels of trigeminal stress and nociception suppression, with

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rising levels of serotonin and norepinephrine in the blood [13,14], reduced stress and salivary cortisol [15,16], greater alertness and concentration [17-19], alleviation of depression [20] and improvement in coordination and posture [21,22].
Finally, other authors have examined the relation among impaired chewing and atherosclerosis [23], decreased gastrointestinal motility [24], and higher incidence of chronic obstructive pulmonary disease [25].
On the other hand, an adequate number of dental elements would seem to reduce obesity incidence, thanks to the stimulation of lipolysis in the visceral adipose tissue and a better satiety state because of the activation of histaminergic fibers of the hypothalamus' ventromedial [26]. Moreover, Kimura et al. have underscored the reduced incidence of anorexia disorders [27].
Based on the above considerations, the following study aims at exploring the correlation between the use of an orthodontic device (i.e. functional activator) and variations in terms of cognitive function, stress, alertness and concentration.

Materials and Methods

For the study, 10 volunteers were recruited, including 7 males and 3 females, aged between 22 and 30, with an average age of 27.7 yrs (± SD 2.6). At the time of measurements, none of the individuals was undergoing orthodontic treatment. No temporomandibular joint disorders nor degenerative disorders affecting the nervous system were recorded.
Each patient was asked to wear the *Emotiv Pro+* helmet, a device that can detect brain electrical activity, returning a sort of electroencephalographic outcome. The device consists of 2 sensors, which must be positioned in the retro-auricular region, in correspondence with the mastoid process of the temporal bone, and 14 sponge electrodes, screwed to the end of each arm of the headset; the latter must adhere to the scalp, corresponding to the main brain areas (Figure 1), to allow the uptake of neuronal electrical signals. To monitor the percentage of contact between the helmet and the scalp – which should range between 98% and 100% to be optimal and reliable, and to obtain useful data for experimental purposes - the *Emotiv BCI* software was used.
Thanks to its *Performance Metrics*, the function measures six cognitive conditions on a Time-Value graph: "stress" (FRU), "engagement" (ENG), "interest" (VAL), "focus" (FOC), "excitement" (EXC), "relaxation" (MED). "Stress" refers to the degree of comfort experienced by the individual at the time of measurement. The "engagement" condition indicates the extent of the state of alertness and attention to external stimuli. "Interest" is nothing more than the amount of attraction or aversion to existing stimuli. "Focus" expresses the degree of concentration stability. "Excitement" reflects a physiological state of "arousal", or rather activation of the sympathetic nervous system. Finally, "relaxation" indicates the ability to recover after an intense concentration phase. The changes in the values of such conditions were monitored and recorded in three distinct phases, each lasting 10 minutes: phase 1) the subject was observed at rest, before using the activator (Figure 2); phase 2) the subject was monitored during the use of the activator; phase 3) data was collected at rest, after activator removal. For the experiment, a U4 activator was used, at a low level, both in the body and in the shields, for several reasons: to avoid bulkiness, minimize discomfort and measurement distortion, to guarantee a neutral action, thanks to its advancement wall built in class I.
Data for each phase was recorded every 10 seconds; in turn, at the end of the experiment, 60 values per phase were recorded for each subject. The value average of all subjects enabled to obtain a single reference parameter for each cognitive condition in each phase. Hence, it was possible to compare phase 1 with phase 2, phase 2 with

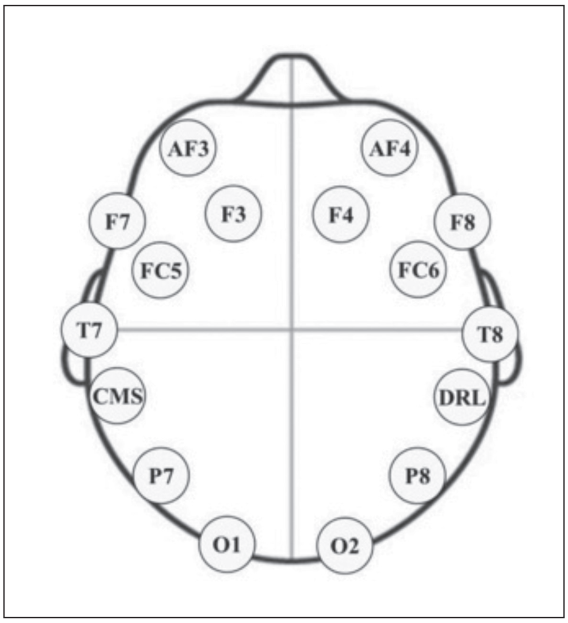

Figure 1. AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 are the brain areas where the sponge electrodes are positioned. DRL and CMS indicate the position of the control electrodes.

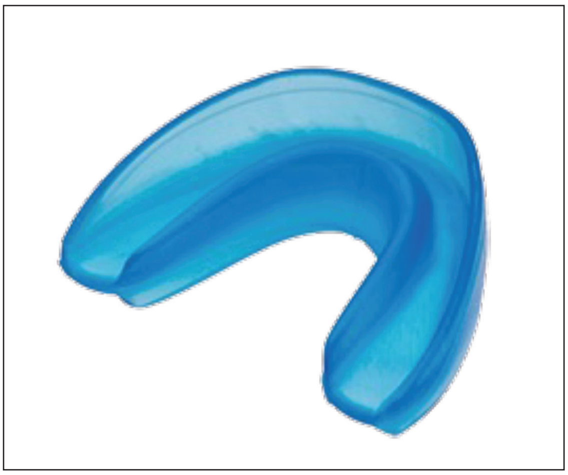

Figure 2. The activator is a removable elastomeric material device, the "fulcrum" of functional orthodontic treatment based on dentosophy. It consists of a single block which contacts both arches, and it is equipped with vestibular, palatal and lingual shields, through which the proper balance between extrinsic forces – i.e. perioral musculature – and intrinsic forces – i.e. tongue - is restored; this way, maxillary growth is properly oriented. Moreover, by using such device, it is possible to re-educate neurovegetative functions such as swallowing, phonation, chewing and breathing.

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phase 3, phase 3 with phase 1. For this purpose, the "p" significance of variations was considered using a *Student's t-test*. To be considered significant, the variation value was to be p value < 0.05. All measurements were carried out by a single operator.

Results

To compare phase 1 with phase 2, phase 2 with phase 3, phase 3 with phase 1, the average values of each cognitive condition were calculated in each of the three phases. The significance of the variations between the phase pairs was assessed by means of the Student's t-Test distribution. Comparing phases 1 and 2 (Table 1), no significant changes were recorded across the six conditions ($p > 0.05$). On the other hand, comparing phases 2 and 3 (Table 2), although the variations in "stress", "engagement" and "interest" were not statistically significant, the conditions "focus", "excitement" and "relaxation" assumed significance ($p < 0.05$). Also comparing phase 3 with phase 1 (Table 3), for both "focus" and "excitement" significant values were recorded; the same cannot be said for the other four conditions.

Discussion

In particular, "relaxation" was recorded as more remarkable in phase 3 (Figure 3). A possible explanation could be that the insertion of the activator, in phase 2, as a new variable in the stomatognathic system led to an increase of the muscular function of the patient and, consequently, an impairment in terms of relaxation, though

Table 1. *Comparison table between T0 (phase 2) and T1 (phase 1).*

VARIABLES	T0		T1		T1-T0	
	Average	DV	Average	DV	Average	t Test (p)
FRU	39,177	10,570	45,203	14,835	6,026	0,120 *
ENG	61,812	8,281	64,403	10,096	2,591	0,414 *
VAL	55,301	5,141	57,173	9,816	1,872	0,634 *
FOC	25,955	9,140	28,384	11,434	2,429	0,578 *
EXC	39,942	5,990	41,427	5,540	1,485	0,571 *
MED	26,793	9,210	30,736	11,612	3,943	0,182 *

** Student's t-Test. Bold indicates statistically significant difference.*

Table 2. *Comparison table between T0 (phase 3) and T1 (phase 2).*

VARIABLES	T0		T1		T1-T0	
	Average	DV	Average	DV	Average	t Test (p)
FRU	45,169	14,825	39,177	10,570	-5,99	0,360 *
ENG	58,017	7,719	61,812	8,281	3,795	0,106 *
VAL	60,427	6,225	55,301	5,141	-5,126	0,112 *
FOC	38,542	12,478	25,955	9,140	-12.587	**0,011 ***
EXC	47,331	4,849	39,942	5,540	-7,389	**0,026 ***
MED	31,870	11,740	26,793	9,210	-5,077	**0,045** *

** Student's t-Test. Bold indicates statistically significant difference.*

Table 3. *Comparison table between T0 (phase 1) and T1 (phase 3).*

VARIABLES	T0		T1		T1-T0	
	Average	DV	Average	DV	Average	t Test (p)
FRU	45,203	14,835	45,169	14,825	-0,034	0,995 *
ENG	64,403	10,096	58,017	7,719	-6,386	0,093 *
VAL	57,173	9,816	60,427	6,225	3,254	0,176 *
FOC	28,384	11,434	38,542	12,478	10,159	**0,035** *
EXC	41,427	5,540	47,331	4,849	5,904	**0,052** *
MED	*30,736*	*11,612*	*31,870*	*11,740*	*1,134*	*0,727 **

** Student's t-Test. Bold indicates statistically significant difference.*

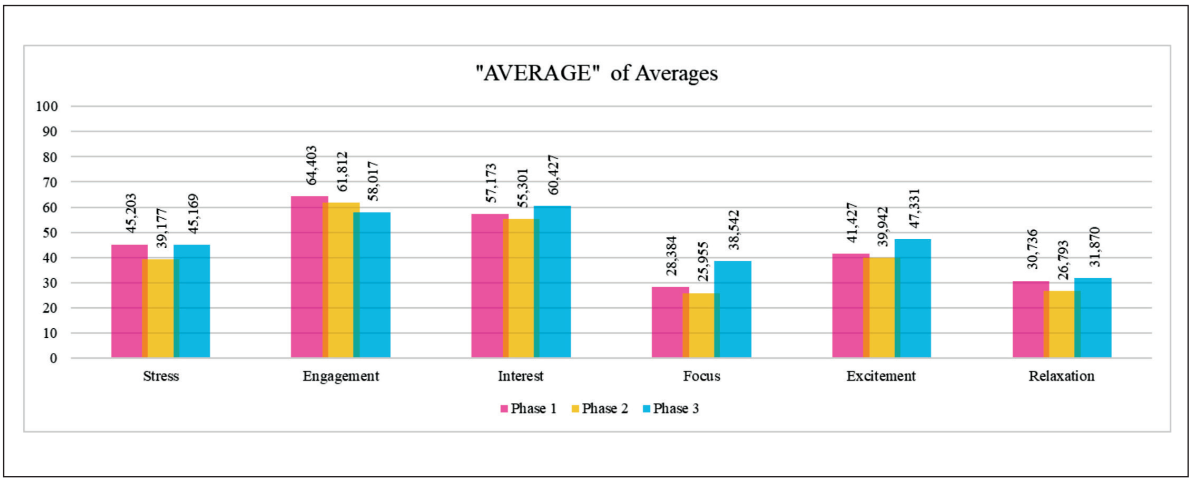

Figure 3. Histogram showing the mean values of each patient for each condition. The values in phase 1 are shown in pink, those in phase 2 in yellow, those in phase 3 in blue. The conditions we are most interested in are those that have shown significance in the variations between the phases in the previous tables, i.e. "focus", "excitement" and "relaxation". All three significantly reduce in phase 2, but only "focus" and "excitement" significantly increase in phase 3, after removing the activator. This could support the hypothesis that the occlusal balance is correlated with the systemic one, and that the functional activator, by restoring the occlusal balance, might have some repercussions at the systemic level, specifically on the cognitive sphere.

quite statistically imperceptible, at $p > 0.05$ comparing phases 1 and 2. However, after removing the activator, the values increased again with a significant variation, as can be seen from the comparison between phase 2 and phase 3; this would indicate an increase in the relaxation level of the subject as the device is removed. Indeed, most patients in the sample reported having perceived somewhat muscle soreness by the end of the experiment, associated with a sense of relief upon activator removal.

On the other hand, "focus" and "excitement" reported different results. Both being part of the cognitive sphere, these conditions significantly increased from phase 2 to phase 3. This would suggest that a modification of the proprioceptive inputs, which are centrally transmitted, can be associated with a variation of the cognitive function, thus confirming a theory supported by several authors, including Sakamoto. In one of his studies, the latter showed how the reaction time to the auditory oddball paradigm substantially decreased in the phase immediately after the end of a chewing exercise [7]. Similarly, in a study conducted by Wilkinson, the author explained that chewing gum can raise a subject's learning skills [28]. Kawakami too highlighted a reduced reaction time to the Stroop test during a gum chewing exercise [3]. Furthermore, introducing the concept of dentosophy, Montaud hypothesized the existence of an interdependence between occlusal balance and systemic balance [29].

Concerning "relaxation", removing the device reduces muscular activation due to the thickness of the utilized material. Such thickness generates greater muscular activity while the system tends to adapt to the greater occlusal vertical dimension. On the other hand, device removal reduces temporary fatigue as "relaxation" increases between phases 2 and 3. The most relevant difference across measurements appears upon device removal rather than during its use. This might suggest that the device's effect manifests over time and not immediately. Indeed, we have recorded significant differences in terms of "focus" and "excitement" between phases 2 and 3, as well as between phases 1 and 3. Hence, one can presume that the activator's use, combined with the crunching muscular activity, generates a proprioceptive stimulus that raises both "focus" and "excitement". Consequently, once activator use is completed, cortical activity increases, raising attention and concentration levels in turn.

Conclusions

Therefore, considering the collected data, the variables of concentration, excitement and relaxation are the aspects undergoing the most significant variation. Among these, the ones that draw our attention are "focus" and "excitement": they significantly increased in phase 3 – compared to phase 2, in which the activator was inserted in the mouth, but also considering the initial situation represented by phase 1 – they suggest that the device can actually trigger a change in the cognitive function, identified in the increased ability to concentrate and pay attention to external stimuli. Moreover, it is possible to continue to hypothesize a link between the use of the functional activator – and the related occlusal balance and benefits for brain activity. It is worth highlighting the fact that only 10 patients were observed in the study. One can assume that by expanding the sample, even those variations that have reached values not far from significance – such as "engagement" between phase 2 and phase 3 – one can reach a $p < 0.05$. Further studies are required to gain more insightful data.

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