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Influence of controlled masticatory muscle activity on dynamic reactive balance

Cagla Fadillioglu[1] | Lisa Kanus[2] | Felix Möhler[1] | Steffen Ringhof[3] | Hans J. Schindler[2,4] | Thorsten Stein[1] | Daniel Hellmann[2,5]

[1]BioMotion Center, Institute of Sports and Sports Science, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

[2]Department of Prosthodontics, University of Würzburg, Würzburg, Germany

[3]Department of Sport and Sport Science, University of Freiburg, Freiburg, Germany

[4]Research Group Biomechanics, Institute for Mechanics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

[5]Dental Academy for Continuing Professional Development, Karlsruhe, Germany

Correspondence
Cagla Fadillioglu, BioMotion Center, Institute of Sports and Sports Science, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany.
Email: cagla.fadillioglu@kit.edu

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Abstract

Background: The influence of the stomatognatic system on human posture control has been investigated under static conditions, but the effects on dynamic balance have not yet been considered.

Objective: Investigating the influence of different functional stomatognatic activities (jaw clenching (JAW), tongue pressing (TON) and habitual jaw position (HAB)) on postural performance during a dynamic reactive balance task.

Methods: Forty-eight physically active and healthy adults were assigned to three groups differing in oral-motor tasks (JAW, TON or HAB). Dynamic reactive balance was assessed by an oscillating platform which was externally perturbed in four directions. Performance was quantified by means of Lehr's damping ratio. Mean speeds of the selected anatomical regions (head, trunk, pelvis, knee and foot) were analysed to determine significant performance differences.

Results: The groups differed significantly in balance performance in direction F (i.e., forwards acceleration of the platform). Post hoc tests revealed that the JAW group had significantly better performance compared with both the HAB and TON groups. Better performance was associated with a decreased mean speed of the analysed anatomical regions.

Conclusion: JAW can improve dynamic reactive balance but the occurrence of positive effects seems to be task-specific and not general. TON seems not to have any observable effects on dynamic reactive balance performance, at least when evaluating it with an oscillating platform. JAW might be a valuable strategy which could possibly reduce the risk of falls in elderly people; however, further investigations are still needed.

KEYWORDS
jaw clenching, perturbation, postural control, posturomed, stomatognatic system, tongue pressing

Thorsten Stein and Daniel Hellmann contributed equally to this work.

1 | INTRODUCTION

Posture control has a vital role in human daily life. It ensures that movements are initiated and executed in an optimal manner both in static and in dynamic conditions (e.g., upright standing and locomotion, respectively).[1] It involves controlling the body's position with respect to the environment for the dual purposes of stability and orientation.[1] Multiple sensory signals from visual, somatosensory and vestibular systems acting on the spinal and supraspinal structures of the central nervous system (CNS) are used to detect and correct instability in posture and to ensure balance.[2] Depending on the balance task at hand, the CNS adapts the weighting and thereby the relative importance of sensory signals. Finally, the sensory information must be transformed into motor commands to ensure the body's balance in a task-specific manner. However, the functioning of these underlying postural control mechanisms is not yet fully understood.[1,3] Impaired postural control may lead to a reduced participation in daily life, an increased risk of falls and even to increased mortality risk.[4]

The significance of the abovementioned sensory systems shows that postural control may also be influenced by motor activity in the masticatory system.[5] There are a variety of studies indicating an influence of stomatognatic motor activity in the form of chewing, tongue activity or different clenching conditions in different jaw relations on human balance and posture under static conditions.[5–12] This means, in particular, a reduced body sway in the anterior–posterior direction,[8] a reduced variability of muscular co-contraction patterns of posture-relevant muscles of the lower extremities and reduced trunk and head sway under the influence of controlled biting activities.[9] This might be interpreted as a body sway stabilising effect. These facts in conjunction with the observations of an improved responsiveness to auditory and visual stimuli,[13] and relevant effects on force development[14] under the influence of biting activities might be of clinical relevance for the prevention of falls in elderly people. For this group, there is evidence for an increased risk of falling resulting from an insufficient dental or prosthetic status.[15,16]

There are several possible explanations for the measured effects of masticatory muscle activity on posture control. First, this could be explained by the stimulation of periodontal receptors or by the different proprioceptive input due to different jaw relations that are centrally integrated along with other sensory input.[17] It is also conceivable that the motor activity in the masticatory system facilitates the excitability of the human motor system in a manner similar to the Jendrassik manoeuvre,[18] which in turn increases the neural drive to the distal muscles.[19,20] A challenge in interpreting the results of these studies is the methodological heterogeneity and the phenomenon of interactions between postural and cognitive tasks, shown in physiological and neurocognitive studies.[21] Therefore, an integrative interpretation of the results appears difficult. However, a variety of neuromuscular interactions, for instance synchronised extension–flexion movements of the head during jaw-opening/closing cycles,[22] substantially increased amplitudes of the human soleus H-reflex during voluntary teeth clenching,[17,23] neck muscle reflex responses triggered by trigeminal stimulation[24,25] and co-contractions of the masticatory and neck muscles[26,27] are also evidence for the close functional integration of the masticatory system in human motor control processes. The neuroanatomical basis for all these phenomena was shown in animal models in the form of numerous neuroanatomical connections of the trigeminal nerve within the brainstem, and projections to all levels of the spinal cord.[28,29]

As mentioned above, the influence of the masticatory system on human posture control has been investigated under static conditions. The studies showed that oral-motor activities such as jaw clenching may contribute to increased postural stability, represented in terms of decreased postural sway in upright bipedal und unipedal standing.[8–11] To the best of our knowledge, the effects of motor activity of the masticatory system on dynamic balance have not yet been investigated in depth.[11]

Therefore, the aim of this study was to investigate the influence of different functional stomatognatic activities on postural performance during a dynamic reactive balance task, which was operationalised with an oscillating platform perturbed in different directions. It was hypothesised that jaw clenching (JAW) and tongue pressing (TON) would influence dynamic reactive balance performance. These changes in task performance were hypothesised to be associated with specific adaptations in the segmental kinematics of the human body. The results of this study may contribute to the understanding of postural control mechanisms, particularly in conjunction with the masticatory system, and might bring up initial hypotheses as to whether masticatory muscle activity might reduce the risk of falls.

2 | METHODS

2.1 | Participants

Forty-eight physically active adults (25 female, 23 male; age: 23.8 ± 2.5 years; height: 1.73 ± 0.09 m; body mass: 69.2 ± 11.4 kg) participated in the study. Their dominant legs were determined based on self-reports or, in case of uncertainty, by means of test trials on the oscillating platform.[30] All participants gave written informed consent prior to the study. They confirmed that they were physically active (participating in any kind of sports regularly, at least 3 times per week), naive to the Posturomed task and had no muscular or neurological diseases. They had also no signs and symptoms of temporomandibular disorders (assessed by means of the RDC/TMD criteria)[31] and presented with full dentition (except for 3rd molars) in neutral occlusion. The study was approved by the Ethics Committee of the Karlsruhe Institute of Technology.

2.2 | Experimental procedure

2.2.1 | Balance tasks

Dynamic reactive balance was assessed by use of an oscillating platform, the Posturomed (Haider-Bioswing, Weiden, Germany). This commercial device consists of a rigid platform (12 kg, 60 cm × 60 cm) and eight 15-cm steel springs of identical strength and can swing along the horizontal plane in all directions. The Posturomed has previously been used in scientific studies to systematically investigate dynamic reactive balance performance after perturbations.[32,33] In the present study, an automatic custom-made release system was used to slowly displace the Posturomed horizontally (up to 2.5 cm) in one of the four possible directions: back (B), front (F), left (L), right (R). The directions used here indicate, by convention, the direction to which the platform was accelerated after release (e.g., B indicates that the platform was accelerated backwards after release, which led to anterior body sway relative to the platform).

The perturbations were applied randomly in one of the four directions. The participants' task was to compensate the perturbation as quickly as possible. Before each trial, participants were asked to stand on the platform on their dominant leg, with hands placed at their hips, eyes focusing at a target whose height was adjusted to their eye level in advance and which was horizontally 4 m away from the centre of the platform. Trials were considered invalid if participants quitted performing their oral-motor task (JAW and TON), had ground contact with the non-standing foot, changed the placement of their standing foot, and released one of the hands from the hip or lost their balance.

2.2.2 | Group assignment and oral-motor tasks

For the assignment, each of the 48 participants had a familiarisation period on the Posturomed consisting of two static trials and two trials with perturbation. Afterwards, a baseline measurement with perturbation and in habitual biting condition was performed to determine the initial balance performance based on Lehr's damping ratio (DR).[32] Based on the subjects' baseline performance value and gender, a balanced assignment to the three groups was ensured such that the initial level of performance difference between groups was minimised. The statistical examination by means of a one-way analysis of variance (ANOVA) revealed no baseline performance differences between the three groups ($p = .767$). The three groups each consisting of 16 participants had to concurrently fulfil one of the following oral-motor tasks during each trial of the experiment:

- JAW: instructed, controlled submaximal jaw clenching—activity of the masticatory muscles during simultaneous occlusal loading,
- TON: instructed, controlled submaximal tongue pressing against the palate—stomatognatic muscle activity without occlusal loading,
- HAB: habitual stomatognatic behaviour—jaw positioning without any instruction.

The respective oral-motor activity was measured by means of EMG recordings (detailed information in the "Data collection" section). As a reference, the JAW group were trained in submaximal jaw clenching at a force of 75 N by use of a RehaBite® (Plastyle GmbH), a medical training device consisting of liquid-filled plastic pads and working based on hydrostatic principles,[34] just before the measurements. During the training, EMG activity was monitored and training ended once the participant achieved a consistent biting force at 75 N (resulting in a mean EMG activity of about 5% maximum voluntary contraction, MVC). The corresponding EMG level of biting activity was used later to determine whether the submaximal jaw clenching condition was met during the experiment. During the balance task measurements, the JAW group performed the clenching task on an Aqualizer® intra-oral splint (medium volume; Dentrade International, Cologne, Germany). The TON group also received training, which consisted of applying a submaximal force with the tip of the tongue against the anterior hard palate. For TON, the training ended once the participants achieved a consistent EMG activity at 5% of their MVC, measured in the region of m. digastricus venter anterior. For both groups, training for the oral-motor task lasted approximately 5 min. The HAB group did not receive any training or instructions.

2.2.3 | Data collection

A wireless EMG system (Noraxon) operating at 2000 Hz was used to measure EMG activity of the masseter for JAW and HAB and of the suprahyoid muscles of the floor of mouth (FoMM) for TON, measured in the region of the digastricus venter anterior muscle. The skin over the corresponding muscles was carefully shaved, abraded and rinsed with alcohol. Bipolar Ag/AgCl surface electrodes (diameter 14 mm, centre-to-centre distance 20 mm; Noraxon Dual Electrodes, Noraxon) were positioned and oriented bilaterally in accordance with the European Recommendations for Surface Electromyography.[35] Afterwards, MVC tests were performed.

Movements of the Posturomed platform and the participants were captured by a 3-D motion capture system (Vicon Motion Systems; Oxford Metrics Group, Oxford, UK; 10 Vantage V8 and 6 Vero V2.2 cameras with a recording frequency of 200 Hz). Four reflective markers were fixed on the upper surface of the platform. Twenty reflective markers were attached to the participants' skin as shown in Figure 1.

After training for the oral-motor task (except for the HAB group), balance task measurements began. Participants repeatedly stood on the platform, as described in the section "Balance tasks," and trials were recorded for 30 s. Between each trial, participants had 2 min of resting time to prevent fatigue. Measurements ended once the participants completed 12 valid trials, three for each direction.

2.3 | Data analysis

In total, 576 trials (48 participants, three valid trials for each of the four directions) were analysed. All data were recorded in Vicon Nexus 2.10 and exported for further processing in MATLAB R2020a (MathWorks).

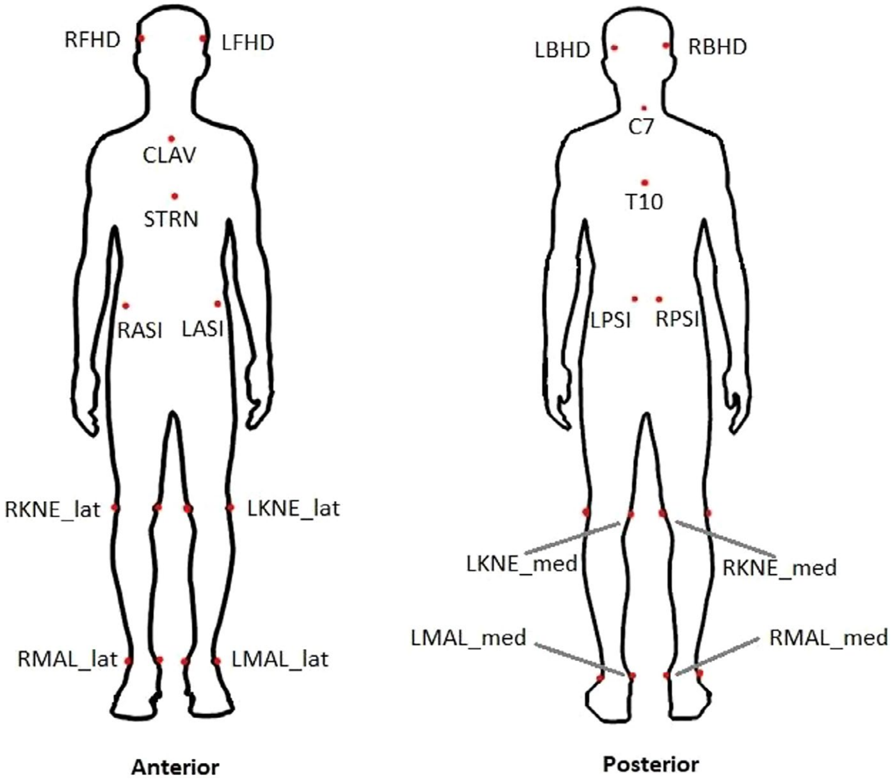

FIGURE 1 Reflective markers used for the five anatomical regions (ARs)

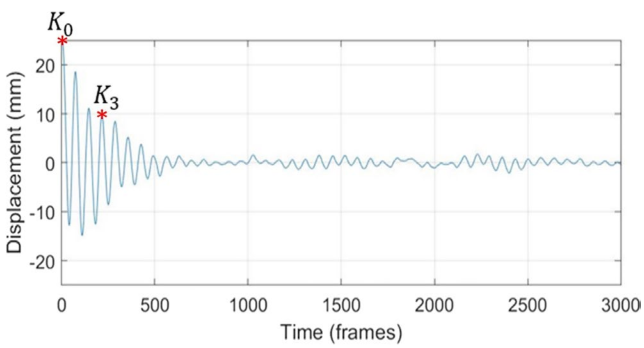

FIGURE 2 Damping ratio calculation. Initial maximum displacement (K_0) and the third positive amplitude (K_3) are shown

Marker data were filtered by use of a fourth-order Butterworth low-pass filter with a cut-off frequency of 10 Hz. Raw EMG data were filtered from 10 to 500 Hz by use of a fourth-order Butterworth band-pass filter, rectified and smoothed using a sliding average with a window frame of 30 ms and normalised to the MVC amplitudes.[9]

To determine the respective mean EMG activities of the measured stomatognatic muscles before and after perturbation, two time windows were used. *Before*: from 2500 ms before the perturbation until the beginning of the perturbation; *After*: from the beginning of the perturbation to the third maximum amplitude (Figure 2), which corresponds to the DR window. The EMG activity of the measured stomatognatic muscles before and after perturbation for three trials for each direction and for each subject was averaged. Finally, R and L directions were re-sorted into ipsilateral (I) and contralateral (C) according to the standing leg of the participants.

Using the Posturomed marker data, DR (Eq. 1)[32] was calculated for each trial to evaluate the dynamic reactive balance performance. DR is a parameter that relates the actual damping to the critical damping value at which the system does not oscillate. It was calculated for the third amplitude (Figure 2) as suggested by Kiss et al.[32] In other words, DR in the present study quantified how well the platform was stabilised within the first three oscillations, with larger DR values representing stronger damping and thus better compensation of the perturbation.

In addition to DR as a measure of the performance, segmental kinematics were studied to analyse the underlying movement patterns. Similar to Ringhof et al.,[10] the body was divided into five anatomical regions (ARs; head, trunk, pelvis, knee and foot). For each AR, the centres were calculated using the markers shown in Figure 1 (head = RFHD, LFHD, RBHD, LBHD; trunk = CLAV, STRN, C7, T10; pelvis = RASI, LASI, RPSI, LPSI; knee = RKNE_med, RKNE_lat or LKNE_med, LKNE_lat; foot = RMAL_med, RMAL_lat or LMAL_med, LMAL_lat). The resulting path lengths in 3D were calculated for the time window defined by the DR. Since the size of this time window is trial-specific, each path length of an AR was divided by the corresponding time window for each subject and trial. This ultimately corresponds to the mean AR speed.

$$DR_i = \frac{\wedge}{\sqrt{\wedge_i^2 + 4\pi^2}}; \text{ where } \wedge_i = \frac{1}{3}\ln\frac{K_0}{K_i},\ K_i\text{: } i^{th} \text{ positive amplitude} \quad (1)$$

TABLE 1 Damping ratio (DR) for all groups and directions and the corresponding ANOVA results

DR	Jaw clenching (JAW)	Tongue pressing (TON)	Habitual (HAB)	p	η_p^2
B	0.062 ± 0.003	0.055 ± 0.003	0.055 ± 0.003	.226	0.064
F	0.066 ± 0.003	0.046 ± 0.003	0.049 ± 0.003	**<.001**	**0.349**
I	0.045 ± 0.003	0.046 ± 0.008	0.048 ± 0.005	.920	0.004
C	0.043 ± 0.005	0.040 ± 0.004	0.037 ± 0.004	.607	0.022

Note: DRs are given as mean ± standard deviation. Significant differences are highlighted in bold ($p < .05$). Partial eta squared of < 0.06, 0.06–0.14, and >0.14 indicate small, medium, and large effects, respectively.

Abbreviations: B, backward; C, contralateral; F, forward; I, ipsilateral.

2.4 | Statistics

IBM SPSS Statistics 25.0 (IBM Corporation) was used to perform statistical tests. Performance parameters (DR) and kinematics parameters (mean AR speed) for three trials for each direction and for each subject were averaged. Kolmogorov-Smirnov and Mauchly's sphericity tests were conducted to confirm the normality and sphericity of data distribution, respectively. Greenhouse–Geisser estimates were used to correct for violations of sphericity.

Each of the four perturbation directions was analysed separately for performance evaluation since postural response may differ depending on the perturbation direction.[33,36–39] For each direction, a one-way ANOVA was performed to compare the groups' balance performances. For the segmental kinematics, a two-way ANOVA [5 ARs × 3 groups] was calculated if significant results were present at the performance level. Tukey post hoc tests were performed in case of significant differences. The level of significance for all statistical tests was set *a* priori to $p < .05$. Partial eta-squared (small effect: $\eta_p^2 < 0.06$; medium effect: $0.06 < \eta_p^2 < 0.14$; large effect: $\eta_p^2 > 0.14$)[40] and Cohen's d (small effect: d < 0.50; medium effect: d = 0.5–0.8; large effect d > 0.8)[41] were calculated as measures of effect size for ANOVA and post hoc tests, respectively.

3 | RESULTS

3.1 | Oral-motor task

All participants in each group fulfilled their individual oral-motor task, in the sense that it was performed before the perturbation and during their balance recovery.

- JAW: mean EMG activity of the musculus masseter was 5.59 ± 3.72% MVC before perturbation and 4.89 ± 3.04% MVC after perturbation.
- TON: all participants showed a mean EMG activity of 3.96 ± 2.35% MVC of the FoMM before the perturbation, and of 3.44 ± 2.06% MVC after perturbation.
- HAB: 3 of the 16 participants showed consistent habitual clenching mean EMG activity of the musculus masseter of 6.12 ± 3.30% MVC before perturbation and 6.39 ± 2.64% MVC after perturbation. The remaining 13 participants consistently showed a constant resting EMG activity of the musculus masseter of 0.31 ± 0.22% MVC before perturbation and 0.34 ± 0.29% MVC after perturbation.

3.2 | Dynamic balance performance

The mean time window of DR was 1.13 ± 0.01 s. The ANOVA results revealed that groups had significantly different performances in direction F (forwards acceleration of the platform after release) with a high effect size ($p < .001$, $\eta_p^2 = 0.349$). According to the post hoc test results, the JAW group had a significantly higher DR compared to both HAB ($p = .001$, d = 1.03) and TON ($p < 0.001$, d = 1.40) groups with high effect sizes.

There were no significant differences in the remaining directions (B: $p = .226$, $\eta_p^2 = 0.064$; I: $p = .920$, $\eta_p^2 = 0.004$; C: $p = .607$, $\eta_p^2 = 0.022$). The statistical results as well as the mean and the standard deviation of DRs for each group and each direction are shown in Table 1.

3.3 | Segmental kinematics

Segmental kinematics were analysed for direction F because it was the only direction that showed a significant difference between groups. The results of two-way ANOVA [5 ARs × 3 groups] revealed a significant group effect with a medium effect size ($p < .001$, $\eta_p^2 = 0.09$) and a significant AR effect with a high effect size ($p < .001$, $\eta_p^2 = 0.83$). However, there was no interaction effect between groups and ARs ($p = .550$, $\eta_p^2 = 0.03$). An overview of the mean AR speed data is illustrated in Figure 3.

The post hoc test results for the group effect showed that the JAW group had significantly lower speeds compared to both HAB ($p < .001$, $d = 2.80$) and TON ($p < .001$, $d = 2.97$) groups with high effect sizes. The post hoc test for the AR effect showed that the foot had the highest mean speed and that it was significantly higher than the other regions with high effect sizes (knee: $p < .001$, $d = 1.59$; pelvis: $p < .001$, $d = 4.57$; trunk: $p < .001$, $d = 4.63$; head: $p < .001$, $d = 3.43$). The knee had the second highest mean speed, and this was significantly higher than the pelvis ($p < .001$, $d = 3.99$), trunk ($p <$

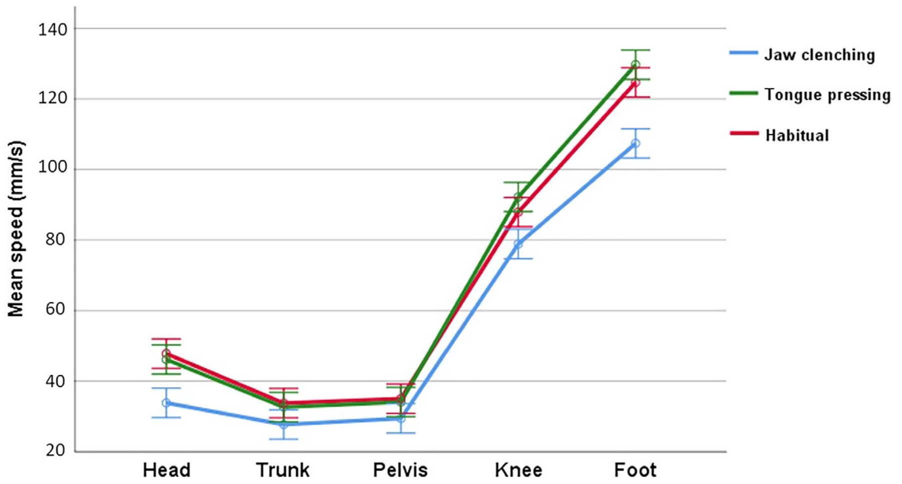

FIGURE 3 Mean speed of anatomical regions (ARs) for all groups. Error bars show ± SD

0.001, d = 4.04) and head ($p < 0.001$, d = 2.39), each with a high effect size. The mean speeds of the trunk and pelvis did not differ significantly from each other and were the lowest among all ARs. The head had a significantly higher mean speed than the pelvis ($p = .036$, $d = 0.69$) and trunk ($p = .009$, $d = .74$) with medium effect sizes.

4 | DISCUSSION

The aim of this study was to investigate the effects of motor activity of the masticatory system in the form of jaw clenching (JAW) and tongue pressing (TON) on dynamic reactive balance performance and to subsequently explain significant performance effects on the level of segmental kinematics. This study showed that JAW enhanced the dynamic reactive balance performance significantly in the forward direction of perturbation, demonstrated by an increased DR that was accompanied by a decreased mean speed of the analysed ARs. In the remaining three directions, no significant changes occurred. Based on these findings, two conclusions can be drawn: (1) JAW can improve dynamic reactive balance but the occurrence of the positive effects seems to be task-specific and not general. (2) TON seems not to have any observable effects on dynamic reactive balance performance, at least when evaluated on an oscillating platform.

4.1 | Jaw clenching improves dynamic reactive balance in a task-specific way

Dynamic reactive balance was assessed by use of an oscillating platform which was randomly perturbed in four different directions. The four directions of perturbation were analysed independently, as suggested by Freyler et al.[33] because muscle spindles provide different information dependent on the direction as well the velocity of perturbations.[39] In addition, the direction of surface translation is an important factor for the sensation, processing and output of the postural responses.[33,37] Therefore, the four directions of perturbations were treated as different tasks.

The participants' task was to compensate the perturbations as quickly as possible. To be able to assess the quality of the task solution, the DR was chosen because it is a proper method to characterise reactive balancing capacity after sudden perturbations.[32] The results for the DR parameter revealed that jaw clenching improved the dynamic reactive balance performance only in the F direction. This finding is in line with the perturbation direction dependency of postural control.[33,36–39] Explicitly, F indicates that the platform was accelerated forwards after release, which led to posterior acceleration of the body with respect to the support surface. A study analysing the effects of the type and direction of support surface perturbation on postural responses[38] showed that a forward translation is more unstable than a backward one and led to faster muscle activation as well as to faster and larger hip and knee joint movements. In another study comparing postural responses to backward and forward perturbations,[37] it was shown that a startling auditory stimulus resulted in better balance control but only in the backward body sway condition. Therefore, the authors suggested that postural responses to backward and forward perturbations may be processed by different neural circuits. In line with these findings, dynamic reactive balance performance improvement in direction F may be attributed to a higher difficulty level of the task compared to direction B. It may also be a reasonable explanation that JAW is associated with adaptations in neural circuits that are recruited during forward translation of the platform.

Segmental kinematics were analysed in direction F, aiming at understanding the underlying postural control strategies that improved dynamic reactive balance. The two main findings were as follows: (1) across the three groups the foot had the highest mean speed, followed by the knee and head. The mean speeds of the trunk and pelvis did not differ from each other and were lower than the mean speeds of the foot, knee and head; (2) the JAW group had a lower mean AR speed compared to both the HAB and TON groups. Consequently, the different oral-motor tasks did not affect the relationship between regional mean speeds (see also Figure 3).

The finding that the trunk and pelvis had the lowest mean speed across ARs may be explained by the stability prioritisation of proximal segments over distal ones during balancing.[42,43] The speeds of lower body ARs were higher than the head, possibly because platform perturbations are compensated mainly at the knee and ankle joints and the head remains stiller compared to lower body regions. In addition, the participants were instructed to fix their gaze at a stationary target, which possibly also contributed to the lower speed of the head. The second main finding, that the JAW group had an overall lower speed in ARs than the HAB and TON groups, may be attributed to enhanced body stiffness, similar to the study by Ringhof et al.[10] However, merely based on mean AR speed results, it is difficult to draw this conclusion. Therefore, in the future studies the activity of trunk muscle groups should be analysed.

4.2 | Influence of stomatognatic motor behaviour on dynamic reactive balance performance

There is no consensus in existing literature about the effects of jaw clenching on motor behaviour. It can possibly be explained by the stimulation of periodontal receptors or by the different proprioceptive inputs due to different jaw relations. Another explanation could be the facilitation of human motor system excitability. In the present study, we hypothesised that both JAW and TON would influence dynamic reactive balance performance. This could be due to either neurophysiological coupling or an effect shown in posture-cognition studies, showing that the release of attention away from balance control and towards a secondary task—in this case, to clench or press the tongue against the palate—can enhance postural stability.[21] In the latter case, both JAW and TON would enhance postural stability. Since there is no significant difference between TON and HAB in the present study, it was concluded that dynamic reactive balance performance improvement was not associated only with the stomatognatic motor activity in general or with the dual-task paradigm. Contrarily, the significant differences between the JAW and the HAB/TON groups indicate a specific effect of instructed jaw clenching activity but in a task-specific manner. It should also be noted that both the partial eta-squared (η_p^2 = 0.349) and Cohen's d ($d_{JAW\text{-}HAB}$ =1.03 and $d_{JAW\text{-}TON}$ =1.40) results indicated high effect sizes for group comparisons which strengthen the explanatory power of the results considerably and minimise the possibility that the findings were random effects.

A secondary finding of this study is that participants in the HAB group showed different oral-motor behaviours. While in 13 participants the mandible was in a resting position with no relevant muscle activity of the jaw closing muscles, three participants showed clenching activity in the sense of muscle activity comparable to the JAW group. The percentage distribution of these different habitual motor behaviours is consistent with available data regarding the prevalence of awake bruxism.[44] Since the clenching activity was performed before the perturbation and during the balance recovery, in these individuals clenching might also be part of the physiological repertoire during coping with demanding motor tasks.[11] However, further studies are needed to clarify this hypothesis.

Another interesting finding was regarding the segmental kinematics. Mean AR speeds of these three participants in the HAB group with clenching were larger than the mean AR speeds of the HAB group without clenching as well as than those of the TON group and the JAW group (see Appendix 1). This might indicate that conscious, non-habituated clenching has a different influence on balance behaviour in comparison with participants who perform clenching as a part of their physiological repertoire. However, this hypothesis is vague and needs to be investigated in further studies.

4.3 | Limitations

All the participants were physically active adults. Accordingly, statements can only be made for this age group. Deliberate care was taken to ensure a homogeneous sample to minimise altered postural control mechanisms due to, for example, age[45] or neurological disorders.[46] The participants were allocated into three groups with different oral-motor tasks. On the one hand, this can be considered as a limitation because of the possible baseline performance differences between groups. However, in order to overcome this problem, a baseline measurement was conducted in habitual biting condition to parallelise the three different groups in terms of both performance and gender. The statistical results revealed no baseline performance differences between the three groups (p = .767). One might think that it would have been purposeful if all subjects had performed all oral-motor tasks. However, "habitual" in this study meant that no instruction was given regarding the status of the masticatory organ. Thus, an unconscious, ancestral behavioural pattern of the masticatory system during the balancing task could be expected. By definition, an "instructed" behavioural pattern can never correspond to an unconsciously performed behaviour. An instructed “habitual” oral-motor behaviour would have potentially resulted in dual-task effects, and therefore, it would have been ultimately difficult to distinguish between cognitive and postural effects (i.e., thinking about the instructed behaviour and performing different oral-motor tasks, respectively). On the other hand, building of three groups provided two main advantages. Firstly, possible carry-over effects between different oral-motor tasks were avoided. For example, some physiological effects could have still existed after jaw clenching or tongue pressing such as an increased excitability of the human motor system or muscles of the masticatory system in a fatigued state. Secondly, if all the participants conducted all of the three oral-motor tasks for each of the four directions separately, the valid trials needed would be 36. Considering the invalid trials as well, the total trials conducted could increase to a level at which fatigue sets in and data quality decreases consequently.

In this study, the Posturomed oscillating platform was chosen to assess dynamic reactive balance performance. The Posturomed is a widely used device for scientific studies as well as for training or rehabilitation.[32,33,43,47] However, it should be noted that stabilising a moving platform represents a different balance task than balancing the body on a rigid surface.[48] Therefore, it is worth adding that the results in this study cannot directly be transferred to stable ground conditions (e.g., recovering from a perturbation during upright standing on a rigid surface), since balance performance under various dynamic balance conditions cannot be considered directly interchangeable.[30]

The dynamic balance performance was assessed by use of DR as suggested in other studies.[32,47] Mean speed of ARs was chosen for kinematic analysis following Ringhof et al.[10] as explained in detail in the "Data analysis" section. Despite being widely used parameters, it is important to note that the calculation of these parameters is based on linear methods, and such traditional approaches for assessing postural stability may not fully characterise the non-linear properties of postural control.[49] Therefore, it would be advisable to perform non-linear analysis using, for example, maximum Lyopunov exponent[43] or entropy measures[49] to further extend the knowledge regarding the effects of oral-motor activity on postural control.

5 | CONCLUSION AND OUTLOOK

The aim of this study was to investigate the influence of different functional stomatognatic statuses (i.e., JAW, TON, HAB) on postural performance during a dynamic reactive balance task. To the best of our knowledge, this study was the first to analyse the effects of JAW on dynamic reactive balance performance and also the first to investigate the effects of TON related to postural control. The results showed that JAW improves dynamic reactive balance but the occurrence of the positive effects seems to be task-specific and not general. Improved dynamic balance performance of the JAW group was associated with overall decreased speeds of ARs, but without any AR-specific changes due to functional stomatognatic status. In addition, TON seems not to have any observable effects on dynamic balance performance, at least when evaluating it with an oscillating platform. The results show that dynamic reactive balance performance improvement in this study was not associated with stomatognatic motor activity per se or the with dual-task paradigm, but in particular with jaw clenching activity.

Therefore, the direction-dependent improvement in dynamic reactive balance performance due to JAW should be investigated in more detail. For this purpose, future studies should analyse control strategies at the muscular level, such as muscular co-contractions, to reveal if postural control in the presence of controlled oral-motor activities leads to stiffer joints in a directionally dependent manner in the Posturomed task. Subsequently, an in-depth analysis of adaptations in motor coordination on a kinematic as well as on a muscular level would be useful, for example by use of matrix factorisation algorithms to extract kinematic[50] or muscle synergies.[43]

Considering the initially stated potential clinical relevance of this study in terms of an influence of oral-motor training on the risk of falls, it is too early to draw final conclusions. However, previous studies have found jaw clenching can stabilise body sway in the anterior–posterior direction under static conditions,[9,10] similar to results from the present study under dynamic conditions. This might therefore be an aspect which should be further investigated, since it might be a valuable strategy which could reduce the risk of falls in general or maybe especially in elderly people.

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest in respect of authorship and/or publication of this article.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Cagla Fadillioglu https://orcid.org/0000-0003-4283-281X

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APPENDIX 1

TABLE A1 Mean speed of the five anatomical regions given as mean and standard deviation (SD) for different groups

		Head in mm/s	Trunk in mm/s	Pelvis in mm/s	Knee in mm/s	Foot in mm/s
JAW	*Mean*	33.82	27.68	29.41	78.88	107.40
	SD	9.72	7.02	7.54	12.20	19.02
TON	*Mean*	46.12	32.64	34.06	92.21	129.71
	SD	23.22	9.43	7.72	18.38	27.44
HAB all	*Mean*	47.79	33.75	35.03	87.91	124.70
	SD	19.50	9.53	9.38	18.43	27.41
HAB w/o clenching	*Mean*	42.01	31.66	33.11	84.88	118.99
	SD	12.87	7.85	6.75	17.74	22.67
HAB with clenching	*Mean*	72.81	42.80	43.32	101.07	149.47
	SD	26.47	12.64	16.11	18.44	37.67

Abbreviations: HAB, habitual jaw position; JAW, jaw clenching; TON, tongue pressing.