Prediction of Ergogenic Mouthguard Effects in Volleyball: A Pilot Trial

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ABSTRACT

Dental occlusion may affect static and dynamic balance. The effects of a mouthguard on pinpoint accuracy in volleyball were investigated in 28 players who completed a volleyball specific test. Also, masticatory electromyographic tests were performed. The mean pinpoint accuracy was significantly higher with a mouthguard (68.6 ± 9.3 vs. 64.0 ± 7.0 points from 100; $p < 0.006$). However, differential mouthguard effects were seen, and three subgroups were classified: Group 1 (markedly improved pinpoint accuracy), Group 2 (improved pinpoint accuracy), and Group 3 (reduced pinpoint accuracy). Group 1 had a high masseter resting tone, the masseter activity was low in MVC (maximum voluntary clench) and increased in BOC (maximum bite on cotton rolls; $p < 0.04$). This indicates a masseter weakness, which would be compensated by a mouthguard. In Group 2, the masseter activity in MVC was high-normal with an imbalance which was improved in BOC ($p < 0.01$), indicating a possible mouthguard benefit. In Group 3, MVC and BOC were in a high-normal range and showed no relevant deficits. In these subjects the mouthguard had adverse effects. Overall, subjects with masticatory deficits had a benefit from the mouthguard in pinpoint accuracy. Positive or negative mouthguard responders may be detectible from electromyographic tests.

Introduction

It is suggested that a relationship between the masticatory system and the body movement system exists [1]. Studies showed that different jaw positions caused changes in gait stability while running with increasing speeds [2, 3]. A functional correlation was found between the trigeminal and cervical system, with reciprocal co-activations and inhibitions of the jaw, neck, shoulder, and limb muscles during performance [4–8]. The mandibular proprioception, assisted by the trigeminal nerve and mediated by the masticatory muscles and periodontal ligament, contributes to head posture control via the sternocleidomastoid muscles [9]. Several studies showed that teeth clenching may play an important role in rapid body posture stabilization [10–12], gait stabilization [2], posture stability, and balance control [13]. The stomatognathic system may influence the muscle functions in other parts of the body, e. g., the range of hip movement [5], the visual stabilization quality [14], and the head posture [9]. Julià-Sánchez et al. [15] compared the body balance on unstable platforms under opposing dental occlusion and fatigue conditions for two extreme levels of stability (stable/unstable). They concluded that the sensory information for balance control is linked to the dental occlusion and comes strongly into effect in more difficult conditions such as instability and fatigue.

It is speculated whether disharmonies in dental occlusion can modify muscle functions throughout the body. Occlusal interferences, either natural or experimental, may impair the function of the jaw muscles and temporomandibular joints [7, 16, 17]. The loss of occlusal support and the instability of the mandibular position might influence weight distribution and may cause reduced agility [18].

Based on these findings, it is the study hypothesis that mouthguard use may have positive effects on the intermuscular coordination in sports for two reasons:

1. Mouthguards may facilitate powerful jaw-clenching and a subsequent concurrent activation potentiation through the remote voluntary contraction of the mandible muscles.
2. Mouthguards may compensate for muscle imbalances or pathologies in the temporomandibular system.

Volleyball requires specific abilities and skills. The motor output is composed of the conditional abilities, as well as the coordinative capabilities of coupling, orientation, balance, adaptation, rhythmization and differentiation. The coordinative ability includes the precision of movement and thus the pinpoint accuracy of the athlete. Owing to these complexities, the pinpoint accuracy in volleyball was used in the current study as a model for mouthguard effects on intermuscular coordination. To the best of our knowledge, no previous study has analyzed mouthguard effects in a sport-specific volleyball test.

Materials and Methods

Subjects

A total of 28 healthy subjects, 15 women and 13 men, 19 to 39 years old (mean age: 25.2 ± 5.2 years; height: 177.9 ± 8.3 cm; weight: 73.0 ± 9.1 kg) participated in this study. The subjects completed an inclusion criteria questionnaire. Only right-handed individuals with a complete and sound permanent dentition; no periodontal problems; no prostheses or reconstructions; and no orthopedic, myogenic, or arthrogenic complaints related to temporomandibular dysfunctions were considered for participation. Subjects with past orthopedic and present acute or chronic complaints were excluded.

The study was approved by the Institutional Review Board and Human Research Committee, No. 445–15–21122015. The subjects were informed of the benefits and risks of the investigation prior to signing the institutionally approved informed consent document to participate in the study. The study conformed to the Standards for Ethics in Sport and Exercise Science Research [19] and required players to provide informed consent before participation. None of the subjects reported former use of a mouthguard.

Mouthguard

A “vented boil-and-bite” mouthguard was used (Nike, Beaverton, OR, USA). This mouthguard (MG) consists of a special flexible, shock-absorbent plastic. The MG was placed in boiling water for 30 s and then carefully placed in the subject´s mouth to cover the upper teeth. The subject was instructed to bite down. Moderate pressure was placed on the lips and cheeks for 30 s. The MG was then removed and rinsed in cold water.

SinfoMed K7-system

A myofunctional examination was carried out with the SinfoMed K7-system (SinfoMed, Frechen, Germany). It measures masticatory muscle tension and neuromuscular activities. Using bipolar surface electrodes, electromyographic (EMG) data can be taken from several muscle sites simultaneously. The EMG activities of the following muscle groups were recorded: temporalis, masseter, cervical group, and digastrics.

The EMG activity was recorded in three different tests:

1. Resting tone of the four muscle groups at both sides for 14 s. This test was repeated three times and the data of the third test were used.
2. Maximum voluntary clench (MVC) in the intercuspal position: the subjects had to clench two times as hard as possible and maintain the level of contraction for 2 s with an intervening 1 s break between clenches.
3. Maximum bite on cotton rolls (BOC) positioned on the lateral teeth: the subjects had to clench two times as hard as possible and maintain the level of contraction for 2 s with an intervening 1 s break between clenches.

For all tests, the subjects were placed on a chair and had to maintain a natural, erect and relaxed position without a head or neck support.

Interpretation of the masticatory EMG tests

Experiment 1 (resting tone) assessed muscular output such as fatigue, hyperactivity, and passivity. A tone above threshold (masseter > 2 µV; temporalis > 2.2 µV; digastrics > 1.7 µV) indicates a muscle overload or muscle weakness, respectively.

In experiments 2 and 3, the MVC normal range is 220–250 µV. MVC and BOC are function tests and interpreted as follows: a) MVC below threshold indicates intercuspal disorder and muscular weakness; b) side differences indicate muscular imbalance in MVC or BOC.

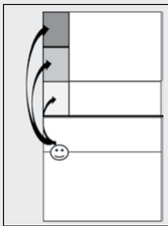
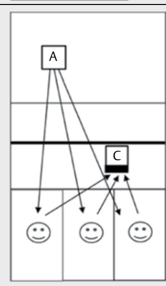
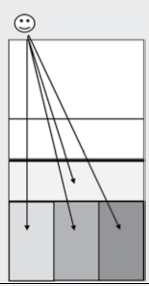
In experiment 3, higher BOC values indicate an improvement of muscular imbalance, e. g., due to a compensation of intercuspal disturbance by the cotton rolls. Lower BOC values indicate muscle fatigue.

Volleyball testing

The sport-specific testing included ten offensive and defensive volleyball components, such as passing (short, medium, long), digging (right, center, left), and servicing (back right, back center, back left, short). The participants performed these exercises (▶ **Fig. 1**) with and without an MG in a randomized order. Different marked target fields had to be hit (▶ **Fig. 1**). The number of hits was recorded (maximum 100 points per each test with and without mouthguard). Finally, the sum of hits was calculated separately for mouthguard (MG) and no mouthguard (NoMG) use. The test sessions were performed on one day in an indoor team sports hall. The net height was 2.24 m for women and 2.43 m for men.

Statistical analysis

All data are presented as the means ± SD. A paired t-test was performed to compare the results with the MG vs. no MG use. The Mann-Whitney U-test was used for the comparison of group differences. A p-value < 0.05 was considered significant, and a p-value < 0.005 was considered highly significant. Statistical analyses were performed using GraphPadInStat software (GraphPad Software, La Jolla, CA, USA).

	**36 points**	**Upper pass** • Upper pass from 3.5 m behind the net (marked line) • A total of 12 balls per target field (short, medium, long) • Target field size: 1 x 3 m • Number of hits is noted (max. 36)
	**36 points**	**Lower pass (digging)** • Ball throw by a professional assist (A) from the middle of the field of the other side • The tested subject stands 6 m behind the net (marked) and digs the ball to the catcher (C), who stands inside a gymnastic ring (diameter: 0.8 m) near the net • The lower pass must have an adequate trajectory (fly over a rope, which is 1.5 m high and about 1.5 m behind the net parallel to the centerline) • The catcher must catch the ball without leaving the ring and without touching the net or rope. Otherwise no point is given for the lower pass • A total of 12 balls per position (right, center, left) • Number of hits is noted (max. 36)
	**28 points**	**Overhand serve** • A total of 7 overhand serves from baseline per target fields (back right, back center, back left, short) • Target field size: 3 x 6 m and 9 x 3 m • Number of hits is noted (max. 28)

☺ = subject, **A** = professional assist, **C** = catcher

▶ **Fig. 1** Volleyball test protocol

Results

Pinpoint accuracy

The pinpoint accuracy (PA) of the total group (n = 28) was significantly higher when using an MG vs. NoMG (68.6 ± 9.3 vs. 64.0 ± 7.0 points from 100; p < 0.006). However, some subjects performed worse, some better, and some markedly better with an MG. Accordingly, three subgroups were distinguished. The criterion was a pinpoint count difference between the individual results with an MG and NoMG of at least 5 points (≥ 50 % of the standard deviation). A difference of less than 5 points was therefore omitted (5 subjects). Four participants did not come for the SinfoMed K7-measurement. The point count of Group 1 was two digits better, with an MG (n = 5; 76.1 ± 10.0 vs. 61.0 ± 9.0 points; p < 0.016). The point count of Group 2 was one digit better, with an MG (n = 9; 70.1 ± 7.6 vs. 64.4 ± 7.8 points; p < 0.001). The point count of Group 3 was reduced, with an MG (n = 6; 59.7 ± 5.5 vs. 66.0 ± 4.2 points; p < 0.0008).

Masticatory resting EMG

The results of the masticatory resting EMG of the three subgroups are shown in ▶ **Table 1**. The masseter resting tone was increased in Group 1 (threshold 2 µV). The resting tone of the digastric muscles was increased in all groups (threshold 1.7 µV). No increased resting tone of the cervical or temporalis groups was found in any group (threshold 2.2 µV) (▶ **Table 1**). When comparing the muscle tones of each side, only the left masseter tone of Group 1 was significantly higher than in Group 2 (p < 0.03). In a comparison of the cumulative values of all masticatory muscles, Group 2 had a significantly lower resting tone vs. Group 1 (p < 0.022) and vs. Group 3 (p < 0.015).

Maximum voluntary clenching (MVC) and bite on cotton rolls (BOC)

▶ **Table 1** The electromyographic (EMG) resting tones of the muscle groups temporalis anterior, masseter, cervical group, and digastrics.

	Group 1 n = 5	Group 2 n = 9	Group 3 n = 6
	µV		
Left temporalis	2.04 (0.27)	2.50 (1.30)	2.70 (0.75)
Right temporalis	1.78 (0.61)	1.73 (0.73)	2.32 (1.11)
Mean value temporalis	1.91 (0.38)	2.11 (0.89)	2.51 (0.56)
Mean side difference temporalis	0.34 (0.50)	1.03 (0.87)	1.25 (0.79)
Left masseter	2.42 (1.02) *	1.26 (0.44) *	1.98 (0.97)
Right masseter	2.44 (0.93)	1.51 (0.68)	1.95 (0.62)
Mean value masseter	2.43 (0.86)	1.38 (0.55)	1.97 (0.78)
Mean side difference masseter	0.51 (0.58)	0.30 (0.27)	0.40 (0.22)
Left cervicalis	2.90 (1.32)	1.74 (0.83)	1.95 (0.80)
Right cervicalis	1.82 (0.79)	1.75 (1.32)	2.02 (0.53)
Mean value cervicalis	1.70 (0.95)	1.75 (0.97)	1.98 (0.51)
Mean side difference cervicalis	1.08 (1.06)	0.70 (0.74)	0.83 (0.79)
Left digastric	2.02 (0.49)	2.37 (1.32)	2.03 (0.71)
Right digastric	1.82 (0.22)	2.23 (1.07)	2.37 (0.74)
Mean value digastric	1.92 (0.33)	2.30 (1.16)	2.05 (0.93)
Mean side difference digastric	0.32 (0.23)	0.49 (0.44)	0.47 (0.31)
Mean activity of all masticatory muscles	2.16 (0.81)	1.89 (1.05) *	2.16 (0.78)
SD in brackets; * = significant.			

▶ **Table 2** Electromyographic activity of the temporalis anterior and masseter muscles; two times in maximum voluntary clench (MVC 1 + MVC 2) and two times in maximum bite on cotton rolls (BOC 1 + BOC 2).

	Group 1	Group 2	Group 3
	µV		
Left temporalis MVC	173.1 (51.38)	181.73 (73.75)	253.68 (120.99)
Right temporalis MVC	155.15 (66.30)	240.55 (95.93)	243.04 (101.58)
Temporalis MVC	164.13 (56.71)	211.14 (88.35)	248.36 (106.65)
Left masseter MVC	172.51 (93.61)	229.10 (179.29)	230.08 (69.06)
Right masseter MVC	168.44 (111.40)	255.11 (195.43)	252.62 (86.86)
Masseter MVC	170.48 (97.03)	242.10 (182.42)	241.35 (75.73)
Mean MVC of temporalis and masseter	167.30 (77.42)	226.62 (142.13)	244.85 (90.53)
Left temporalis BOC	135.30 (69.32)	223.69 (107.53)	226.26 (113.11)
Right temporalis BOC	133.96 (67.23)	259.12 (98–04)	214.52 (61.99)
Temporalis BOC	134.63 (64.38)	241.40 (101.47)	220.39 (87.18)
Right masseter BOC	209.18 (126.11)	305.24 (164.83)	244.14 (73.51)
Left masseter BOC	230.94 (160.47)	319.29 (199.68)	246.92 (99.16)
Masseter BOC	220.06 (136.34)	312.27 (177.77)	245.53 (83.23)
Mean BOC of temporalis and masseter	177.35 (112.76)	276.84 (147.11)	232.96 (84.34)
SD in brackets.			

In Group 1, the cumulative masticatory activity (masseter and temporalis) was reduced below the threshold in MVC and BOC. In BOC, the temporalis activity decreased insignificantly and the masseter activity increased significantly ($p < 0.04$) in relation to MVC (▶ **Table 2**).

In Group 2, the cumulative masticatory activity in MVC was in the normal threshold range and increased significantly in BOC ($p < 0.009$). The temporalis activity was in the normal MVC range and increased insignificantly in BOC. The masseter activity in MVC was in the normal threshold range and increased significantly in BOC to > 300 µV ($p < 0.012$; ▶ **Table 2**).

Group 3 showed similar activities in MVC and BOC, both within the threshold range (▶ **Table 2**).

Comparison of the masticatory activity in MVC and BOC within the subgroups

In MVC, the cumulative masticatory activity was significantly lower in Group 1 vs. Group 3 ($p < 0.005$). In BOC, the cumulative masticatory activity in Group 1 was significantly lower vs. Group 2 ($p < 0.013$) and also vs. Group 3 ($p < 0.035$).

Comparison of the temporalis and masseter activity in MVC and BOC within the subgroups

In Group 1, temporalis activity was below the threshold (200–250 µV) in MVC and was even lower (though insignificantly) in BOC (▶ **Table 2**). Masseter activity was below the threshold in MVC and increased markedly in BOC to values within the threshold ($p < 0.04$, ▶ **Table 2**).

In Group 2, the cumulative masticatory activity in MVC was within the threshold and increased in BOC. The increase in masseter activity in BOC was significant ($p < 0.012$).

In Group 3, the cumulative masticatory activity in MVC and BOC was within high-normal threshold values.

Discussion

Mouthguards may have ergogenic effects [20]. The purpose of the current study was first, to determine the pinpoint accuracy (PA) with and without an MG and second, to predict possible positive or negative MG effects with an electromyographic (EMG) function test of the masticatory muscles.

The most striking result of the current study is a significant increase in PA with an MG. However, it also appears that some subjects had no or negative effects on PA with an MG. In the literature, three main theories for improved athletic performance due to improved jaw kinetics with an MG are discussed: 1) reduced afferent interstitial C3/4 reflexes economize cardiac workload, ventilation and metabolism; 2) co-activation of main sport-related muscles and concurrent activation potentiation; 3) improvement of masticatory muscle imbalances.

For theory 1, an increased activation of jaw muscles and more powerful clenching may produce a second area of force to improve whole body stability in addition to the core muscles [21]. The activation of the jaw muscles may increase the force production of sport-specific muscles and thereby improve biomechanics and motion economy [22, 23]. It has been speculated that better motion economy reduces the signal output of the muscles via reduced interstitial C3/C4 afferent activity [21, 23].

For theory 2, voluntary teeth-clenching induces a co-activation of the sternocleidomastoid muscles [4, 6–8]. Clenching may also enhance muscular force due to an improved concurrent activation potentiation [20] and may increase the performance of sport- related muscles via neuromuscular responses [22].

For theory 3, the characteristics of the occlusal surfaces, malocclusion [7, 8] and muscle imbalances [24] may impair muscle co-activation. Therefore, jaw repositioning with an MG may also enhance and improve neuromuscular responses in the sport related agonist muscles [22]. It is speculated that, through the change in dental occlusion due to an MG, the central nervous system may receive afferent impulses from the altered jaw position. These alterations of the afferent information in the periodontal ligament, temporomandibular joint or masticatory muscles may cause improvements of the upper body posture by efferent adaption or compensation patterns [1]. Julià-Sánchez et al. [15] compared the body balance on unstable platforms under opposing dental occlusion and fatigue conditions for two extreme levels of stability (stable/unstable). They concluded that the sensory information linked to dental occlusion for balance control comes strongly into effect when more difficult balance control conditions are present (i. e., unstable conditions, fatigue). This may also be relevant in volleyball where a combination of trunk stability, shoulder girdle activity, and body posture is required. The current study supports the concept of a functional coupling between the stomatognathic system and the main sport-related muscles.

Regarding possible reasons for beneficial MG effects on pinpoint accuracy (PA) in Group 1, this subgroup had a high masseter resting tone, indicating a masseter overload, i. e., a muscle weakness. This is confirmed by the low MVC activity. Overload and reduced MVC indicate an intercuspal disorder and a low jaw-clenching force. The positive MG effect can be understood by the BOC results. The cotton rolls in the BOC testing induce a higher intercuspal distance, which also occurs with an MG. In BOC, the masseter activity markedly increased by approximately 30 % ($p < 0.04$). The masseter profits from the pre-distension due to the mouthguard. In the context of the concurrent activation potentiation theory, this consideration would explain the positive effects in Group 1.

As to possible reasons for positive MG effects on PA in Group 2, this subgroup had a low masseter resting tone, indicating a physiological relaxation without signs of a functional disorder. The masseter activity in MVC was high-normal, indicating good muscle power. However, there was a marked difference in MVC between the right and left side, indicating a muscle imbalance. This imbalance was improved by the MG as indicated by an increase in BOC of approximately 30 % ($p < 0.012$). The jaw positioning due to the MG may also explain the improvement in PA by enhanced support of the shoulder girdle [25].

There are several possible reasons for better effects on PA in Group 1 vs. Group 2. In contrast to Group 2, Group 1 had markedly more masticatory muscle problems, such as resting overload and functional weakness, which were positively affected by the MG. So it appears that the mouthguard may have produced ergogenic effects in these groups for different reasons. Whereas in Group 1 the MG may have mainly compensated for intercuspal disorder and muscle weaknesses, in Group 2 only reflex inhibition due to muscular imbalance may have been improved. This may also explain that the MG effects were best in Group 1.

Regarding possible reasons for negative MG effects on PA in Group 3, this subgroup had no increased masseter resting tone and showed similar activities in MVC and BOC within the threshold. So these subjects had no pathologies such as overload or improper clenching and no beneficial effects would be expected from the MG. Therefore, a balanced condition of the masticatory system can be assumed. The MG presumably caused a disturbance in the neuronal muscular regulation of masticatory and peripheral muscles [16, 17] with impaired pinpoint accuracy.

In conclusion, the pinpoint accuracy in volleyball players was significantly better when using a mouthguard. Masticatory EMG characteristics were seen after subdividing the subjects in positive and negative mouthguard responders. It appears that an initial masticatory EMG function test may be useful to detect positive or negative mouthguard effects. When ergogenic effects are expected, the use of a mouthguard may be recommended in case of intercuspal disorders, muscle weakness or imbalance. However, this pilot trial needs more studies to clarify the hypothesis and expected results.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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