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Jaw Biomechanics: Estimation of Activity of Muscles Acting at the Temporomandibular Joint

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Abstract. The aim of this study was to elaborate a method of estimation of activity of surface muscles acting at the temporomandibular joint of the healthy subjects by using a surface electromyography (EMG). The scope of this study involved testing chosen jaw motions (open, close, lateral deviation) and process of mastication occurring during eating food with different toughness (chewing gum, cereal and carrot) by using mixed sides, right side and left side of the jaw.

INTRODUCTION

The process of mastication involves activation of muscles acting at each temporomandibular joint (TMJ) formed between a temporal bone, intraarticular disk and the head of mandible. During this process the mandible does a complex motion (both translational and rotational displacements), which depends on the condition of TMJ (healthy or with dysfunction), configuration of the trunk and head with respect to the gravity forces, toughness (hardness) of the food bitten, external load influence and nervous system acting. Due to this complicity the mastication process should be analysed by considering mechanical and biomechanical constraints and motor control (physiological) factors [1]. Biomechanical constraints depend on the function of musculoskeletal system and its configuration with respect to the external load. The nervous system control behaviour of the musculoskeletal system to avoid injury of this system components.

To estimate the activity (activation) of superficial muscles that cause the motion of the jaw a surface electromyography (EMG) can be applied [2, 3]. It is a non-invasive method allowing us to identify whether a muscle produces neuromuscular activation which provides to muscle contraction. It is worth noting that both pattern of jaw muscle activations and pattern of the jaw motions depend on the individual features developing during the life of the human. However, it is possible to identify the progress of disease of neuromuscular system on the base of EMG data and kinematic data recorded during chosen jaw motions and biting tests.

The aim of this study was to elaborate a method of estimation of activity of surface muscles acting at the temporomandibular joint of the healthy subjects by using EMG. The scope of this study involved testing chosen jaw motions (open, close, lateral deviation) and process of mastication occurring during eating food with different toughness (chewing gum, spoon of cereal and carrot slice) by using mixed sides, right side and left side of the jaw.

METHOD

Five healthy volunteers took part in the study (four females and one male, (66.4 ± 10.1) kg, (175.4 ± 7.4) m). To participate in the study each volunteer gave a written informed consent (Ethic Committee agreement KB/111/2018).

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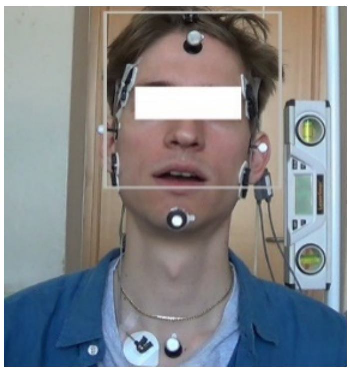
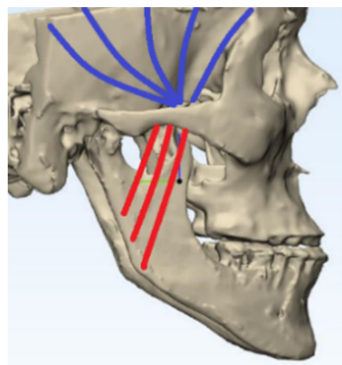
Each volunteer performed in vision-on mode the following tests: 1) mouth opening-closing motions; 2) protrusion-retrusion motions; 3) motions of lateral deviation of mandible; 4) biting a one piece of chewing gum; 5) biting a spoon of cereal; 6) biting a slice of raw carrot. All biting tests were performed by asking subject to bite food by using: 1) mixed sides (preferred motions); 2) only right side of the mandible; 3) only left side of the mandible.

To perform kinematic analyses the *Templo Contemplas* system was used. To estimate activities of four superficial muscles (right *Masseter* (EMG1), left *Masseter* (EMG2), anterior part of right *Temporalis* (EMG3) and anterior part of left *Temporalis* (EMG4)) the *Noraxon Myotrace 400* device was applied (Figure 1). Using the *Myoresearch XP Master Edition* software, the EMG data was processed, i.e. filtered, rectified and smoothed by applying the root mean square algorithm (rms) with 50 ms window. The processed EMG were normalized with respect to the maximum value of EMG signal registered during each series of testing [4]. Activity of each examined muscle was estimated by assuming the EMG threshold equaled to 0.005 and applying the authors' scripts implemented in the *Matlab* software. It was also taken into consideration that electromechanical delay equaled to 50ms [5]. The time scale was normalized to the motion timing and described as a percentage of motion. The phenomenon of muscle co-contraction between the two EMG processed data were calculated by applying a cross-correlation method [6, 7].



(a)



(b)

FIGURE 1. The subject examined (a). The muscle paths examined (the red paths are *Masseter* actons, the blue paths are *Temporalis* actons) (b)

RESULTS

Muscle activities were calculated as mean value of EMG data processed for:

1. mouth opening motion for five trials (Fig. 2);
2. mouth closing motion for five trials (Fig. 2);
3. protrusion-retrusion motion for four trials (Fig. 3);
4. retrusion-protrusion motion for four trials (Fig. 3);
5. lateral deviation from the start (neutral) position to the right side for five trials (Fig. 4);
6. lateral deviation from the start (neutral) position to the left side for five trials (Fig. 4);
7. lateral deviation from the right side to the left side for five trials (Fig. 5);
8. biting a chewing gum by using mixed sides for seven bites counted from third bite (Fig. 6);
9. biting a chewing gum by using a right side for seven bites counted from third bite (Fig. 7);
10. biting a chewing gum by using a left side for seven bites counted from third bite (Fig. 7);
11. biting a cereal by using mixed sides for seven bites counted from third bite (Fig. 8);
12. biting a cereal by using a right side for seven bites counted from third bite (Fig. 9);
13. biting a cereal by using a left side for seven bites counted from third bite (Fig. 9);
14. biting a carrot by using mixed sides for seven bites counted from third bite (Fig. 10);
15. biting a carrot by using a right side for seven bites counted from third bite (Fig. 11);
16. biting a carrot by using a left side for seven bites counted from third bite (Fig. 11).

The muscle co-contraction results for all tested motions (Tables 1–6) were calculated by applying a cross-correlation function given in the *Matlab* and *Statistica* software.

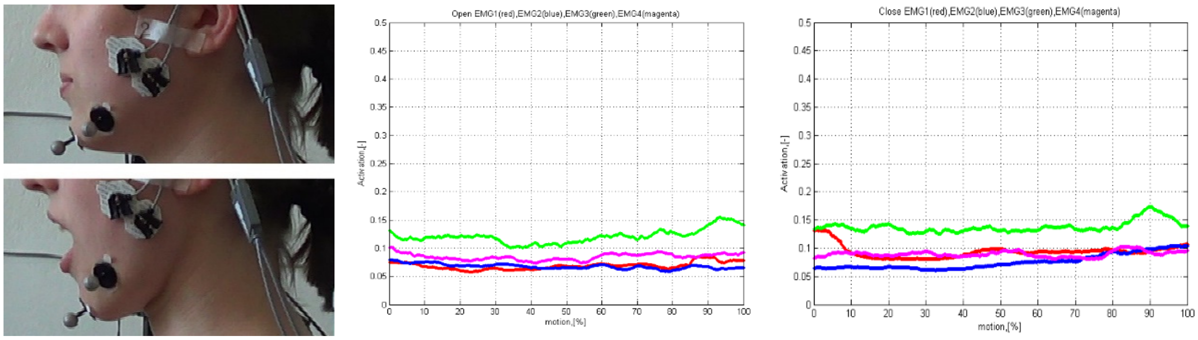
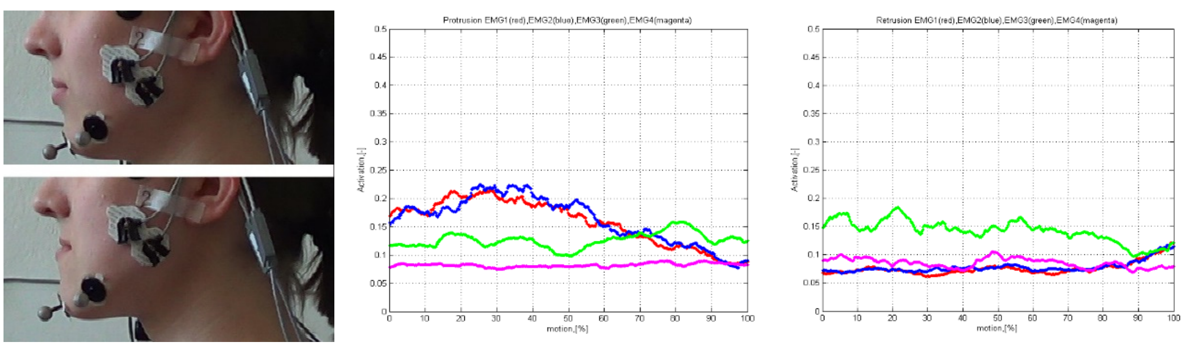


FIGURE 2. Characteristic subject positions during mouth opening-closing motion (a). Estimated muscle activities during mouth opening motion (b) and mouth closing motion (c)

TABLE 1. The cross-correlation results calculated for mouth opening-closing motion

EMG data	Opening motion: Cross-correlation R, [-]	Closing motion: Cross-correlation R, [-]
EMG1 – EMG2	0.964 ± 0.034	0.966 ± 0.041
EMG1 – EMG3	0.935 ± 0.067	0.963 ± 0.027
EMG1 – EMG4	0.962 ± 0.039	0.963 ± 0.029
EMG2 – EMG3	0.964 ± 0.024	0.976 ± 0.011
EMG2 – EMG4	0.983 ± 0.007	0.976± 0.015
EMG3 – EMG4	0.986 ± 0.986	0.987 ± 0.009

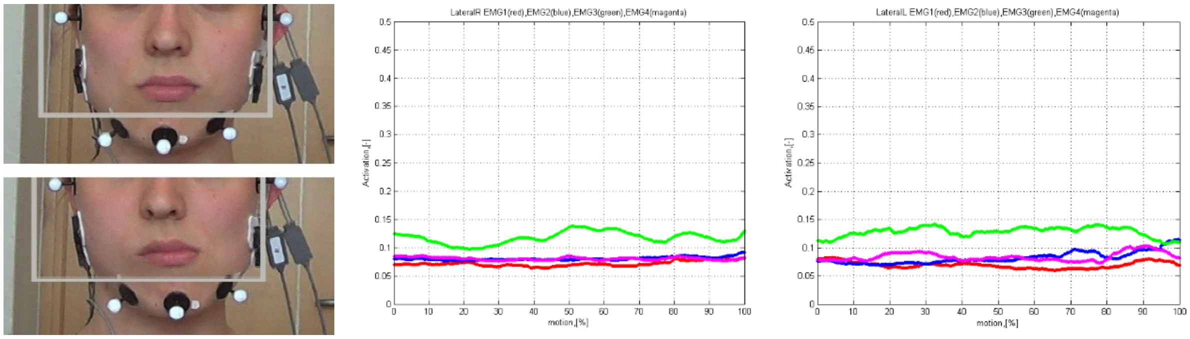


(a) (b) (c)

FIGURE 3. Characteristic subject positions during protrusion-retrusion motion (a). Estimated muscle activities during protrusion-retrusion motion (b) and retrusion-protrusion motion (c)

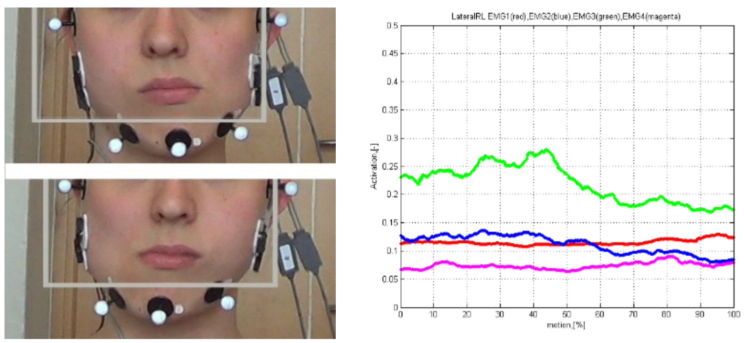
TABLE 2. The cross-correlation results calculated for protrusion-retrusion motion

EMG data	Protrusion-retrusion motion: Cross-correlation R, [-]	Retrusion-protrusion side: Cross-correlation R, [-]
EMG1 – EMG2	0.982 ± 0.012	0.988 ± 0.008
EMG1 – EMG3	0.918 ± 0.065	0.909 ± 0.069
EMG1 – EMG4	0.936 ± 0.046	0.936 ± 0.058
EMG2 – EMG3	0.927 ± 0.055	0.906 ± 0.090
EMG2 – EMG4	0.946± 0.033	0.924 ± 0.109
EMG3 – EMG4	0.978 ± 0.010	0.971 ± 0.014



(a) (b) (c)

FIGURE 4. Characteristic subject positions during lateral motion of mandible (a). Estimated muscle activities during lateral deviation from the start (neutral) position to the right side (b) and lateral deviation from the start (neutral) position to the left side (c)



(a) (b)

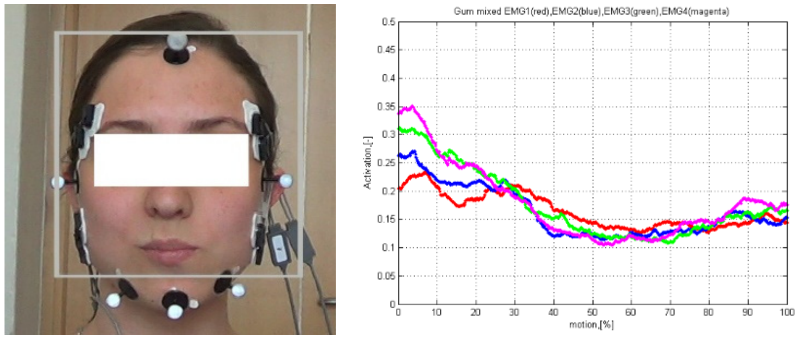
FIGURE 5. Characteristic subject positions during lateral deviation from the right side to the left side (a). Estimated muscle activities during lateral deviation from the right side to the left side (b)

TABLE 3. The cross-correlation results calculated for lateral deviation of mandible

EMG data	Lateral deviation from the start (neutral) position to the right side: Cross-correlation R, [-]	Lateral deviation from the start (neutral) position to the right side: Cross-correlation R, [-]	Lateral deviation from the right side to the left side: Cross-correlation R, [-]
EMG1 – EMG2	0.973 ± 0.019	0.996 ± 0.002	0.932 ± 0.084
EMG1 – EMG3	0.973 ± 0.016	0.964 ± 0.026	0.926 ± 0.085
EMG1 – EMG4	0.970 ± 0.021	0.981 ± 0.017	0.989 ± 0.004
EMG2 – EMG3	0.964 ± 0.039	0.969 ± 0.021	0.982 ± 0.014
EMG2 – EMG4	0.961 ± 0.026	0.983 ± 0.019	0.940 ± 0.081
EMG3 – EMG4	0.959 ± 0.025	0.981 ± 0.013	0.930 ± 0.080

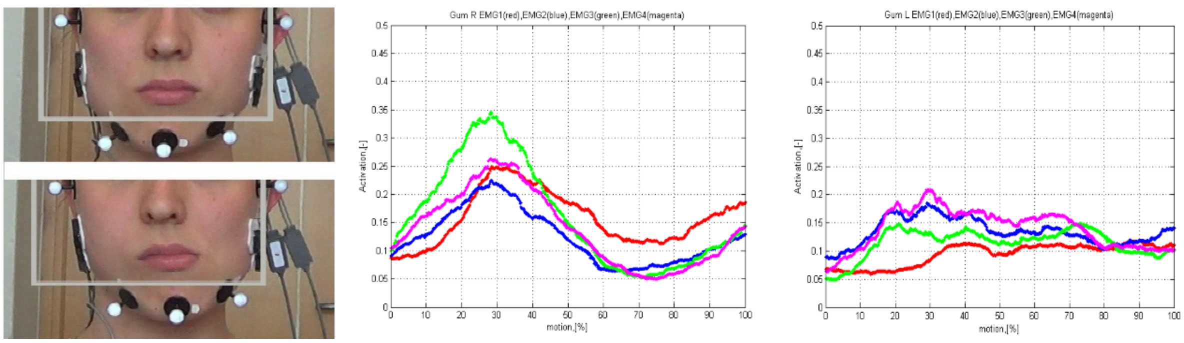
DISCUSSION

The study involved estimation of muscle activity of four superficial muscles (*Masseter* (right and left) and anterior part of right and left *Temporalis*) recorded during the motions of the jaw and biting tests using food with different toughness. Muscle activities were calculated for a group of healthy right dominant persons having symmetrical faces. All tests were performed in a short time period to avoid fatigue developing and emotional confusion that may change the activations of muscles tested.



(a) (b)

FIGURE 6. Chosen subject position during biting a chewing gum by using mixed sides (a). Estimated muscle activities during biting a chewing gum by using mixed sides (b)



(a) (b) (c)

FIGURE 7. Chosen subject positions during biting a chewing gum by using right side and left side (a). Estimated muscle activities during biting a chewing gum by using right side (b) and left side (c)

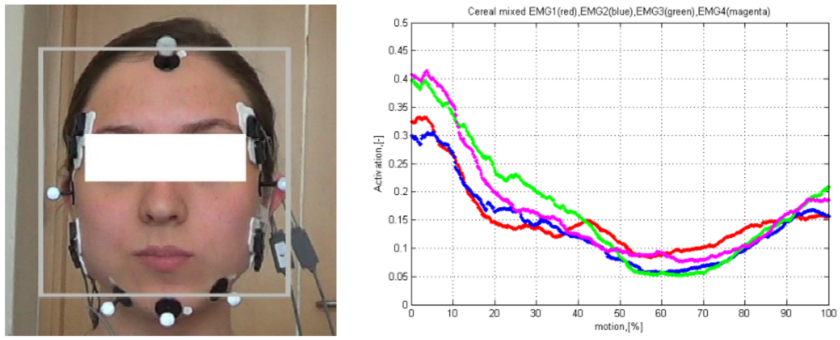
TABLE 4. The cross-correlation results calculated for chewing gum biting test

EMG data	Mixed sides: Cross-correlation R, [-]	Right side: Cross-correlation R, [-]	Left side: Cross-correlation R, [-]
EMG1 – EMG2	0.943 ± 0.048	0.957 ± 0.024	0.955 ± 0.034
EMG1 – EMG3	0.933 ± 0.046	0.955 ± 0.043	0.949 ± 0.000
EMG1 – EMG4	0.947 ± 0.032	0.952 ± 0.052	0.960 ± 0.026
EMG2 – EMG3	0.969 ± 0.034	0.978 ± 0.029	0.976 ± 0.019
EMG2 – EMG4	0.980 ± 0.022	0.973 ± 0.016	0.978 ± 0.013
EMG3 – EMG4	0.985 ± 0.003	0.987 ± 0.006	0.984 ± 0.008

Conclusion about muscle co-contraction (synergy between a pair of muscles) over motions examined was established on the base of the value of the cross-correlation coefficient (R). Taking into consideration that chosen muscles should work in a high coordinated way, the following ranges were set: strong co-contraction ($R \in [0.95; 1]$), moderate co-contraction ($R \in [0.90; 0.95)$), fair co-contraction ($R \in [0.85; 0.9)$) and weak co-contraction ($R < 0.85$)).

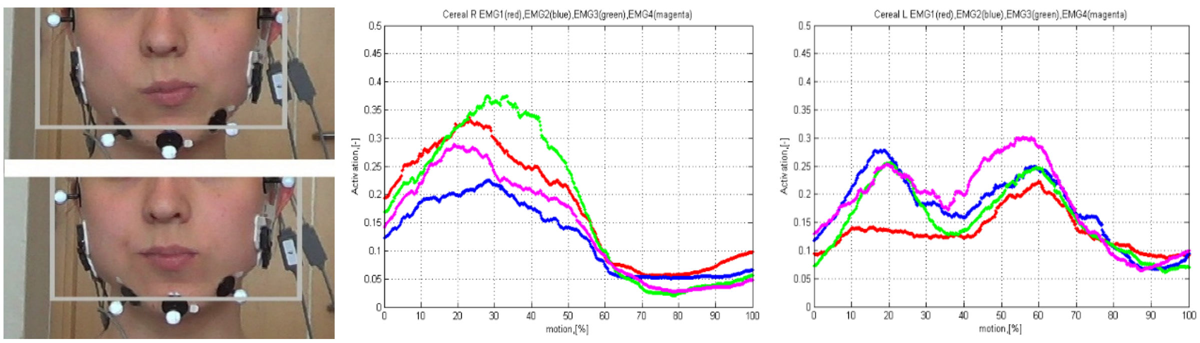
Analysing results of muscle activities, we revealed that:

1. during mouth opening motion and mouth closing motion the anterior part of right *Temporalis* was more activated in comparison with other three muscles (Fig. 2); during this motion it occurred a strong co-contraction between muscle pairs except the one pair (EMG1 – EMG3) over opening motion (Table 1);



(a) (b)

FIGURE 8. Chosen subject position during biting a cereal by using mixed sides (a). Estimated muscle activities during biting a cereal by using mixed sides (b)



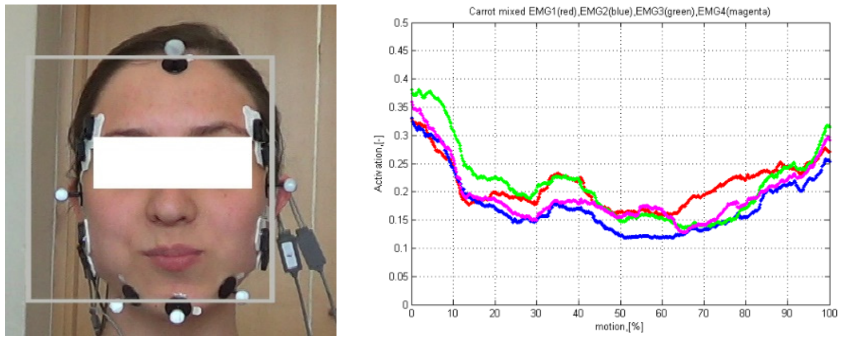
(a) (b) (c)

FIGURE 9. Chosen subject positions during biting a cereal by using right side and left side (a). Estimated muscle activities during biting a cereal by using right side (b) and left side (c)

TABLE 5. The cross-correlation results calculated for cereal biting test

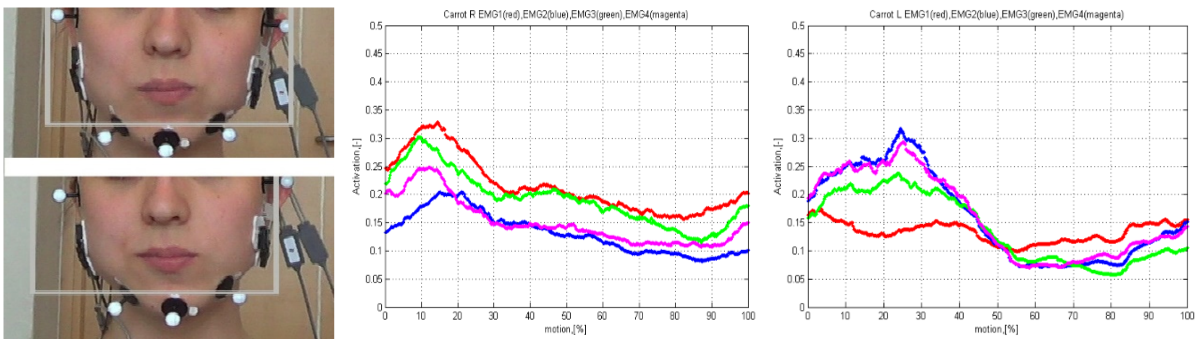
EMG data	Mixed sides: Cross-correlation R, [-]	Right side: Cross-correlation R, [-]	Left side: Cross-correlation R, [-]
EMG1 – EMG2	0.947 ± 0.042	0.972 ± 0.023	0.914 ± 0.076
EMG1 – EMG3	0.951 ± 0.042	0.973 ± 0.019	0.915 ± 0.067
EMG1 – EMG4	0.972 ± 0.019	0.979 ± 0.014	0.937 ± 0.043
EMG2 – EMG3	0.975 ± 0.024	0.943 ± 0.044	0.963 ± 0.028
EMG2 – EMG4	0.970 ± 0.013	0.960 ± 0.029	0.978 ± 0.015
EMG3 – EMG4	0.980 ± 0.008	0.978 ± 0.024	0.982 ± 0.008

2. over protrusion-retrusion motion the right *Masseter* and anterior part of right *Temporalis* were more activated in comparison with the left *Masseter* and anterior part of left *Temporalis* (Fig. 3); on the other hand, during retrusion-protrusion motion the anterior part of right *Temporalis* was more activated in comparison with other three muscles (Fig. 3); during these motions, it was observed a moderate co-contraction between the four pairs of muscles (EMG1 – EMG3, EMG1 – EMG4, EMG2 – EMG3, EMG2 – EMG4) and a strong co-contraction between other pairs of muscles (Table 2);
3. during lateral deviation from the start (neutral) position to the right side (Fig. 4), lateral deviation from the start (neutral) position to the left side (Fig. 4) and lateral deviation from the right side to the left side (Fig. 5), the anterior part of right *Temporalis* was more activated in comparison with other muscles; over these motions it occurred a strong co-contraction between muscle pairs except four muscle pairs (EMG1 – EMG2, EMG1 – EMG3, EMG2 – EMG4, EMG3 – EMG4) over lateral deviation from the right side to the left side (Table 3);



(a) (b)

FIGURE 10. Chosen subject position during biting a carrot by using mixed sides (a). Estimated muscle activities during biting a carrot by using mixed sides (b)



(a) (b) (c)

FIGURE 11. Chosen subject positions during biting a carrot by using right side and left side (a). Estimated muscle activities during biting a carrot by using right side (b) and left side (c)

TABLE 6. The cross-correlation results calculated for carrot biting test

EMG data	Mixed sides: Cross-correlation R, [-]	Right side: Cross-correlation R, [-]	Left side: Cross-correlation R, [-]
EMG1 – EMG2	0.936 ± 0.060	0.975 ± 0.005	0.941 ± 0.058
EMG1 – EMG3	0.944 ± 0.063	0.978 ± 0.021	0.945 ± 0.062
EMG1 – EMG4	0.947 ± 0.042	0.983 ± 0.016	0.960 ± 0.034
EMG2 – EMG3	0.971 ± 0.035	0.964 ± 0.026	0.976 ± 0.020
EMG2 – EMG4	0.977 ± 0.020	0.972 ± 0.014	0.981 ± 0.015
EMG3 – EMG4	0.987 ± 0.003	0.987 ± 0.005	0.985 ± 0.011

4. over biting a chewing gum/cereal/carrot by using mixed sides of the jaw it was observed simultaneous activations of all muscles examined (Figs. 6, 8, 10);
5. there were different patterns of muscle activations during biting a chewing gum/cereal/carrot by using a right side and left side (Figs. 7, 9, 11);
6. over biting a chewing gum, it was observed a strong co-contraction between muscle pairs except three ones (EMG1 – EMG2, EMG1 – EMG3, EMG1 – EMG4) over biting by mixed sided and one pair (EMG1 – EMG3) over biting by using a left side (Table 4);
7. during biting a cereal by using mixed sides it was observed a strong co-contraction except one pair (EMG1 – EMG2) (Table 5); over biting a cereal by using a right side and left side, it was observed a strong co-contraction except one pair (EMG2 – EMG3) over biting by right side and three pairs (EMG1 – EMG2, EMG1 – EMG3, EMG1 – EMG4) over biting by left side (Table 5);

8. during biting a carrot by using mixed sides, it was observed a strong co-contraction between muscles pairs except three pairs (EMG1 – EMG2, EMG1 – EMG3, EMG1 – EMG4) (Table 6); over biting a carrot by using a right side and left side (Fig. 11) it occurred a strong co-contraction between muscle pairs except two pairs (EMG1 – EMG2, EMG1 – EMG3) over biting by left side (Table 6).

CONCLUSIONS

Estimating activities of four superficial muscles (*Masseter* (right and left) and anterior part of *Temporalis* (right and left)) and kinematic data, it is possible to conclude about their shares in the jaw motion performance. Moreover, one can estimate the level of muscle co-contraction between the pair of muscles.

It should be kept in mind that each person uses his/her own neurologic pattern to activate muscles and produce motions. However, it is possible to reveal some similarities during the jaw motions and biting tests. To do this the different testing groups should be completed by diagnosing each subject with respect to the muscular system function, nervous system function, skeletal system function and dental factors.

The proposed method of estimation of activity of surface muscles acting at the temporomandibular joint is a non-invasive method. However, this method cannot be used to test the deep muscles. This method allows establishing a relationship between muscles examined and motion performed by taking into consideration the superficial muscle activations and motion analysis data. The obtained results of muscle activity could be used to model the jaw biomechanics.

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