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Duration and sequence of muscular activation in dentate individuals and complete denture wearers during simulation of activities of daily living

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Occlusal support may influence muscular function during complex motor tasks. This study evaluated the duration and sequence of muscular activation of masticatory (temporal, masseter), postural head/neck (sternocleidomastoid, trapezius), postural trunk (rectus abdominis, paravertebrals), and low extremity strength (rectus femoris, gastrocnemius) muscles during simulation of activities of daily living (ADL) in edentulous women wearing complete dentures (n = 10) and in dentate women (n = 10). Electromyographic activity was recorded during tests of stand-up/sit down in the Chair, sit up/lie down in the Bed and lift/lower Bags. Occlusal support (dentures) had a significant effect on duration of muscular activation in the Chair Test: the masseter muscle activated longer with dentures during the standing movement. The masseter and sternocleidomastoid muscles showed significant alteration in their order of activation in non-denture-wearing women. For the Bed Test, dentures had significant effect for the gastrocnemius during the sitting-up phase and for the rectus abdominis during the lying-down movement. For the Bag Test, head/neck muscles were activated in a different order as a function of occlusal support. Anticipation of activation of the paravertebral muscles, rectus abdominis, and gastrocnemius was observed in dentate women compared with denture wearers. These findings suggest that occlusal support influences electromyographic activity of some muscles during simulation of ADL.

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Loss of teeth and occlusal impairment not only compromise masticatory function but may also influence other motor systems related to postural control (1), speed of body movements (2), and physical performance, as measured by dynamic strength, agility, and balance (1, 3). Furthermore, the absence of occlusal support is associated with a decrease in the ability to perform activities of daily living (ADL) in the elderly (3, 4), and the use of dentures has been encouraged to improve ADL (1, 5). The relationship between masticatory function and other body motor systems is mediated by muscular activity and can be assessed using surface electromyography (EMG). For example, during dental clenching, masticatory muscles showed a functional connection with cervical (6–8), trunk (7, 8), and lower limb (9) muscles, and occlusion modifications influenced EMG activity of masticatory and head posture (10) muscles.

Electromyography is used to compare the amplitude of muscular activation during rest and voluntary maximum contraction in static conditions. Duration of muscular activation, latency time, and sequence of activation are other variables that can be assessed using EMG (8, 11, 12). Duration of activation is defined as the time interval between the onset and the end of muscular activity (11). Latency time (i.e. the time interval that precedes muscular activation as a response to a specific stimulus) has been related to age (13) and occlusal status (2, 12, 14), and it can be used to determine the sequence of muscular activation in different strategies applied in a specific movement (15–18). The combined evaluation of several electromyographic variables, such as amplitude, latency, duration, and sequence of activation, may allow a more comprehensive analysis of muscular activity during complex movements. However, to date, no study has analyzed the impact of occlusal support on such variables during routine movements considering muscle groups of different parts of the human body.

Therefore, it is important to determine whether a lack of occlusal support would impact muscular function during complex motor tasks. The aim of this study was to compare the duration and sequence of muscular activation of several muscle groups during simulation of ADL both in edentulous subjects, wearing or not wearing their complete dentures (CDs), and dentate subjects. The null hypothesis was that occlusal support did not affect the muscle activity of masticatory, postural head/neck, postural trunk, and low extremity strength muscles during simulation of ADL.

Material and methods

This was an observational study, with a cross-sectional design. The research protocol was approved by the University Ethics Committee in compliance with federal regulations and the Declaration of Helsinki and was registered in a national system for research in humans (CAAE-0602.0.002.000-05).

Study participants

A convenience sample was recruited from the population of edentulous patients or among students of the Pontifical Catholic University of Rio Grande do Sul, in Porto Alegre, Brazil. Two groups were selected: edentulous women wearing dentures; and dentate women. The dentate group was chosen as a gold standard comparison group considering their possible best physical conditions of dentition and muscular force for adult women. Also, at the Outpatient Prosthodontics Clinic most female patients were older and partially or completely edentulous.

Inclusion criteria for the first group were as follows: edentulous women wearing dentures in both the maxilla and the mandible; 50–70 yr of age; in good health; and showing adequate quality of dentures (19) regarding retention, stability, and occlusion. Exclusion criteria were: a history of maxillofacial surgery in the previous 3 months; presence of head or neck myofascial pain [including temporomandibular joint (TMJ) problems]; diagnosis of dementia; gait impairment; history of fracture of leg bones or knee surgery in the previous 5 yr; report of arthritis and/or pain in the lower limbs; history of heart attack in the previous year; and body mass index (BMI) above 31. Body mass index is defined as body mass (weight) divided by the square of body height and is used to quantify the amount of tissue mass (muscle, fat, and bone) and categorize a subject as underweight, normal weight, overweight, or obese based on that value. Ten participants with age between 50 and 68 yr (mean ± SD: 58.2 ± 5.6 yr) were selected.

Inclusion criteria for the dentate women were: female gender; 20–30 yr of age; adequate dental occlusion (minimum of 28 teeth, bilateral occlusal support, absence of relevant skeletal alterations); no report of orofacial pain or any dental problem; good general health; and BMI below 31. Ten participants with age between 20 and 29 yr (mean ± SD: 24.8 ± 3.7 yr) and BMI between 20 and 23 (mean ± SD: 22 ± 1) were selected.

Procedures

All participants voluntarily signed an informed consent form and were examined in the following sequence: clinical examination; measurement of anthropometric variables (height, weight, BMI); and acquisition of electromyographic data during simulation of ADL.

Electromyographic instrumentation and data acquisition

Surface EMG was used to record the muscle activity of eight muscles, on the right side: masticatory (temporal, masseter); head and neck (sternocleidomastoid, trapezius); trunk (rectus abdominis, paravertebral); and lower limb (rectus femoris, gastrocnemius medialis). Disposable, self-adhesive, silver-silver chloride electrodes (Noraxon, Scottsdale, AZ, USA), with bipolar configuration, 10 mm diameter and 20 mm interelectrode distance between centers, were placed over the bellies of the selected muscles parallel to muscular fibers, according to standard anatomic landmarks (20) (Table 1). One reference ground silver-silver chloride electrode (Medi-Trace 200 adult; Graphic Controls, New York, NY, USA) was attached over the left tibia.

Electromyographic activity was recorded using an eight-channel computerized instrument (Bortec Electronics, Calgary, AB, Canada) comprised of pre-amplifiers (fixed gain of 500) which were located approximately 10 cm away from the electrodes. The sampling frequency was set at 2,000 Hz for each channel.

Electromyographic signals were recorded during three kinesiologic tests simulating ADL: performing stand up/sit down in a chair (Chair Test); performing sit up/lie down in the bed (Bed Test); and when lifting/lowering bags (Bag Test) (20) (Table 2). Edentulous women performed the trials with and without their CDs (i.e. occlusal support), and the order of the trials was randomly chosen to prevent bias from motor learning. Before recording the actual trials in triplicate, the individuals practiced the movements. The same researcher gave verbal instruction, individually, to all subjects, and visual feedback was provided to standardize the timing of the movements during the test.

Analysis of EMG signals

The analogue EMG signal was amplified, digitized, and digitally filtered. To process and analyze the EMG signals, SAD32 (System of Data Acquisition - version 2.59b), a homemade software, developed by the Laboratory of Mechanical Measurements of the Mechanical Engineering School, Federal University of Rio Grande do Sul, Porto Alegre, was used. Input signals were digitally filtered in the frequency domain using the fast Fourier transform (FFT) algorithm (21) with a third-order Butterworth filter (22) and cut-off frequencies between 10 and 400 Hz. The filtered signals were smoothened by computing the root mean square (RMS) value in 500 ms-moving windows and weighed using a Hamming function (23). The representative signals for each muscle were subsampled to 1,000 Hz, so that each signal point was equal to 1 ms.

For each muscle, a graph of amplitude (V) vs. time (ms) was generated for muscular activity during the kinesiologic test (Fig. 1). A baseline amplitude value corresponding to the value for individual muscular rest was computed, and values exceeding this mean value plus 3 SD values of the mean were taken to signify muscle activation. This was based on considering the EMG signal in the rest period as a stochastic variable following a normal distribution in which 99.7% of the values will be below the mean plus 3 SD values.

Table 1

Position of the bipolar electrodes on the muscles evaluated [based on Baldisserotto *et al. (20)]*

Muscle	Electrode position
Temporal muscle	Electrode placed at the intersection of two reference lines. First reference line: between the mandibular angle and the condyle head, with an inclination of 20°. Second reference line: tangent to the ear and passing through the cantus
Masseter muscle	Parallel to the fibers, with the upper pole of the electrode between the tragus-labial commissure and the exocanthion–gonion lines
Sternocleidomastoid muscle	Parallel to the muscle fibers with superior pole at the same vertical height of the gonion
Trapezius muscle	Upper portion: shoulder positioned at 90° of abduction. A supramedial electrode and an infralateral electrode at a point 2 cm lateral to the half-distance between the C7 spinous process and the lateral end of the acromial process
Rectus abdominis muscle	6 cm above the navel and 3 cm to the right of the midline
Paravertebral muscles	Between L1 and L2, parallel and lateral to the right of the spine
Rectus femoris muscle	10–15 cm from the upper border of the patella; the electrode was placed parallel to the orientation of the muscle fibers
Gastrocnemius medialis muscle	50.3 ± 5.7% of the distance between the medial side of the popliteal cavity to the medial side of the Achilles tendon insertion, from the Achilles tendon

Table 2

Brief description of the simulation of activities of daily living (Chair Test, Bed Test, and Bag Test) [based on Baldisserotto *et al. (20)]*

Test	Initial position	Movement
Chair Test Stand up/sit down in a chair	Participant sitting in a chair (46 cm high), with back support but without arm and head support. Initially, feet are completely supported by the floor (no shoes) and knees and hips are flexed to 90°	The test was performed in triplicate with predetermined timing: 5 s of rest in seated position, 3 s to stand up, 5 s of rest in upright position, and 3 s to sit down.
Bed Test Sit up/lie down in the bed	Participant lying down on the left side of the body, in a bed 80 cm high, hips flexed with legs off the bed, without foot support. The head is supported by a pillow to keep the neck on the long axis of the spine	Subject started the movement by rising her head and trunk to a sitting position, with the support of her hands keeping her legs folded out of the bed, without her feet touching the floor. After 5 s, she made the movement of lying down again, returning to the initial position. The test was performed in triplicate with an interval of 30-s rest in the initial position (lying down).
Bag Test Lift/lower the bags	Participant standing in an upright position with two rigid plastic bags (4 kg weight each), with a single handle, positioned on the right and left sides of the body	Participant performed the movement of lowering, picking up, and lifting the bags with arms extended until the upright position was achieved. Afterward, the participant sustained the bags in an upright position, lowered the bags, and dropped the bags onto the floor. The test was performed in triplicate with predetermined time intervals: 3 s for lifting the bags from the floor, 3 s for sustaining in the upright position, 3 s for lowering the bags on the floor, and return to the initial position. An interval of 3 s of rest between movements was defined.

The onset and the end of muscular activity during each up/down test movement were marked in relation to the baseline values and used to determine the values of duration of muscular activation (ms) and latency time (ms). Based on latency time data, we determined the order of muscular activation during a specific movement.

Statistical analysis

To compare the outcome variable 'duration of muscular activation' in edentulous women, data were analyzed by ANOVA for repeated measures with Bonferroni correction for each movement of the ADL tests. The repeated-measures variable was occlusal status as these women were tested both with and without their dentures in place. Data analysis for edentulous women (with dentures) vs. dentate women was performed using multivariable ANOVA (factors: group, muscle) with Bonferroni correction for each movement of the ADL tests. Age and BMI were considered as covariates in the models.

Data on the outcome variable 'sequence of muscular activation' were analyzed by the Wilcoxon test for

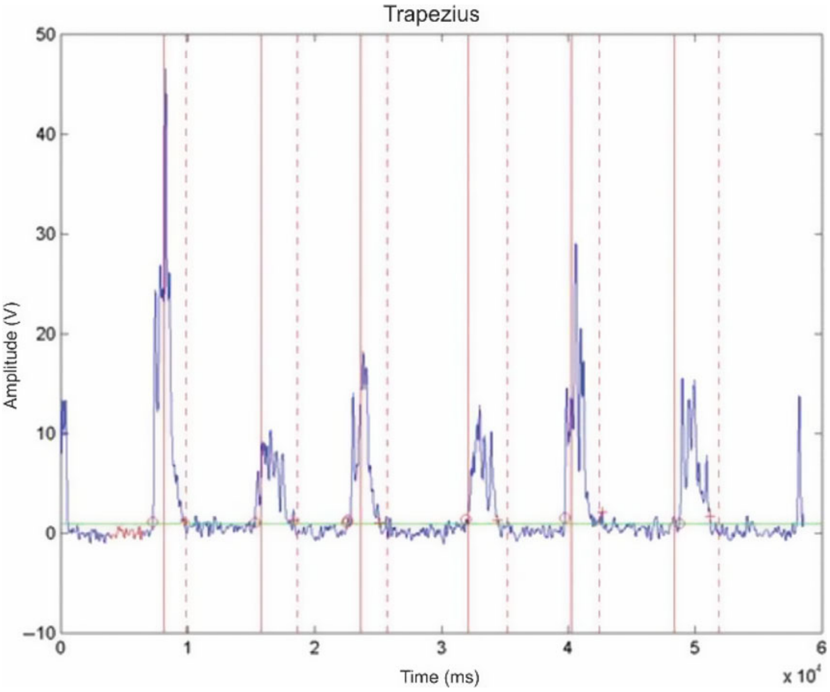

Fig. 1. Example of an eight-channel electromyography recording of the signal onset and duration of activity of trapezius muscles during the Chair Test.

Table 3

Chair Test: comparison of duration of muscular activation (in ms) between edentulous women with and without dentures, and between edentulous women with dentures and dentate women

Muscle/movement	Edentulous women with dentures (A1) Mean (SD)	Edentulous women without dentures (A2) Mean (SD)	P* (A1 vs. A2)	Dentate women (B) Mean (SD)	P† (A1 vs. B)
Temporal					
Stand up	1,068 (919)	970 (592)	0.078	1,362 (863)	0.671
Sit down	1,136 (882)	907 (729)	0.428	859 (1,122)	0.625
Masseter					
Stand up	978 (705)	331 (404)	**0.048**	1,005 (622)	0.327
Sit down	866 (811)	392 (607)	0.209	854 (675)	0.716
Sternocleidomastoid					
Stand up	1,774 (762)	1,241 (847)	0.086	1,462 (762)	0.731
Sit down	1,561 (1,072)	1,729 (857)	0.525	1,490 (740)	0.126
Trapezius					
Stand up	2,317 (363)	2,198 (763)	0.601	2,407 (800)	0.704
Sit down	2,430 (732)	2,126 (1,046)	0.291	1,940 (685)	0.343
Rectus abdominis					
Stand up	1,030 (625)	944 (628)	0.635	1,097 (712)	0.580
Sit down	691 (744)	815 (983)	0.701	683 (913)	0.512
Paravertebrals					
Stand up	2,482 (548)	2,315 (845)	0.648	2,401 (416)	0.990
Sit down	2,216 (819)	2,005 (1,092)	0.489	2,313 (554)	0.281
Rectus femoris					
Stand up	2,177 (502)	2,063 (501)	0.549	2,089 (371)	0.659
Sit down	1,733 (593)	1,817 (692)	0.567	1,742 (441)	0.336
Gastrocnemius					
Stand up	1,551 (844)	1,476 (556)	0.699	1,669 (696)	0.195
Sit down	2,097 (551)	2,072 (641)	0.770	2,011 (865)	0.814

*ANOVA for repeated measurements with Bonferroni correction.
†Multivariable ANOVA with Bonferroni correction.
P values < 0.05.

comparisons in edentulous women (i.e. with vs. without dentures) and by the Mann–Whitney *U*-test for comparisons between edentulous women (with dentures) and dentate women. A significance level of 0.025 was set for all tests to reject the null hypotheses considering a Bonferroni correction for each movement of the ADL tests.

Results

Table 3 shows measurements of duration of muscular activation in edentulous women with and without dentures, and in dentate women, made during the Chair Test. The activation time of the masseter muscle was three times longer during the standing-up movement when the participants were wearing their dentures than when they were without dentures ($P = 0.048$). There was no statistically significant difference in Chair Test movements between dentate women and edentulous women using their dentures.

Table 4 shows the results of measurements of duration of muscular activation during the Bed Test in edentulous women with and without dentures and in dentate women. Duration of activation was not affected by denture presence for any muscle or movement. Edentulous women with dentures showed longer activation time of the trapezius muscle than did dentate women during the Bed Test sitting-up movement ($P = 0.003$).

Table 5 shows the results of measurements of the duration of muscular activation for edentulous women with and without dentures, and for dentate women, during the Bag Test. Duration of muscular activation was not affected by denture presence among edentulous women for any muscle or movement. The sternocleidomastoid muscle showed a longer period of activation in dentate women during the movement of lowering bags ($P = 0.046$).

Sequence of muscular activation

The results regarding the sequence of muscular activation are shown in Figs 2–4. For the Chair Test (Fig. 2), there was a homogeneous pattern of activation of the temporal muscles in edentulous women, irrespective of whether they were with or without their dentures. Comparing the results from denture-wearing and non-denture-wearing edentulous women in the stand-up movement, the masseter muscle showed significant ($P = 0.013$) alteration in the order of activation when edentulous women did not wear their dentures. In the sit-down movement, the masseter ($P = 0.017$) and sternocleidomastoid ($P = 0.007$) muscles also activated in a different order in women without dentures. When comparing denture-wearing edentulous women with dentate women, the trapezius ($P = 0.023$) muscle assumed a more posterior position in the sequence of muscular activation in the dentate women, in the sit-down movement.

Table 4

Bed Test: comparison of duration of muscular activation (in ms) between edentulous women with and without dentures, and between edentulous women with dentures and dentate women

Muscle/movement	Edentulous women with dentures (A1) Mean (SD)	Edentulous women without dentures (A2) Mean (SD)	P^* (A1 vs. A2)	Dentate women (B) Mean (SD)	$P^{\dagger}$ (A1 vs. B)
Temporal					
Sit up	1,880 (1,413)	1,892 (1,108)	0.980	1,538 (806)	0.583
Lie down	1,612 (1,020)	1,632 (823)	0.958	1,651 (1,018)	0.168
Masseter					
Sit up	1,547 (1,336)	1,429 (1,261)	0.435	1,638 (886)	0.312
Lie down	1,687 (1,295)	1,233 (1,034)	0.338	1,926 (522)	0.959
Sternocleidomastoid					
Sit up	2,543 (1,098)	2,195 (972)	0.319	2,137 (1,105)	0.056
Lie down	2,673 (505)	2,314 (758)	0.217	2,361 (941)	0.787
Trapezius					
Sit up	3,804 (1,379)	3,726 (906)	0.787	2,698 (702)	**0.003**
Lie down	3,471 (1,097)	3,158 (1,075)	0.252	2,510 (537)	0.075
Rectus abdominis					
Sit up	2,434 (1,188)	2,558 (1,171)	0.342	2,006 (840)	0.339
Lie down	2,333 (1,179)	2,459 (756)	0.636	2,108 (677)	0.706
Paravertebrals					
Sit up	2,672 (1,129)	2,672 (1,129)	0.926	1,886 (844)	0.727
Lie down	2,128 (1,251)	2,124 (984)	0.992	1,469 (1,182)	0.978
Rectus femoris					
Sit up	2,423 (1,257)	2,247 (541)	0.643	1,743 (659)	0.481
Lie down	2,092 (1,213)	1,729 (1,173)	0.546	1,169 (937)	0.745
Gastrocnemius					
Sit up	895 (849)	1,090 (891)	0.543	1,261 (991)	0.205
Lie down	973 (862)	1,006 (1,101)	0.941	1,548 (714)	0.565

*ANOVA for repeated measurements with Bonferroni correction.

†Multivariable ANOVA with Bonferroni correction.

P values < 0.05.

Table 5

Bag Test: comparison of measurements of duration of muscular activation (in ms) between edentulous women with and without dentures, and between edentulous women with dentures and dentate women

Muscle/movement	Edentulous women with dentures (A1) Mean (SD)	Edentulous women without dentures (A2) Mean (SD)	P^* (A1 vs. A2)	Dentate women (B) Mean (SD)	$P^\dagger$ (A1 vs. B)
Temporal					
Lift	1,617 (1,125)	1,524 (1,167)	0.237	1,505 (1,100)	0.125
Lower	1,941 (1,339)	1,905 (1,197)	0.651	1,164 (965)	0.177
Masseter					
Lift	1,437 (866)	1,338 (885)	0.947	1,517 (1,160)	0.691
Lower	1,601 (1,195)	1,437 (1,118)	0.840	1,230 (1,027)	0.603
Sternocleidomastoid					
Lift	2,575 (743)	2,604 (1,418)	0.338	2,919 (827)	0.419
Lower	2,264 (819)	2,429 (1,208)	0.197	2,843 (652)	**0.046**
Trapezius					
Lift	3,020 (549)	2,823 (954)	0.952	2,396 (588)	0.236
Lower	2,817 (869)	2,427 (1,057)	0.758	2,133 (943)	0.730
Rectus abdominis					
Lift	2,031 (1,267)	1,531 (1,235)	0.355	1,490 (1,292)	0.547
Lower	1,953 (1,514)	1,431 (1,362)	0.323	1,480 (1,475)	0.249
Paravertebrals					
Lift	3,469 (515)	3,522 (980)	0.561	3,361 (565)	0.557
Lower	3,818 (949)	3,917 (1,072)	0.342	3,539 (738)	0.575
Rectus femoris					
Lift	3,328 (646)	3,531 (1,029)	0.295	3,100 (890)	0.088
Lower	3,557 (935)	3,916 (1,037)	0.258	3,413 (735)	0.355
Gastrocnemius					
Lift	2,432 (1,077)	2,239 (1,071)	0.159	2,563 (965)	0.059
Lower	2,410 (1,341)	1,939 (1,227)	0.108	2,280 (1,232)	0.291

*ANOVA for repeated measurements with Bonferroni correction.

†Multivariable ANOVA with Bonferroni correction.

P values < 0.05.

Comparison of the results obtained for denture-wearing and non-denture-wearing edentulous women in the Bed Test (Fig. 3) showed that the presence of dentures had a significant effect on the order of activation for the gastrocnemius muscle ($P = 0.008$) during the sitting-up movement and for the rectus abdominis muscle ($P = 0.004$) during the lying-down movement. Comparison of the gastrocnemius muscle between denture-wearing edentulous women and naturally dentate women showed that this muscle assumed a significantly ($P = 0.001$) more posterior position in the sequence of activation in edentulous women, in the lie-down movement.

For the Bag Test (Fig. 4), when comparing denture-wearing and non-denture-wearing edentulous women, the sternocleidomastoid ($P = 0.005$) and trapezius ($P = 0.012$) muscles activated in a different order as a function of occlusal support in the lowering phase. There was no statistically significant difference between denture-wearing edentulous and dentate women in the lifting and lowering movements.

Discussion

The results of this study show that the occlusal support provided by CDs affects muscular activity during simulation of ADL. In general, significant differences related to denture wearing were found for the duration and sequence of muscular activation in edentulous women, particularly for the masticatory and head/neck postural muscles. In relation to EMG amplitude or intensity, others have found that older denture wearers needed stronger activation of masticatory muscles to achieve maximum voluntary contraction in comparison with younger and older dentate subjects (24). The EMG amplitude may not be the most appropriate outcome measure to evaluate muscular activity in ADL tests because the muscle activation is submaximal, and different strategies can be used to perform complex movements (15, 17). Therefore, other EMG variables, such as duration and sequence of muscular activation, may be more sensitive for detecting the effects of occlusal support on muscular activity during ADL.

When performing the stand-up movement from the chair, denture wearers showed a longer duration of activation of the masseter muscles when they were wearing their dentures. This suggests that adequate occlusal support is related to activation of masticatory and cervical muscles to stabilize the head and neck during dynamic tasks. This can be explained by previous findings of co-contraction of these muscles during maximum dental clenching (6–8) and the role of dentures in mandibular stabilization during physical exercises (2). Analysis of the sequence of muscular activation showed that the sternocleidomastoid and trapezius muscles were activated at the start of the movement, and the

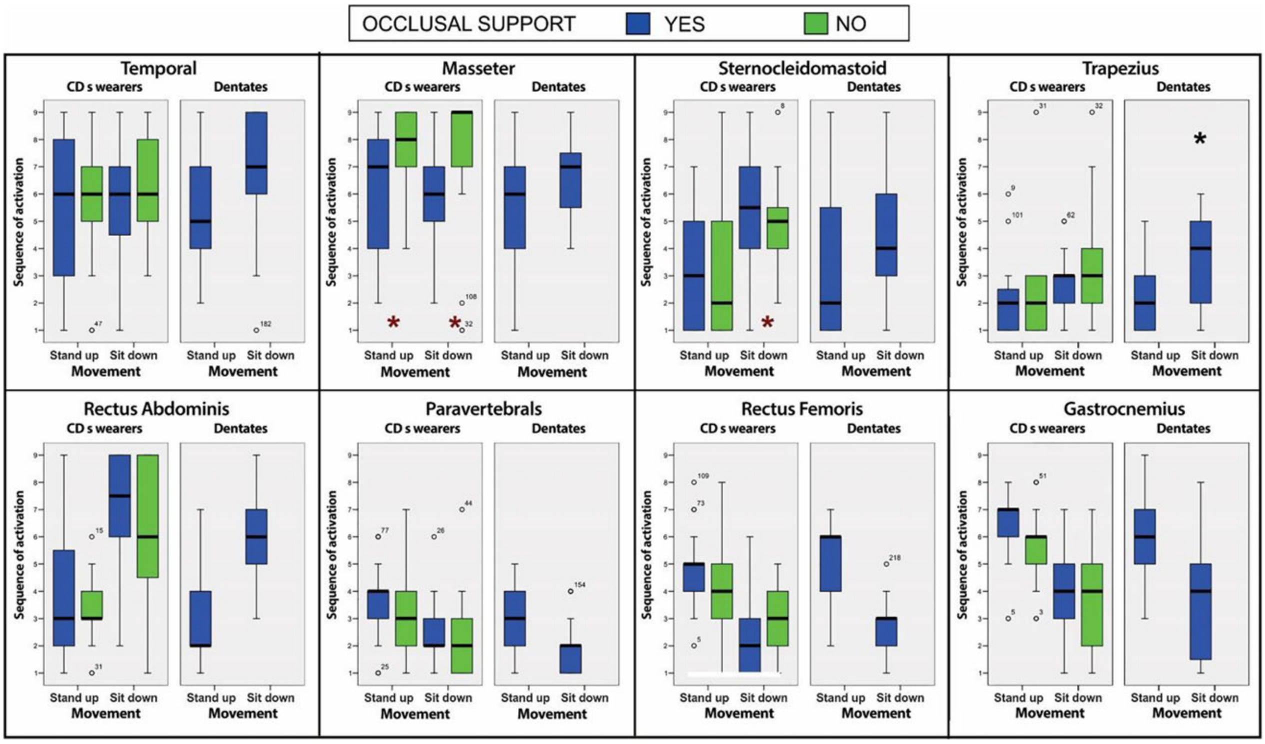

Fig. 2. Chair Test: distribution of the sequence of muscular activation in the stand-up and sit-down movements for edentulous women [with and without complete dentures (CDs)] and for dentate women. Blue bars refer to the presence of occlusal support (CDs or teeth), and green bars refer to absence of occlusal support (without CDs). Red asterisks indicate significant difference compared the conditions with and without CDs for edentulous women. Black asterisks refer to the comparison between edentulous women with CDs and dentate women.

temporal and masseter muscles contracted at the end, as initial and final postural muscles, respectively. The stand-up movement from a chair starts from a situation of complete body stability and progresses to other, less-stable, positions, requiring postural adjustment to place the center of gravity adequately after simultaneous displacements of the body (15, 25–27). The stand-up movement is more complex than the sit-down movement because it is performed against gravity (27), which might explain the longer duration of activity of the sternocleidomastoid and masticatory muscles to stabilize the head and neck. The sternocleidomastoid, trapezius, and rectus abdominis muscles were the first muscles to activate during the stand-up movement. These muscles are responsible for displacing the center of gravity forward and aligning the subject's head to enable them to keep their balance (15). These anticipatory postural adjustments of the non-focal muscles (i.e. muscles that are not directly involved in the movement) allow adequate performance of specific tasks (13, 28), such as arm elevation (18), stand-up/sit-down (15, 16), and sit-up from the bed (17).

The paravertebral and rectus femoris muscles can be considered as strength muscles for the stand-up movement as they display the largest EMG amplitudes (20) and an intermediate position in the sequence of activation. A tendency for earlier activation of the rectus femoris and gastrocnemius muscles was observed when the occlusal support was removed, which suggests that the strength muscles are needed more in situations of occlusal impairment. The activation of strength muscles initiates after the postural muscles guarantee that the center of gravity is properly localized (15). When an occlusal instability occurs, the activation of the strength muscles may compensate for greater difficulty in stabilizing the center of gravity. Likewise, during the sit-down movement, the results of the present study suggest that the loss of occlusal support influences the displacement of the center of gravity, so the masseter and cervical muscles need to modify their activation to improve body balance (15, 26, 27). The importance of occlusal support for the movements of stand-up/sit-down is more evident considering that the duration and sequence of activation were not different between denture wearers and dentate individuals. This suggests that provision of dentures maintained a postural control similar to the occlusal support given by the natural dentition.

Comparing the three tests, the possible combined effect of occlusal support and age was more evident in the Bed Test. The head and neck postural muscles (sternocleidomastoid and trapezius muscles) were activated for longer in denture wearers. Bleuse *et al.* (13) reported modifications in the sequence of activation between young and old individuals, and described longer activation of some muscles in old subjects to compensate for the lower stability caused by delay in the postural

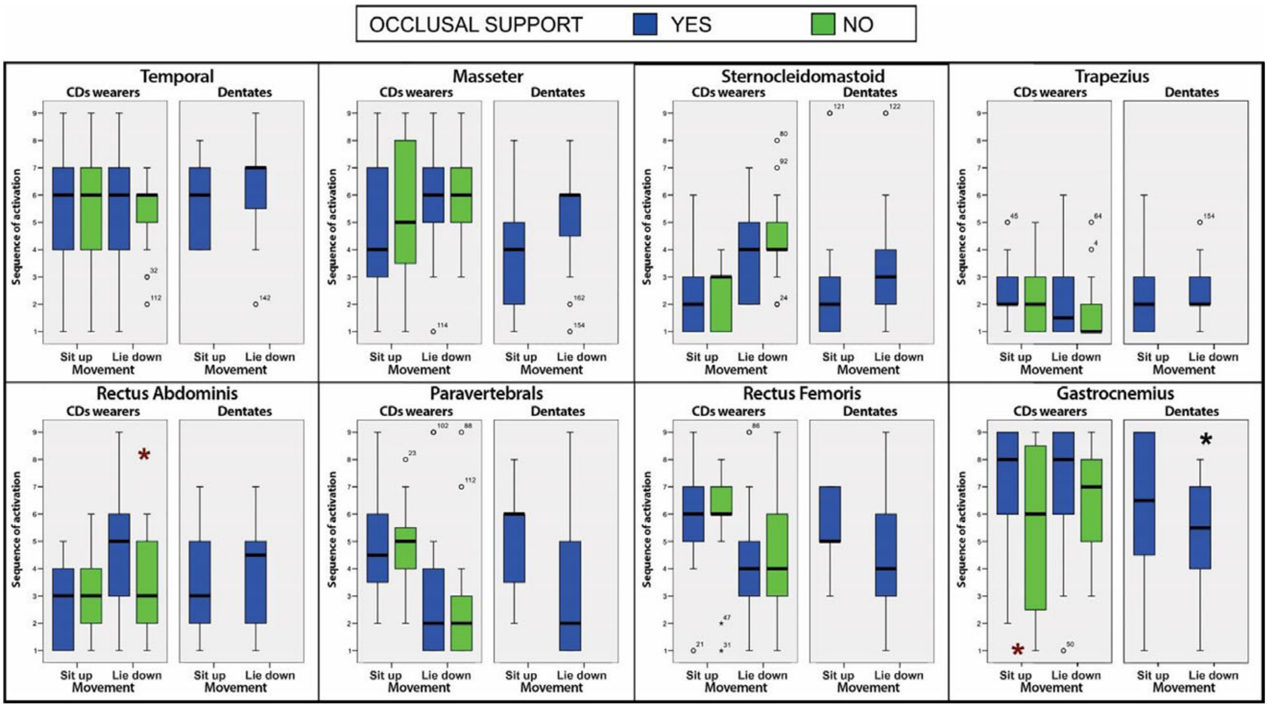

Fig. 3. Bed Test: distribution of the sequence of muscular activation in the sit-up and lie-down movements for edentulous women [with and without complete dentures (CDs)] and for dentate women. Blue bars refer to the presence of occlusal support (CDs or teeth), and green bars refer to the absence of occlusal support (without CDs). Red asterisks indicate significant difference compared the conditions with and without CDs for edentulous women. Black asterisks refer to the comparison between edentulous women with CDs and dentate women.

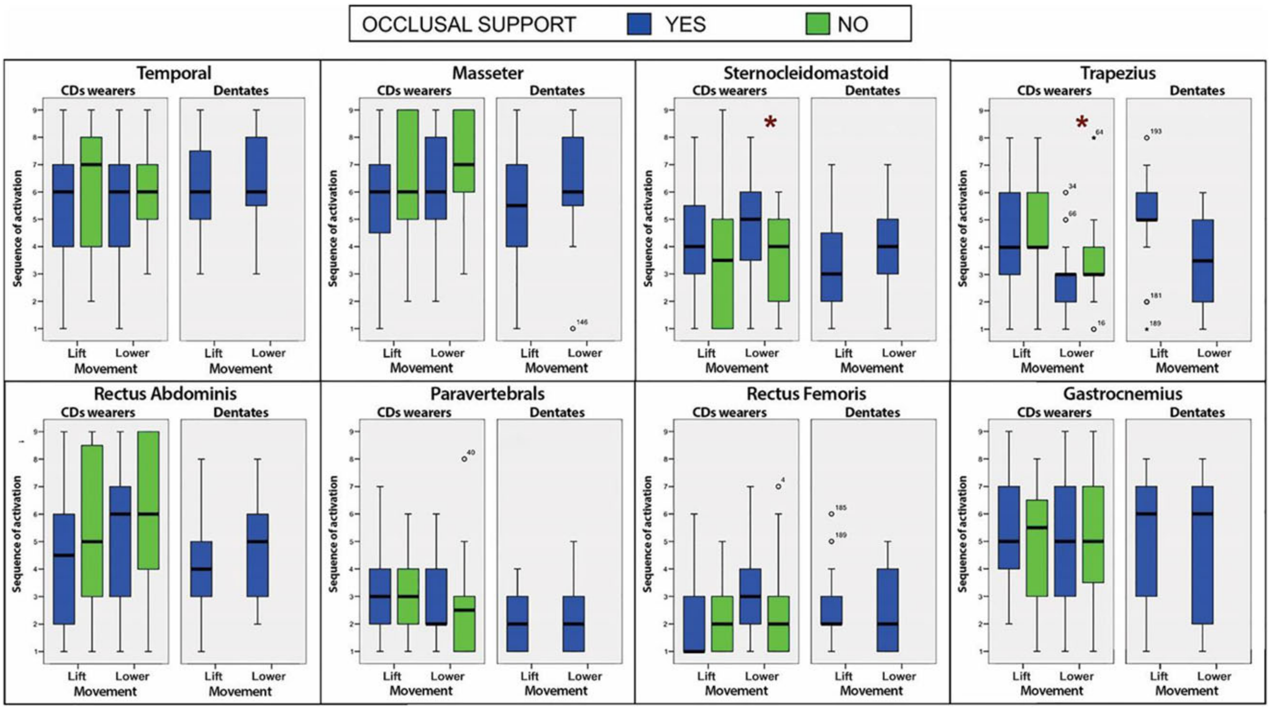

Fig. 4. Bag Test: distribution of the sequence of muscular activation in the lifting and lowering movements for edentulous women [with and without complete dentures (CDs)] and for dentate women. Blue bars refer to the presence of occlusal support (CDs or teeth), and green bars refer to the absence of occlusal support (without CDs). Red asterisks indicate significant difference compared the conditions with and without CDs for edentulous women. Black asterisks refer to the comparison between edentulous women with CDs and dentate women.

control system. The denture wearers of the present study cannot be formally classified as old persons, but age might have contributed to the longer activation of the neck postural muscles, promoting displacement of the center of gravity in the direction of the feet in the initial phase of trunk flexion (17). However, this hypothesis could only be tested against a group of dentate old people or a group of young denture wearers.

For the Bed Test, no significant effect of dentures on duration of activation was found, but the muscles with larger EMG amplitude (rectus abdominis and gastrocnemius) activated earlier with denture removal (20). The sternocleidomastoid, trapezius, and rectus abdominis muscles were the first muscles to activate during the sitting-up movement. Cordo *et al.* (17) also found that the sternocleidomastoid and rectus abdominis muscles were responsible for starting the rising movement from the bed so they can be considered to function simultaneously as postural and strength muscles. The muscular activity of the right and left sides was probably different for some muscle groups because the Bed Test movements were not symmetrical (assessment in the right side), whereas the Chair Test and Bag Test movements were symmetrical. The test of lifting and lowering bags with weights showed a homogeneous pattern of activation in both complete denture wearers and dentate individuals. Although the initial position (erect position) may have implicated in small displacement of the center of gravity, the masticatory and head and neck postural muscles activated in a different order when dentures were not present.

Previous studies have shown that the absence of occlusal support influences ADL. Walking on a level surface and toilet use (two items of the Barthel Index) decreased in slightly dependent persons with no occlusal support (4). Furuta *et al.* (5) reported that denture wearing leads to recovered swallowing function and improved nutritional status and indirectly improves ADL in the elderly. Although the present study has not used validated ADL tests, similar movements were simulated for the EMG analysis. The presence of occlusal support in the form of dentures was associated with a long duration of activation of masticatory and neck muscles, which shows the importance of head and neck stabilization during complex movements that displace the body's center of gravity, such as standing up from a chair. Furthermore, during the Bed Test, the sequence and amplitude of activation of the strength muscles (rectus abdominis and gastrocnemius muscles) changed as a function of occlusal support. Genkai *et al.* (4) also showed that mobility is related to muscular strength and body balance, which are influenced by occlusal support.

In summary, the results of this study suggest that occlusal support influences EMG duration and sequence of activation of several muscle groups during simulation of ADL. One limitation of this study is that a kinesiologic assessment was not performed concurrently to the EMG data acquisition, which would determine the relative role of individual muscles in each phase of the complex ADL movements. Therefore, it was not possible to analyze data of a possible re-activation of one muscle in later phases of the same movement or define the exact phase when the muscle was activated, which would prove the postural role of the masseter muscle in the Chair Test, for example. Another limitation of this exploratory study is the possibility of some false-positive results because of multiple hypothesis testing in a small sample size, even after using a conservative Bonferroni correction. Besides, a definite assessment of the individual main effect of age on muscular activity was not possible within the present study design. The results may be valid for healthy CD wearers with age below 60 yr. Thus, complementary data should be added from older dentate and edentate subjects, as well as from persons with compromised health, to investigate possible risk factors for ADL movements.

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References

1. Okubo M, Fujinami Y, Minakuchi S. Effect of complete dentures on body balance during standing and walking in elderly people. *J Prosthodont Res* 2010; **54**: 42–47.
2. Ishijima T, Hirai T, Koshino H, Konishi Y, Yokoyama Y. The relationship between occlusal support and physical exercise ability. *J Oral Rehabil* 1998; **25**: 468–471.
3. Okuyama N, Yamaga T, Yoshihara A, Nohno K, Yoshitake Y, Kimura Y, Shimada M, Nakagawa N, Nishimuta M, Ohashi M, Miyazaki H. Influence of dental occlusion on physical fitness decline in a healthy Japanese elderly population. *Arch Gerontol Geriatr* 2011; **52**: 172–176.
4. Genkai S, Kikutani T, Suzuki R, Tamura F, Yamashita Y, Yoshida M. Loss of occlusal support affects the decline in activities of daily living in elderly people receiving home care. *J Prosthodont Res* 2015; **59**: 243–248.
5. Furuta M, Komiya-Nonaka M, Akifusa S, Shimazaki Y, Adachi M, Kinoshita T, Kikutani T, Yamashita Y. Interrelationship of oral health status, swallowing function, nutritional status, and cognitive ability with activities of daily living in Japanese elderly people receiving home care services due to physical disabilities. *Community Dent Oral Epidemiol* 2013; **41**: 173–181.
6. Clark GT, Browne PA, Nakano M, Yang Q. Co-activation of sternocleidomastoid muscles during maximum clenching. *J Dent Res* 1993; **72**: 1499–1502.
7. Ehrlich R, Garlick D, Ninio M. The effect of jaw clenching on the electromyographic activities of 2 neck and 2 trunk muscles. *J Orofac Pain* 1999; **13**: 115–120.
8. Tecco S, Mummolo S, Marchetti E, Tetè S, Campanella V, Gatto R, Gallusi G, Tagliabue A, Marzo G. sEMG activity of masticatory, neck, and trunk muscles during the treatment of scoliosis with functional braces. A longitudinal controlled study. *J Electromyogr Kinesiol* 2011; **21**: 885–892.
9. Valentino B, Melito F. Functional relationships between the muscles of mastication and muscles of the leg. An electromyographic study. *Surg Radiol Anat* 1991; **13**: 33–37.

10. Kibana Y, Ishijima T, Hirai T. Occlusal support and head posture. *J Oral Rehabil* 2002; **29**: 58–63.
11. Rilo B, Da Silva JL, Gude F, Santana U. Myoelectric activity during unilateral chewing in healthy subjects: cycle duration and order of muscle activation. *J Prosthet Dent* 1998; **80**: 462–466.
12. Hosoda M, Masuda T, Isozaki K, Takayanagi K, Sakata K, Takakuda K, Nitta O, Morita S. Effect of occlusion status on the time required for initiation of recovery in response to external disturbances in the standing position. *Clin Biomech* 2007; **22**: 369–373.
13. Bleuse S, Cassim F, Blatt JL, Labyt E, Derambure P, Guieu JD, Defebvre L. Effect of age on anticipatory postural adjustments in unilateral arm movement. *Gait Posture* 2006; **24**: 203–210.
14. Morozumi K, Yamamoto I, Fujiwara T, Nishiya T, Takeuchi Y, Umeki C, Ichikawa T, Karaduno H. Effect of dentures wearing on motor reaction time and balance function in elderly people. *J Physiol Anthropol Appl Human Sci* 2004; **23**: 129–137.
15. Goulart FR, Valls-Sole J. Patterned electromyographic activity in the sit-to-stand movement. *Clin Neurophysiol* 1999; **110**: 1634–1640.
16. Ashford S, de Souza L. A comparison of the timing of muscle activity during sitting down compared to standing up. *Physiother Res Int* 2000; **5**: 111–128.
17. Cordo PJ, Gurfinkel VS, Smith TC, Hodges PW, Verschueren SM, Brumagne S. The sit-up: complex kinematics and muscle activity in voluntary axial movement. *J Electromyogr Kinesiol* 2003; **13**: 239–252.
18. Carvalho R, Vasconcelos O, Gonçalves P, Conceição F, Vilas-Boas JP. The effects of physical activity in the anticipatory postural adjustments in elderly people. *Mot Control* 2010; **14**: 371–379.
19. Shinkai RS, Hatch JP, Rugh JD, Sakai S, Mobley CC, Saunders MJ. Dietary intake in edentulous subjects with good and poor quality complete dentures. *J Prosthet Dent* 2002; **87**: 490–498.
20. Baldisserotto SM, Trindade DCC, Loss JF, Shinkai RSA. Reliability of EMG activity in complete denture users during simulation of activities of daily living. *Rev Odonto Ciênc* 2010; **25**: 42–47.
21. de Luca CJ. Physiology and mathematics of myoelectric signals. *IEEE Trans Biomed Eng* 1979; **26**: 313–325.
22. Gaszynska E, Kopacz K, Fronczek-Wojciechowska M, Padula G, Szatko F. Electromyographic activity of masticatory muscles in elderly women–a pilot study. *Clin Interv Aging* 2017; **12**: 111–116.
23. van Lieshout PH, Bose A, Namasivayam AK. Physiological effects of an 8-week mechanically aided resistance facial exercise program. *Int J Orofacial Myology* 2002; **28**: 49–73.
24. Alajbeg IZ, Valentic-Peruzovic M, Alajbeg I, Cifrek M. The influence of age and dental status on elevator and depressor muscle activity. *J Oral Rehabil* 2006; **33**: 94–101.
25. Mourey F, Grishin A, D'Athis P, Pozzo T, Stapley P. Standing up from a chair as a dynamic equilibrium task: a comparison between young and elderly subjects. *J Gerontol A Biol Sci Med Sci* 2000; **55**: B425–B431.
26. Lanzetta D, Cattaneo D, Pellegatta D, Cardini R. Trunk control in unstable sitting posture during functional activities in healthy subjects and patients with multiple sclerosis. *Arch Phys Med Rehabil* 2004; **85**: 279–283.
27. Dubost V, Beauchet O, Manckoundia P, Herrmann F, Mourey F. Decreased trunk angular displacement during sitting down: an early feature of aging. *Phys Ther* 2005; **85**: 404–412.
28. Tyler AE, Karst GM. Timing of muscle activity during reaching while standing: systematic changes with target distance. *Gait Posture* 2004; **20**: 126–133.