Neck and Shoulder Muscle Fatigue in High Performance Aircrafts Pilots: Effects of a Training Program (Part 2)

Giorgia Chini[1(✉)], Alessio Silvetti[1], Roberto Vitalone[2], Valeria Di Muzio[2], Marco Lucertini[2], Elena Lucertini[3], and Francesco Draicchio[1]

[1] DIMEILA, INAIL Research Area, Monte Porzio Catone, Rome, Italy
giorgia.chini@gmail.com, {al.silvetti, f.draicchio}@inail.it

[2] Experimental Flight Center, Aerospace Medicine Department, Pratica di Mare, Rome, Italy
{roberto.vitalone, valeria.dinuzio, marco.lucertini}@aeronautica.it

[3] Sapienza, University of Rome, Rome, Italy

Abstract. The aim of the study is to investigate the effect of a specific training on muscle fatigue by means of the analysis of the amplitude and spectral parameters of surface electromyography.

This report is a second part of our first paper on muscle fatigue in high performance pilots.

One experienced jet pilot was enrolled for this study. sEMG activity of the neck and shoulder muscles was recorded before and soon after a flight on European Fighter Aircraft. Afterwards, the pilot followed a specific neck and shoulder muscles training and he was recorded before and soon after a flight. Muscle activity was recorded bilaterally from Sternocleidomastoid, Upper and Middle Trapezius muscles. The temporal changes of amplitude and frequency of the sEMG signals were calculated on root mean square values, median frequency of the power spectrum and on spectral full width at half maximum.

The main finding of this study is that training strengthened the muscles of both the dominant and non-dominant side, as through the fatigue indexes we observed less fatigue after flight after the training.

It is possible to conclude that it would be important to incorporate neck and shoulder specific training in the list of operational duties. Moreover, by studying sEMG fatigue parameters, it is possible to obtain more detailed information about neck stress in order to deeper understand some of the causative factors for neck pain, so it would be possible to provide recommendations and tools to increase and improve the career longevity of jet pilots.

Keywords: Neck pain · Surface electromyography · Muscle fatigue · Jet pilots · RMS · MDF · FWHM

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1 Introduction

It is well known that neck pain and discomfort are reported with high prevalence among jet pilots compared to the general population, e.g. [1–6]. Hamalainen [7] states that it is important to perform further epidemiological studies to understand the risk factors and the contribution of specific neck training in order to prevent acute neck pain among fighter pilots. Some interventions would focus on aircraft design and personal protective equipment, while others are directed towards pilot training. In literature, various primary prevention strategies are reported, such as preflight warm-up, in-flight techniques, muscle resistance training, neck-specific training regimens and techniques. Different studies have suggested resistance training interventions designed just for the neck muscles [8–12], while other have indicated whole-body resistance training, either alone or together with neck specific training, [9–12]. The importance of specific physical exercise has also been emphasized by Harrison et al. [13], which found that the smaller muscles are more prone to increase muscular activity while wearing a night vision goggle (NVG) and a night vision goggle with counterweight (NVGcw) and suggested the importance of incorporating neck-specific training regimens in the list of operational duties.

The strengthening of neck and shoulder muscles in jet pilots is very important because they are exposed to forces that easily exceed 4 Gz and have been associated with potential neck injury [14, 15]. Furthermore, in a review by Cockwell [8], the author summarizes five common neck movements that under high Gz forces can considerably increase neck damage in jet pilots: (i) rotation beyond 35°, (ii) lateral bending, (iii) extension beyond 30°, (iv) flexion beyond 15° and (v) "check six" maneuvers.

Another risk factor to take into account is jet seat-back angle. A 30° backward seat on one hand increases G tolerance reducing blood displacement due to sustained high G, but F-16 pilots require 15° forward neck flexion with respect to the trunk, in order to maintain a horizontal gaze. It has been proved [16] that an F-16 jet pilot showed higher neck muscle and joint reaction forces if compared with those of other jets due to its 30° reclining seat-back respect to more vertically oriented seats (12°–13°) such as F-15, F-22 and Eurofighter Typhoon jets.

Verde's survey questionnaire [17] confirms these data. She found a neck pain incidence of 48.6% in F-16 pilots compared with 5.7% in Eurofighter Typhoon pilots. She also found a significant association between neck pain and an age over 30 years, total flight hours and flight hours exceeding 600 h. Total flight hours have also been reported as a significant factor also in the paper of Albano et al. [9]. He found that neck injury risk increases by 6.9% per 100 h of total flying time in F-16 jet pilots.

Surface electromyography has already been widely used to quantify muscle activity in jet pilots, e.g. [5, 13, 18]. For example, Bjorn et al., recorded the sEMG from eight muscles, i.e. bilaterally from the sternocleidomastoid, upper neck extensors and upper shoulder muscles in five fast-jet pilots on active flying duty. Each pilot performed two flights in a dynamic flight simulator, one session wearing NVG and one session with standard helmet mockup (control session). The pilots were exposed seven times to 3 Gz and aerial combat maneuvers, and three times to 7 Gz. The authors found that the additional helmet load, induced by night-vision equipment, causes greater muscle activity than flying with standard helmet mockup during the more demanding maneuvers. Sovelius et al. examined the sEMG of eleven Finnish Air Force pilots. The pilots flew two basic air combat maneuvering sorties with and without a lumbar support in random order. During these sorties the sEMG activity of the sternocleidomastoid, cervical, thoracic and lumbar erector spinae muscles was recorded by means of bipolar surface electrodes. Their results show that there seems to be a tendency toward a lower muscle strain and increased number of sEMG gaps when the lumbar support is worn. Moreover, the pilots' subjective experiences were mostly positive after the flights with the support. Lastly, Harrison et al. investigated sEMG of neck and shoulder muscle in helicopter pilots in four different conditions randomly ordered: without helmet, helmet only, helmet with NVG and helmet with NVG with counterweight. They examined the activity of eight muscles, bilaterally recorded: splenius capitis, sternocleidomastoid, upper and lower trapezius. They found a prevalence of increased muscle activity while subjects wore the NVG or NVGcw in smaller muscle groups (i.e. the sternocleidomastoid and splenius capitis).

However, to our knowledge, no one has investigated neck muscle fatigue in isometric conditions pre and post flight on Eurofighter Typhoon aircraft (EFA) before and after a specific neck and shoulder muscle training.

This preliminary study aims to propose a method to investigate the effect of specific training on muscle fatigue before and after a flight on EFA by analyzing the temporal and spectral changes in the amplitude of the sEMG signal, evaluated using the Root Mean Square (RMS) and the Median Frequency (MDF) and Full Width at Half Maximum (FWHM). This report is a second part of our first paper on muscle fatigue in high performance pilots [19].

2 Materials and Methods

2.1 Subjects

One male pilot was enrolled for this preliminary study. His height was 1.75 m, weight 70.5 kg and body mass index 23.02 kg/m^2. He was left-handed, on active flying duty, medically fit for flying duties and had no history of acute or chronic neck injuries, but he experienced some musculoskeletal symptoms related to flying during his career. After a full explanation of the experimental procedure, he signed the written informed consent to participate in the study. The experiment was approved by the local ethics committee, in compliance with the Helsinki Declaration and its revisions.

2.2 Instrumental Evaluation

The enrolled subject was screened using a 16-channel Wi-Fi transmission surface electromyography (FreeEMG300 System, BTS, Milan, Italy) to detect the sEMG activity of the neck and shoulder muscles before and soon after the flight, and before and after a specific neck and shoulder muscle training. Training consisted of 6-weeks specific exercises, twice a week for 30 min (Fig. 1).

After skin preparation, bipolar surface electrodes Ag/AgCl (F9079, FIAB, Florence, Italy) prepared with electro-conductive gel (diameter 1 cm, distance between the electrodes 2 cm) were placed along the direction of the muscle fibers of the right and left sternocleidomastoid (SCM), upper trapezius and middle trapezius (UT and MT, respectively) according to the atlas of muscle innervation zones [20], (Fig. 2). The electrodes' positions were marked with a dermographic pen, to put the electrodes back in the same points after the flight, in case they moved due to sweating.

The forces were measured using a digital dynamometer with a maximum load of 100 kg (Ergo Meter, Globus, Treviso, Italy).

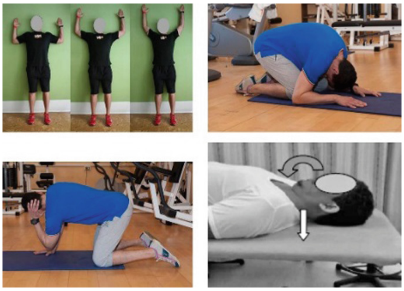

Fig. 1. Examples of the exercises performed during the specific neck and shoulder training.

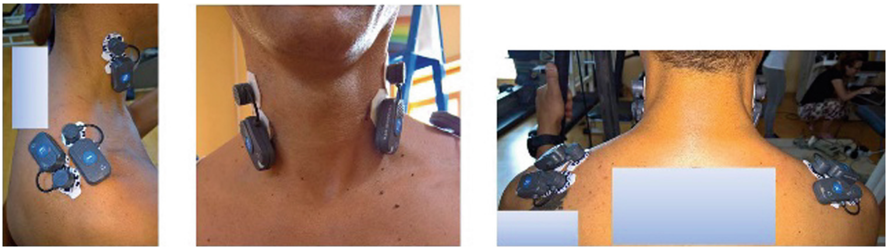

Fig. 2. Electrodes placement according the atlas of muscle innervation zones.

2.3 Experimental Procedure

Both before and after muscle training, data about the subject were acquired in two sessions: at rest (baseline, before the flight) and in fatigue condition (after the flight). Each session experimental procedure is explained in more detail in the following paragraphs.

2.4 Baseline (at Rest)

Before the flight, the subject performed isometric maximal voluntary contractions (iMVC) of each muscle to determine the maximum exerted force using a dynamometer. These tasks were repeated three times after a rest period of 3 min between trials [21], in order to compute a mean maximum force value. To determine the MVC force, the subject was instructed to increase the force from zero to his maximal force level, and to hold it for 5 s. After a 2 min rest from the last iMVC, a 40% iMVC contraction (C40) followed, and after a 3 min rest from C40 a 60% iMVC contraction (C60) was performed for each muscle. The subject exerted a force target level of 40% and 60% of iMVC shown on the dynamometer's display (Fig. 3). The subject was encouraged to keep these force levels for as long as he could to sustain an isometric contraction of each muscle, and in any case for no longer than 2 min. The contractions ended when the subject deviated from the sub-maximal force for more than 5 s. On the assumption that the most stressed muscles were SCM and UT, the maximal and submaximal contractions were performed in the order reported in Appendix in Table 1.

Fig. 3. This figure shows the subject looking at the dynamometer's display while performing the fatiguing tasks (40% and 60% of isometric maximum voluntary contraction illustrated on the dynamometer's display).

2.5 Fatigue Condition

Soon after the flight, the subject performed sub-maximal contractions of each muscle in the same order as at rest. First C40, and 3 min later C60, were carried out. As at rest, the subject was encouraged to keep these force levels for as long as he could sustain an isometric contraction of each muscle, and in any case for no longer than 2 min. The contractions ended when the subject deviated from the sub-maximal force for more than 5 s. After the flight, the submaximal contractions were performed in the order reported in Appendix in Table 2.

2.6 Data Analysis

The acquired sEMG signals were processed using Analyzer software (Smart Analyzer, BTS, Milan, Italy) and Matlab (MATLAB 8.5.0, MathWorks, Natick, MA, USA) to calculate the fatigue indexes. Raw sEMG signals were bandpass filtered (cutoff frequencies 10–45 Hz). Fatigue plots were calculated on root mean square values (rms) and median frequency of the power spectrum (MDF). Fatigue indices were calculated for each signal by subdividing the signal into 500 ms epochs, within which amplitude and frequency parameters were calculated. Since these parameters have proven to have a linear trend [22], the linear regression was evaluated and then data were normalized with respect to the intercept with the y-axis. The normalized slope, indicating the variation rate with respect to the initial value, was used as the fatigue index. Fast Fourier transformation (FFT) was performed on the filtered sEMG signals, and the FWHM was computed as the frequency interval in which the FFT amplitude is above 50% of its maximum.

3 Results

The fatigue index values before the training, calculated by using RMS, MDF and FWHM, are shown in Fig. 4 for each sub-maximal contraction, and both before and after the flight.

As far as the right side is concerned, in the C40 contraction, the RMS increases for both the UT and MT, and it remains roughly the same for the SCM after the flight. On the other hand, the MDF decreases both for the SCM and MT, and it remains almost the same for the UT after the flight. Lastly, the FWHM decreases only for the UT, and it increases both for the SCM and for the MT. In the C60 contraction, the RMS decreases for the UT and MT after the flight, while it increases for the SCM. On the other hand, the MDF decreases for both the SCM and MT after the flight, while it increases for the UT. The FWHM decreases only for the UT and it remains roughly the same both for the SCM and for the MT.

As regarding the left side, in the C40 contraction, the RMS decreases for all the three investigated muscles after the flight. In the same way, the MDF decreases for all the three investigated muscles after the flight. The FWHM decreases both for the UT and MT, and it slightly increases for the SCM. In the C60 contraction, the RMS increases for all the three investigated muscles after the flight. On the other hand, the MDF decreases for both the UT and MT after the flight, while it remains nearly the same for the SCM after the flight. The FWHM decreases only for the MT, it slightly increases for the UT, and it remains roughly the same for the SCM.

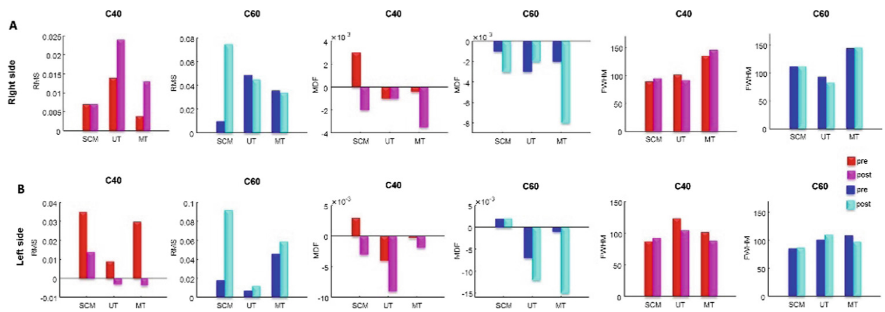

Fig. 4. Bar heights represent the root mean square (RMS), median frequency (MDF) and full width at half maximum (FWHM) values for each muscle both at 40% and at 60% of the isometric maximal voluntary contraction (C40 and C60), before and soon after the flight, before the training.

The fatigue index values after the training, calculated by using RMS, MDF and FWHM, are shown in Fig. 5 for each sub-maximal contraction, and both before and after the flight.

As far as the right side is concerned, in the C40 contraction, the RMS decreases for the MT and UT after the flight, while it increases for the SCM after the flight. On the other hand, the MDF increases for both the SCM and UT, while it decreases for the MT after the flight. The FWHM decreases for all the three investigated muscles. In the C60 contraction, the RMS increases for all the three investigated muscles after the flight. The MDF increases for all the three investigated muscles after the flight. The FWHM decreases both for the UT and MT and it slightly increases for the SCM.

As regarding the left side, in the C40 contraction, the RMS decreases for the SCM after the flight, while it remains almost the same for both the UT and MT, after the flight. The MDF decreases for both the UT and MT after the flight, while it remains approximately the same for the SCM after the flight. The FWHM decreases for all the three investigated muscles.

In the C60 contraction, the RMS increases for the SCM and UT after the flight, while it decreases for the MT after the flight. Lastly, the MDF decreases for the three muscles investigated after the flight. The FWHM decreases only for the MT, and it remains the same for both the SCM and the UT.

Table 3 in Appendix shows the difference after and before the flight for each index (delta), both before and after the training. Particularly it seems that RMS and FWHM are not affected by training.

Table 4 in Appendix shows the maximal recorded force values exerted before the flight, before and after the training. All muscles force values significantly grew after the training.

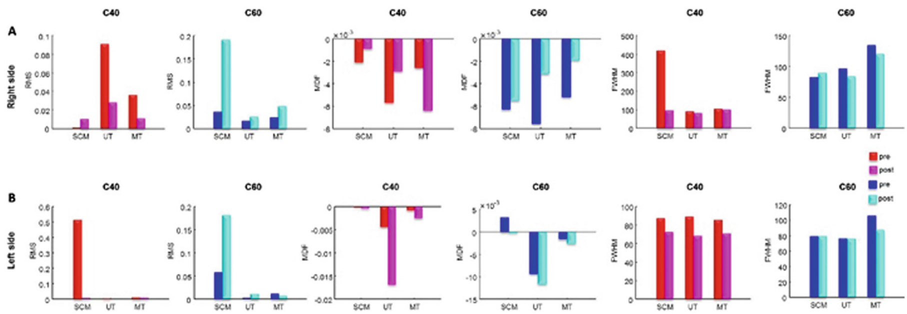

Fig. 5. Bar heights represent the root mean square (RMS), median frequency (MDF) and full width at half maximum (FWHM) values for each muscle both at 40% and at 60% of the isometric maximal voluntary contraction (C40 and C60), before and soon after the flight, after the training.

4 Discussion

In this study, we investigated for the first time the effect of a specific neck and shoulder training on the myoelectric manifestations of muscle fatigue of the neck and shoulder muscles, before and soon after a daytime flight on European Fighter Aircraft.

It is well known that neck pain and discomfort are often reported by jet pilots, and the cause of the aircrew's neck trouble is most likely multifactorial, but it is difficult to assess precisely. By definition, neck 'trouble' includes any combination of neck ache, pain, discomfort [23], acute pain, chronic pain, stress and strain [24]. On one hand, it is very difficult to link these subjective indicators to specific etiology; on the other hand, several contributing occupational factors are likely implicated within the injury process. Among these factors, frequency and duration of the whole body's postures including neck during flight, poor helmet fit, poor cockpit ergonomics and vibration [13, 25], use of night vision goggles (NVG) and counter-weight (CW) systems, and the number of hours wearing NVG during a mission [22] can be considered. Hence, it is important to be able to detect neck muscle fatigue in order to obtain more detailed information about neck stress. Moreover, since the importance of a specific training has been demonstrated for jet pilots, it is important to quantify its effects in such a way that, if a specific training proves to be useful to prevent acute neck pain in pilots, it could be suggested to be inserted among operational duties.

Hence, in this study, we investigated the effect of training in fighter pilots before and soon after a diurnal flight, therefore we did not take into account NGV and CW usage.

In particular, we found that the fatigue indexes calculated from the neck and shoulder muscles are quite sensitive in detecting jet pilots' fatigue. More in detail, before the training, it can be observed (see Fig. 4) that the RMS values showed a significant increase after the flight, mostly for the C60 isometric sub-maximal contraction than for the C40 isometric sub-maximal contraction. This result denotes that the stress for all three analyzed muscles is high to sustain in the C60 isometric sub-maximal contraction. As far as the MDF is concerned (see Fig. 4), MDF values show a remarkable decrease, almost always in both the C40 and in the C60 isometric sub-maximal contractions after the flight. This result could be attributed to a greater sensitivity of the MDF index, which appears suitable to be used in such analysis.

After the training, as regards the RMS, it slightly decreases on the non-dominant side, while it remains almost the same on the dominant side in the C40 isometric submaximal contraction (see Fig. 5). In the C60 isometric submaximal contraction, the RMS, both on the dominant and non-dominant side, does not considerably increase after the flight (see Fig. 5). These results show that the effort is more sustainable after training. As far as the MDF is concerned, it can be observed that after the flight, both in the C40 and C60 isometric submaximal contraction, the MDF does not decrease for the non-dominant side (except for the middle trapezius at the C40 isometric sub-maximal contraction), and it does not decrease a lot both in the C40 and C60 isometric sub-maximal contraction for all the three muscles of the dominant side (see Fig. 5).

As showed in the Table 3, which reports data differences between after and before the flight (delta) MDF seems to be more affected by the training (in particular on the left side, dominant in the studied subject).

These results show again that training strengthened the muscles of both the dominant and non-dominant side, so they can sustain the contraction with less fatigue. As far as the FWHM is concerned (see Figs. 3 and 4), both before and after the training it is not possible to identify a well-defined index trend before and after the flight, therefore FWHM may not be the most adequate index to give information about muscle fatigue in such conditions. Anyway, this could be due to the fact that this study is a case report and only one subject was analyzed, therefore it should be tested on a larger population.

The performed training was quite effective as showed by the increase of the maximal forces reported in Table 4.

The results of this study strengthen the suggestion, aimed previously at helicopter pilots [13, 25], to incorporate neck and shoulder specific training in the list of operational duties. Our data are in agreement with the work of Wickes and Greeves [26], who provided an early argument that general fitness and regular physical activity provided a protective benefit against flight-related neck pain. These myoelectric fatigue indicators may be useful to evaluate neck and shoulder muscle engagement, and they may be helpful to define physical exercise limits.

Moreover, since a less favorable body posture due to poor cockpit ergonomics could be an occupational factor in the onset of neck pain, as previously demonstrated by Verde et al. [17], the fatigue assessment could be a practical tool to obtain more detailed information about neck stress and provide an insight for helmet and seat design improvements.

Limitations of the study are related to the sEMG method, which include the possible presence of crosstalk, noise and problems related to the electrode location, electrode–skin impedance, size, configuration and distance [27]. To minimize these problems, we used the European Recommendations for Surface Electromyography (SENIAM) [28] and the muscle innervation atlas [20] as references. Moreover, these preliminary results should be confirmed in a larger sample.

Future examinations would be helpful to expand the analyzed sample, in order to validate a protective neck training protocol or ergonomic changes to the cockpit and the helmet.

5 Conclusion

In conclusion, this study confirms the suggestion, aimed previously at helicopter pilots, to incorporate neck and shoulder specific training in the list of operational duties. Another conclusion that can be drawn from our results is that it is possible to obtain more detailed information about neck stress through sEMG fatigue parameters, which can be useful for helmet and seat design improvements. In fact, the reduction in some of the causative factors for neck pain may help to increase the career longevity of jet pilots, reducing the work compensation cost and the costs associated with the training of new aircrews.

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Appendix

Tables

Table 1. Task run order before the flight. Abbreviations used: C40 = isometric contraction at 40% of the isometric maximal voluntary contraction; C60 = isometric contraction at 60% of the isometric maximal voluntary contraction; iMVC = isometric maximal voluntary contraction; SCM = sternocleidomastoid; MT = middle trapezius; UT = upper trapezius.

Order	Task	Muscle	Side	Repetition	Rest duration
1	iMVC	SCM	Both	2	2 min
2	C40	SCM	Both	1	2 min after iMVC
3	C60	SCM	Both	1	3 min after iC40
4	iMVC	UT	Dominant	2	2 min
5	C40	UT	Dominant	1	2 min after iMVC
6	C60	UT	Dominant	1	3 min after iC40
7	iMVC	UT	Not dominant	2	2 min
8	C40	UT	Not dominant	1	2 min after iMVC
9	C60	UT	Not dominant	1	3 min after iC40
10	iMVC	MT	Dominant	2	2 min
11	C40	MT	Dominant	1	2 min after iMVC
12	C60	MT	Dominant	1	3 min after iC40
13	iMVC	MT	Not dominant	2	2 min
14	C40	MT	Not dominant	1	2 min after iMVC
15	C60	MT	Not dominant	1	3 min after iC40

Table 2. Task run order after the flight. Abbreviations used: C40 = isometric contraction at 40% of the isometric maximal voluntary contraction; C60 = isometric contraction at 60% of the isometric maximal voluntary contraction; SCM = sternocleidomastoid; MT = middle trapezius; UT = upper trapezius.

Order	Task	Muscle	Side	Repetition	Rest duration
1	C40	SCM	Both	1	Soon after flight
2	C60	SCM	Both	1	3 min after 1
3	C40	UT	Dominant	1	Soon after 2
4	C40	UT	Not dominant	1	Soon after 3
5	C60	UT	Dominant	1	Soon after 4
6	C60	UT	Not dominant	1	Soon after 5
7	C40	MT	Dominant	1	Soon after 6
8	C40	MT	Not dominant	1	Soon after 7
9	C60	MT	Dominant	1	Soon after 8
10	C60	MT	Not dominant	1	Soon after 9

Table 3. Difference after and before the flight for each index (delta), both before (pre) and after the training (post). Abbreviations used: C40 = isometric contraction at 40% of the isometric maximal voluntary contraction; C60 = isometric contraction at 60% of the isometric maximal voluntary contraction; SCM = sternocleidomastoid; MT = middle trapezius; UT = upper trapezius.

Muscle	C40				C60			
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	right RMS delta		*left RMS delta*		*right RMS delta*		*left RMS delta*	
SCM	0.000	0.009	-0.021	−0.505	0.065	0.155	0.074	0.123
UT	0.010	−0.063	−0.012	−0.006	−0.004	0.009	0.005	0.009
MT	0.009	−0.026	−0.034	−0.002	−0.002	0.024	0.013	−0.005
	right MDF delta		*left MDF delta*		*right MDF delta*		*left MDF delta*	
SCM	−0.005	0.001	−0.006	0.000	−0.002	0.001	0.000	−0.004
UT	0.000	0.003	−0.005	−0.013	0.001	0.005	−0.005	−0.002
MT	−0.003	−0.004	−0.002	−0.002	−0.006	0.003	−0.014	−0.001
	right FWHM delta		*left FWHM delta*		*right FWHM delta*		*left FWHM delta*	
SCM	5.585	−322.779	5.235	6.361	−0.741	−14.742	0.650	−0.181
UT	−9.965	−9.726	−18.918	−12.767	−10.866	−20.740	8.647	−0.650
MT	10.412	−5.603	−13.714	−14.489	0.533	−14.419	−11.728	−18.587

Table 4. Mean values of the maximum force value recorded with the dynamometer during the iMVC, for each investigated muscle before and after the training. Abbreviations used: iMVC = isometric maximal voluntary contraction; SCM = sternocleidomastoid; MT = middle trapezius; UT = upper trapezius.

Muscle	Maximum force values [kg]	
	Pre-training	Post-training
SCM	19.1	23
Right UT	8.8	10.5
Left UT	9.1	11.1
Right MT	54.6	57.5
Left MT	57.7	60.1

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