Electromyography is a method of recording the electrical potential changes of a muscle, allowing access to the patterns of muscular electrical activity, and providing research on likely synergies, and the predominance of muscles in determined patterns of movement. Therefore, the objective of this study was to describe the electromyographic activity of upper-limbs muscles during (name of the maneuvers) in an aircraft T-27. The team of authors of this article works directly with the physical preparation in military pilots of the Brazilian Air Force. Thus, the interest in this study was based on the evidence of the high index of injuries in pilots and the lack of knowledge about the mechanical forces applied to the pilots during the accomplishment of maneuvers in this.
Materials and methods

Participants

Twelve male flight instructors of the Brazilian AFA (mean age: 28.8±2.5 years; weight: 68.9±7.4Kg; height: 1.73±0.04cm) participated voluntarily in this study. A signed express consent (Free and Informed Consent Term - TCLE) was obtained prior to starting participation, according to resolution 196/96 of CEP. Opinion Number: 1.015.756 Date of the Rapporteur: 04/14/2015, CAAE: 40667114.7.0000.5504.

Inclusion/exclusion criteria

Were considered suitable for this study were flight attendants who were approved in the Physical Fitness Assessment Test (TACF) regulated through the Systemic Standard of the Aeronautical Command (NSCA) 54-1 (2004), performed each semester in the AFA, and aviators who underwent an annual examination at the Aeronautical Medicine Center (CEMAL), the Aeronautical Health Organization (OSA), designated by the ANAC, through an agreement with the Aeronautical Command (COMAER), and obtained the Certificate of Physical Capacity. Were considered unable to participate in this study, the military that was disapproved, in any of the reports related to the Test of Assessment of the conditioning and medical evaluation, according to the Technical Instructions of the Aeronautical Health Inspections.

Instrumentation

A surface electromyography system (Trigno, Wireless EMG system, Delsysinc, Boston, MA, USA) was used to record muscle activity of the upper-limbs. The electric signal of the Prototype for the SFA-EMB312/T27 (University of Sao Paulo, Ribeirao Preto, SP, Brazil) was used for the skeletal muscles most active in performing maneuvers and acrobatics (Figure 2).

Procedures

Participants were informed on the procedures and objectives of the study. After participants have signed the informed consent, all procedures for data collection were conducted at the Laboratory of Biomechanics and Motor Control (LABIOCOM) of School of Physical Education and Sports of the University of São Paulo (EEFERP-USP). Prior to data collection, the skin was cleaned with isopropyl alcohol, upper limbs hair were scraped, and a light scraping of the skin was performed to remove dead cells. Thereafter, surface electrodes were placed on the belly of 10 muscles (flexor carpi radialis, extensor carpi ulnaris, brachial biceps, brachial triceps, anterior deltid, posterior deltid, upper trapezius, pectoralis major, infraspinitus, and latissimus dorsi), following the Surface Electromyography for the Noninvasive Assessment of Muscles (SENIAM) recommendations (Figure 3A)(Figure 3B). Surface electromyography was used as it provides greater comfort for the volunteer and is easy to manage for the researcher.
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The total time for each direction was 60 seconds. The load in Kgf in these movements was 30kgf and is equivalent to the maximum force applied to the spot during the execution of stunts on the T-27 aircraft subjected to a 5Gz + gravitational force. EMG recordings. The sampling frequency of the surface EMG signal was in the order of 2000Hz. The electrodes used were distance between the electrodes was 20mm from center to center. Figures 4–7 shows the execution of the analyzed movements.

The root mean square (RMS) of the signals was analyzed through the electromyographic amplitude of each of the selected muscles in the front, the back, External Rotation, and Internal Rotation.

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movements. The RMS values were smoothed in the program Delsys–trigno wireless, exported to the format “.txt” and passed to the MatLab program, where a specific routine was used to remove the mean and peak values for each trial in each condition. The RMS data (Root Mean Square) found through the routine created in the MatLab program was normalized by the peak of the EMG signal of each volunteer. This methodological procedure was based on another study produced and already published by our team of researchers. The input signals were amplified up to 1000 times by the preamplifier in the cable and filtered within a frequency of 20Hz to 800Hz with active filters. The electromyography had a gain adjustment in the final stage and offset, which made it ideal for the system. The electromyographic electrodes used in this study captured the bipolar signal in the passive configuration, with an instrumentation amplifier INA 118 near the electrodes, amplifying the signal 1000 times near the signal source, thus avoiding degradation of the signal-to-noise ratio.

**Statistical analysis**

Descriptive statistics and outcome values were expressed by mean±standard deviation. All statistical analyses were performed using the Action Add-in from the Microsoft Excel (version, company, city). To analyze the data distribution, the Shapiro-Wilk normality test was applied.

**Results**

There was a higher mean electromyographic activation of the anterior deltoid muscle in the front movement (162,280mV); the flexor carpi radialis muscle in the back movement (123,349mV); the brachial biceps muscle in the Internal Rotation movement (440,263mV); and the posterior deltoid muscle in the external rotation movement (545,028mV). Through the analysis of the mean electromyographic activation, there was greater muscle activation in the external rotation movement (1325,928mV) followed by the internal rotation (990,0680mV), the back (516,93mV), and the front movements (485,904mV). Details on the mean and peak EMG activity of each muscle are available in Table 1 & Table 2, respectively. The analysis of peak electromyographic activation showed that the highest values were presented for the Anterior Deltoid muscle (334,234mV) in the front movement; the Flexor Carpi Radialis is muscle in the back movement (407,969mV), the Brachial Biceps muscle in the Internal Rotation movement (314,587mV), and the Posterior Deltoid Muscle in the External Rotation movement (1277,229 mV). The analysis of the peak electromyographic activation showed greater muscle activation in the External Rotation movement (3598,876 mV), followed by the Internal Rotation (1598,964mV), the back (1371,476mV), and the front movements (993,856mV) (Table 2).

| Muscles            | Front         | Back          | Int. Rotation | Ext. Rotation |
|--------------------|---------------|---------------|---------------|---------------|
| Flexor Carpi Radialis | 7,440         | 123,349       | 81,184        | 182,141       |
| Extensor Carpi Ulnaris | 37,092       | 25,752        | 41,724        | 39,354        |
| Brachial Biceps    | 9,659         | 54,043        | 314,587       | 20,926        |
| Brachial Triceps   | 52,088        | 18723         | 40,771        | 62,312        |
| Anterior Deltoid   | 162,280       | 9,045         | 72,617        | 121,446       |
| Posterior Deltoid  | 105,173       | 110,030       | 13,536        | 545,028       |
| Upper Trapezius    | 8,709         | 59,506        | 9,955         | 125,662       |
| Pectoralis Major   | 6,005         | 7,517         | 225,504       | 9,693         |
| Infra-spinal       | 78,904        | 53,972        | 16,035        | 175,009       |
| Latissimus Dorsi   | 18,550        | 54,997        | 48,475        | 44,353        |
| Mean               | 48,590        | 51,693        | 86,439        | 132,592       |
| Standard Deviation | 52,39         | 39,65         | 101,79        | 157,59        |
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Table 2 Analysis of the Peak Electromyographic amplitude in microvolt’s (mean±SD)

| Muscle                | Front | Back | Int. Rotation | Ext. Rotation |
|-----------------------|-------|------|---------------|---------------|
| Flexor Carpi Radialis| 21,693| 407,969| 268,368 | 572,583 |
| Extensor Carpi Ulnaris| 55,785 | 55,431 | 126,201| 95,449 |
| Brachial Biceps       | 16,758 | 262,987| 440,263| 94,332 |
| Brachial Triceps      | 83,028 | 37,861| 73,188| 173,620 |
| Anterior Deltoid      | 334,234| 27,925 | 238,549| 432,402 |
| Posterior Deltoid     | 203,173| 145,888| 47,771| 1,277,229 |
| Upper Trapezius       | 21,403| 133,301| 19,160| 369,121 |
| Pectoralis Major      | 13,459| 17,230 | 264,760| 19,093 |
| Infra-spinal          | 206,431| 156,022| 39,222| 470,104 |
| Latissimus Dorsi      | 37,886 | 126,859| 207,154| 94,938 |
| Mean                  | 99,385| 137,147| 172,464| 257,960 |
| Standard Deviation    | 110,38| 121,37| 134,91| 203,32 |

Discussion

For a better understanding of muscle strength, the present study sought through the electromyographic analysis to find out which intensity the upper limb muscles are requested during the execution of simulated acrobatics.

The present study used EMG methods to suggest a specific training needed for pilots from the Brazilian Air Force Academy (AFA), in terms of muscular activation. There was higher mean electromyographic activation for the Anterior Deltoid muscle in the front movement (162,280mV); the Flexor Carpi Radial muscle was in the back movement; (123,349mV) the Brachial Biceps Muscle in the Internal Rotation movement (440,263mV), and the Posterior Deltoid Muscle in the External Rotation movement (545,028mV). Through the analysis of the mean electromyographic activation, there was greater muscle activation in the External Rotation movement (1325,928mV) followed by the Internal Rotation (990,0680mV), the back (516,93mV), and the front movements (485,904mV). The analysis of the peak electromyographic activation demonstrated that the highest values were presented for the Anterior Deltoid muscle (334,234 mV) in the front movement; the Flexor Carpi Radial muscle was in the back movement (407,969mV), the Brachial Biceps Muscle in the Internal Rotation movement (314,587mV), and the posterior Deltoid Muscle in the External Rotation movement (1277,229mV).

The analysis of the peak electromyographic activation demonstrated greater muscle activation in the External Rotation movement (3598,876mV), followed by the Internal Rotation (1598,964mV), back (1371,476mV), and front movements (993,856mV). The overload is increased when the pilot is subjected to aGz+ force during acrobatic maneuvers. This force is external and compresses the pilot in the seat, increasing the effort necessary during movement of the limbs. This overload can cause pain and injury. The acceleration force is proportional to the velocity and inversely proportional to the angle of the curve that the aircraft performs. As it is a compressive force that can reach a value of 5Gz+ during acrobatic maneuvers, it causes an increase in body weight and body segments by up to 5 times (according to the value of Gz+), exposing pilots to severe joint and muscular overloads that may cause injuries. Adaptations are highly necessary, and the lack of specific physical training can reduce unequal flight conditions, causing postural alterations in pilots. As the fleet of EMB 312 T-27-Tucano aircraft at the Brazilian Air Force (BAF) is very large with a high manufacturing cost and no forecast for replacement with newer models, there is a need for adequate adaptation of the pilots to this aircraft. In this way, the pilots can have favorable conditions to pilot, without greater physical overloads and with satisfactory conditions to eject in case of extreme necessity. Knowledge of the morphological characteristics of BAF pilots is of great value in the development of new aircraft designs and in adaptations of aircraft already manufactured or acquired.

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None.

Conflict of interest

The authors declare that there is no conflict on interest.

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