

# Biomechanical study of the influence of the weight of equipment on selected trunk muscles

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Overexertion and pain of the musculoskeletal system may occur partly owing to load application by the equipment. Both the weight of equipment and the duration of loading are relevant. The aim of the present study was to examine the extent of loading and resultant strain in the trunk muscles. Therefore, the trunk posture of soldiers and muscular activity in reaction to different equipment components (helmet, load-carrying equipment, gun and backpack) were evaluated. Electromyography was performed and a visual assessment of body axis was conducted based on standardised planar images. Data indicate that the activity of the trunk muscles examined (latissimus dorsi, trapezius and pectoralis major) is dependent on the weight and distribution of the equipment components. Activity in the trapezius muscle, for instance, was doubled during specific load application. Moreover, the method of carrying the rifle had a significant influence on the activity of the trapezius muscle (one-sided decrease of activity by 50%). Subjects were able to stabilise the body axis in the coronal plane through increased muscle activity, however, in the sagittal plane a compensatory ventral inclination of the body was observed. Uneven load distribution can lead to an irregular strain on the musculoskeletal system.

*Key words: activity, EMG, equipment, posture*

## 1. Introduction

Compared with the general population, soldiers bear a higher risk of injury and strain on the musculoskeletal system [1]. Various factors are relevant for the occurrence of injuries, such as physical fitness, age, gender, smoking habits and biomechanical properties such as foot shape and spinal curvature [1]–[5]. A main cause of symptoms is the carrying of heavy loads over long distances [5]. Earlier studies discussed different influences of equipment, showing, for example, that footwear can cause specific changes to the activity of muscles in the lower extremities [6]. Equipment weight is also relevant to stride length and frequency, range of motion of joints

and orientation of the body axes in space [7]. Mastalerz et al. found a link between trunk inclination and muscular activity [8].

Furthermore, the weight of equipment and its distribution on the body influences the vertical load and bearing pressure on the sole of the foot. Foot arch stability is influenced by pre-existing conditions such as splayed or flat feet [9]. The centre of mass of the body in the transverse plane shifts toward the additional load, though the centre of mass does not shift in the sagittal plane. A compensatory ventral inclination of the sagittal axis, however, does occur [9]. Equipment weight also influences the activity of the trunk muscles. Load-bearing systems supported on the hips influence the activity of muscles such as the trapezius and erector spinae muscles [10]. When wearing only

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a backpack, Al-Khabbaz et al. showed that there is no significant change in muscle activity of the erector spinae, in contrast to the rectus abdominis [11]. Furthermore, the authors reported a significant backward inclination while rotation and side flexion remained almost the same [11].

The aim of the present study was to record the influence of gradually increased equipment load (helmet, load-carrying equipment, backpack and rifle) on the activity of the trapezius, pectoralis major and latissimus dorsi muscles on both sides of the body, by means of electromyography and determination of the influence on posture by visual assessment. We hypothesised that heavy load carrying may lead to increased muscular activity during walking and load distribution can influence the orientation and inclination of body axis in the coronal plane.

## 2. Materials and methods

### 2.1. Subjects

37 professional soldiers volunteered to take part in this study. Five soldiers did not complete the analysis, however data obtained prior to them aborting the experiment was used in the study. This study was approved by the local ethical committee of the University of Rostock (file no.: A 2009 36). All subjects were fully informed of the content of the study and gave their written consent. Subjects were between 20 and 53 years of age (mean: 29 years, median: 26 years, standard deviation: 8.3 years), weighed between 62.5 kg and 112 kg (mean: 81.5 kg; median: 81 kg, standard deviation: 10.6 kg), were between 163 cm and 193 cm in height (mean: 177.8 cm; median: 179 cm, standard deviation: 6.7 cm) and had a BMI of between 21 kg/m<sup>2</sup> and 34 kg/m<sup>2</sup> (mean: 25.9 kg/m<sup>2</sup>; median: 26 kg/m<sup>2</sup>, standard deviation: 3 kg/m<sup>2</sup>). All subjects had finished basic military training when they participated in the study. Prior to the actual examination, subjects underwent a physical examination for orthopaedic diseases and to test the range of motion of their ankles, knees, hips and shoulders, as well as the curvature of the spine.

In the measurement protocol, subjects successively added pieces of equipment (helmet, load-carrying equipment, backpack and rifle) in the order shown in Fig. 1. The weight of each piece of equipment is listed in Table 1.



Fig. 1. Location of markers (from left to right) and order in which equipment was added: control, helmet, load-carrying equipment, backpack, rifle (in front of the body) and rifle (slung over the right shoulder)

Table 1. Individual weight of equipment components used

Equipment	Weight
Helmet	1.5 kg
Load-carrying equipment	1 kg
Backpack	15 kg
Rifle (G 36)	3.63 kg

### 2.2. EMG measurements

Dynamic instead of kinetic surface electromyography (EMG) was performed on both pectoralis major and latissimus dorsi muscles, as well as on the descending parts of the trapezius muscles, in accordance with the standards for reporting EMG data of the International Society of Electrophysiology and Kinesiology [12], using a wireless EMG system (Noraxon Telemyo 2400T<sup>TM</sup>, Noraxon, Scottsdale, Arizona, USA). Recordings were made using bipolar Ag/AgCl electrodes (Blue Sensor P<sup>TM</sup>, Ambu, Germany) with an active electrode diameter of 7 mm. Electrode sites were shaved, cleaned with alcohol, dried and slightly abraded before electrodes were applied. Electrodes were placed both longitudinally and axially over the muscle belly of interest, spaced approximately 40 mm apart (centre-to-centre) [13]. It should be noted that electrode placement was in part determined by the distribution of the equipment. EMG data were sampled at a frequency of 1500 Hz. Signals were amplified, filtered (10–400 Hz) and transmitted via a wireless transmitter to a personal computer.

Using the software MyoResearch<sup>TM</sup> for further processing (Noraxon, Scottsdale, Arizona, USA), the EMG data were full wave rectified, smoothed and the amplitude normalised. Each recording consisted of at least five double steps. For every piece of equipment added, subjects spent a warm-up period of about two

minutes on a treadmill. EMG measurement was taken as the subjects walked on a treadmill at a constant speed of 3.2 km/h (0.89 m/s). Average step length was measured by video analysis using the Dartfish software (Version 4.0.6.0.; Dartfish; Taufkirchen, Germany) and amounted to approximately  $0.64 \text{ m} \pm 0.01 \text{ m}$  (mean value  $\pm$  standard deviation). Surface electromyograms of the pectoralis major and latissimus dorsi muscles, as well as of the descending part of the trapezius muscle, were analysed using the variables of mean amplitude, peak and area under the curve (AUC).

### 2.3. Static measurement of body axis and determination of shoulder height

Standardised image analysis was performed on frontal and sagittal images of the subjects. To this end, soldiers were asked to stand before a backdrop with markings indicating height and then photographed with a stationary DSLR camera (Nikon D50, Tokyo, Japan). To support measurement, markers were attached to the following locations on the bodies of subjects: the lateral malleolus, the cleft of the knee joint (laterally, ventrocraniially to the head of the fibula), the greater trochanter, the lateral epicondyle of the humerus, the acromion and the tragus (laterally). The body axis was measured by determining the deviation of an imaginary straight line joining the lateral malleolus and tragus from the vertical axis in space. On the coronal plane, the deviation of an imaginary straight line running from midway between the medial malleoli through the navel and midway between the nipples to the base of the nose from the vertical image axis was determined.

In order to determine shoulder height, the distance from the upper edge of the sole of the boot to the acromion was measured in the sagittal plane along a straight vertical line. In order to ensure comparability of the measurements taken, values were expressed as percentages of the respective control value. GIMP 2 open source software (GNU Image Manipulation Program, GNU General Public Licence, Version 2.6.11 [www.gimp.org](http://www.gimp.org)) was used to determine the angle of deviation of the body axis and the shoulder height.

### 2.4. Statistical methods

For all data collected during the trial and describing the sample, descriptive statistics were computed for continuous and categorical variables. The statistics computed included mean, median, standard deviation (SD), minimum and maximum of continuous vari-

ables, frequencies and relative frequencies of categorical factors.

Because of the small number of cases distribution of variables within population was not evaluated. Therefore, nonparametric methods were used because they are based on weaker assumptions and do not assume a normal distribution.

Each test subject successively added pieces of equipment, therefore at first the Friedman test (FR) was used to compare observations repeated on the same subjects. If we had evidence to reject the null hypothesis the paired Wilcoxon test (WI) for dependent samples was performed. Generally, all  $p$  values are the result of two-tailed statistical tests, with values of  $p < 0.05$  regarded as significant. If necessary, adjustments of the alpha level were carried out by Bonferroni correction. All data were stored and analysed using the statistics program IBM® SPSS®, Version 21.0 (SPSS Inc. Chicago, Illinois, USA).

## 3. Results

### 3.1. Electromyography

#### *Pectoralis major*

The treadmill analysis shows significantly increasing muscle activity under an increasingly heavy equipment load (FR,  $p < 0.001$ ). Based on the area under the curve, Fig. 2 illustrates muscle activity in

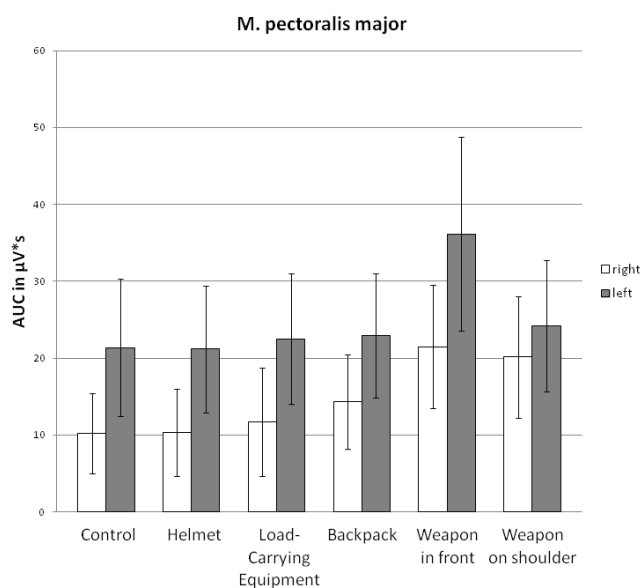


Fig. 2. EMG of pectoralis major muscle: area under the curve on right and left side under increasing load in  $\mu\text{V}\cdot\text{s}$

the right and left pectoralis major muscles. Amplitude and peak are not shown but their trend was similar to that of the AUC. Whilst wearing only the helmet does not cause a significant increase in muscle activity (right side, helmet vs. control, WI,  $p = 0.217$ ), maximum activity is reached when the rifle was carried in front of the body (both sides, weapon in front vs. control, WI,  $p < 0.001$ ). Activity is significantly higher on the left side than on the right for all levels of equipment load (WI,  $p < 0.001$ ). When subjects carried the rifle slung over the right shoulder instead of in front of the body, the activity of both pectoralis major muscles decreases (right side, weapon on shoulder vs. weapon in front, WI,  $p = 0.019$ ), with the decrease being more marked on the left side (weapon on shoulder vs. weapon in front, WI,  $p < 0.001$ ).

#### *Trapezius (descending part)*

Figure 3 shows the change (as a percentage) in mean amplitude of muscular activity in the upper right and left trapezius muscles. Peak and area under the curve develop similarly, i.e., muscular activity increases with the increasing weight of equipment (FR,  $p < 0.001$ ). As for the pectoralis major muscle, activity of the trapezius muscle is at its maximum when the rifle is carried in front of the body (both sides, weapon in front vs. control, WI,  $p < 0.001$ ). Carrying the rifle slung over the right shoulder significantly decreases muscular activity only in the left trapezius muscle (WI,

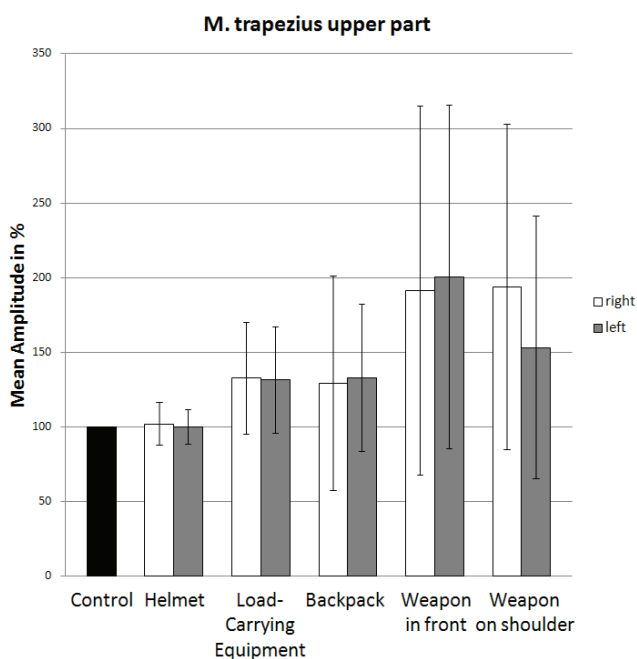


Fig. 3. EMG of trapezius muscle (upper part): mean amplitude on right and left side under increasing load as a percentage of control measurement

$p < 0.001$ ). Significant differences between the left and right muscles only occur when the weight of the rifle was moved from the front of the body to the right shoulder (weapon on shoulder vs. weapon in front, WI,  $p = 0.014$ ).

#### *Latissimus dorsi muscle*

Figure 4 illustrates the course of muscular activation in the latissimus dorsi muscle based on average peak values. AUC and mean amplitude values behave similarly. As the weight of equipment is successively increased, muscular activity of the latissimus dorsi muscle shows a significant increase only when the rifle is added, with maximum activity occurring when the rifle is carried in front of the body (right side, weapon in front vs. control, WI,  $p < 0.001$ ). Activity on the right side is significantly higher than on the left (weapon in front, WI,  $p < 0.001$ ). When the rifle is carried slung over the right shoulder, muscular activity in the right latissimus dorsi muscle decreases significantly (right side, weapon on shoulder vs. weapon in front, WI,  $p = 0.014$ ).

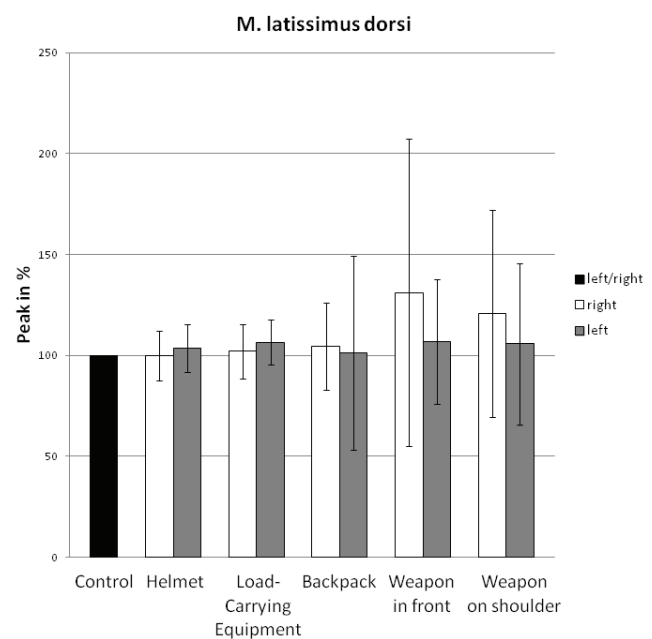


Fig. 4. EMG of latissimus dorsi muscle: mean peak on right and left side under increasing load as a percentage of control measurement

## 3.2. Static body measurement

#### *Vertical body axis (coronal plane)*

Figure 5 illustrates the deviation of the body axis in the coronal plane. Small loads (helmet and load-carrying equipment) lead to a deviation of the vertical body axis

to the right (helmet vs. control, WI,  $p = 0.05$ ). As weight increased with the backpack and rifle added, the body axis deviates  $0.8^\circ \pm 0.9^\circ$  and  $0.8^\circ \pm 0.9^\circ$  to the left (backpack vs. helm, WI,  $p = 0.001$ ). When the rifle is moved from the front of the body to the right shoulder, the axis again deviates to the right (weapon on shoulder vs. weapon in front, WI,  $p < 0.001$ ).

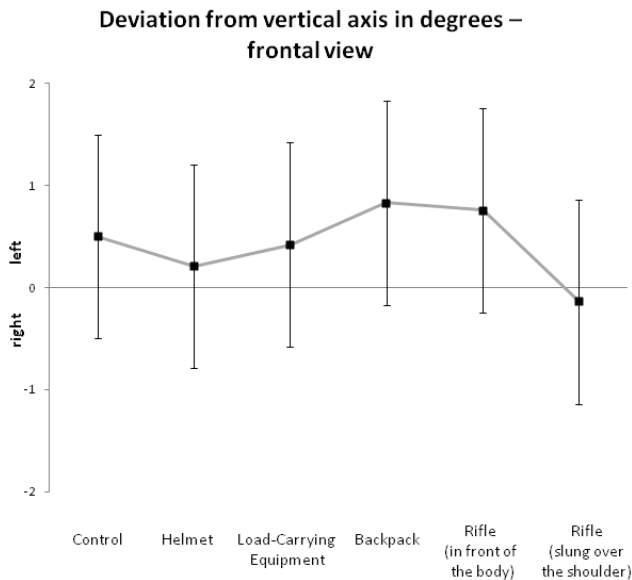


Fig. 5. Static body axis measurement: degree of deviation of body axis in the coronal plane from the vertical image axis under increasing load

*Shoulder height*

Measurement of the height of the right shoulder in the sagittal plane (Fig. 6) reveals that subjects steadily

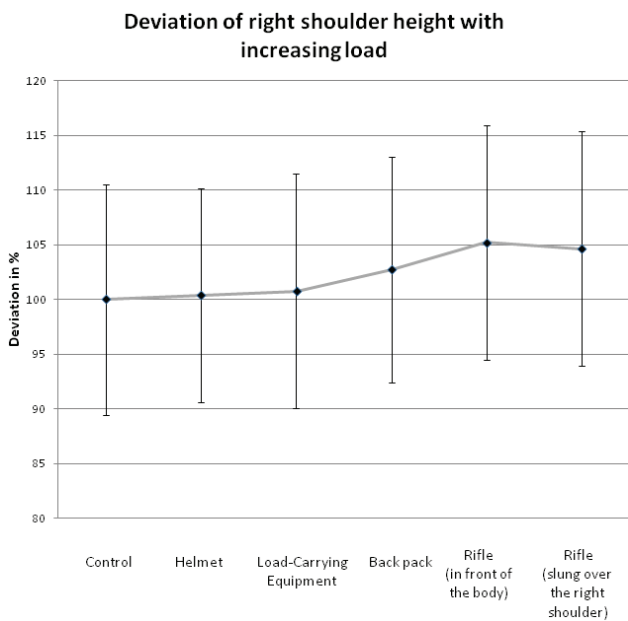


Fig. 6. Relative change in shoulder height under increasing load compared to control measurement as a percentage

raise their shoulder with each increasing level of weight (FR,  $p < 0.001$ ).

We have significant increase for the comparisons backpack vs. load-carrying equipment (WI,  $p = 0.004$ ) and rifle in front vs. backpack (WI,  $p < 0.001$ ). But, shifting the rifle from the front of the body to the right shoulder, and the resulting redistribution of weight, do not lead to a significant change in shoulder height ( $p = 0.389$ ).

## 4. Discussion

The objective of this study was the analysis of trunk muscles under the influence of increasing equipment load. The M. pectoralis major is relevant for internal rotation and adduction of the arms and lowering of the shoulder. Pectoralis major also supports inspiration in a fixed arm position [14], and it is not involved in swinging the arms while walking [15]. Our present study of load-dependent muscle activity revealed an increase in the activity of the pectoralis major. A significant difference between sides, in favour of the left side, became apparent in the control examination without equipment, with the left side bearing a lower load of the equipment once it was added. The sharp increase in muscle activity when the rifle was carried in front of the body can be ascribed to the above function. In such a position, both shoulders must generate force for internal rotation and adduction to stabilise the rifle. The decrease in activation when the rifle was carried slung across the right shoulder might be due to the relatively neutral position of the upper right arm, as well as the load being taken off the left arm. The fact that the right side does not return to below the initial level is due to the adduction necessary to stabilise the weapon in this position.

The trapezius muscle is responsible for the medial movement of the scapula. It also contributes to cranial and caudal movements of the scapula [14]. It is almost constantly active during walking [15]. Owing to the function of this muscle, activity in the descending part increases through the weight of the rifle and the position of the weapon in front of the body, as this requires lifting the shoulder. Activity of the left trapezius muscle decreases when the rifle is carried on the right shoulder. Activity on the right side also decreases slightly. This may be because the rifle is directly supported by, and resting flat against, the body, resulting in a redistribution of force and thus easing the load on the trapezius muscle. Bobet et al. demon-

strated the dependency to position a backpack for activity of the upper trapezius [16].

The latissimus dorsi muscle is involved in internal rotation, adduction and retroversion of the arm [14]. During walking it is only active in the pre-swing and loading response sequences [15]. When the rifle is carried in front of the body, retroversion of the right side is of great importance, the body of the weapon being moved along. Once the rifle is slung over the shoulder, muscle activity decreases, again on the right side, because the arm is held in a relatively fixed position and is somewhat restricted from swinging when walking. Muscular activity remains almost unchanged on the left side. The left arm can swing regardless of whether it holds the light barrel of the gun or not. It must be kept in mind that this is a kinetic examination and differences specific to sequences of walking can influence observations [15]. The appearance of side-specific differences in muscular activity is thus also due to stabilising movements. In kinetic examinations, the body's centre of gravity shifts in a sinusoidal movement in the transversal and sagittal plane [15]. The maximum is always reached in mid-stance on the side of the supporting limb [15]. Stabilising movements become necessary with an increasingly uneven load distribution. Static pedobarographic evaluations have shown an uneven distribution of increased vertical forces under load pressure [9], with the lower extremity opposite the dominant hand carrying the greater load. Increased trunk muscle activation of the dominant side may be a compensation mechanism.

In this kinetic examination on the treadmill, all muscles examined show load-specific effects in subjects. In particular the method of carrying the rifle has a strong influence on the trunk muscles, as it stimulates compensation and thus stabilisation in muscles, especially if the rifle is carried freely in front of the body. Axis deviations measured in the frontal plane, while minor, are a sign of stabilisation of the centre of mass with an increasing ventral inclination as equipment load increases [7], [9]. Another visible sign of induced muscle activity, especially of the trapezius muscle, is increased shoulder height with increased load. Here the compensatory effect becomes evident: when the backpack and rifle are carried, which, following the force of gravity pull the shoulders downwards, the shoulders are raised to compensate. To diminish this increased muscle activity, load-carrying equipment that is close to the body should be used and no additional weight should be carried ventrally, to avoid strong ventral inclination [7], [10] and harmful compensation mechanisms, especially during long marches. Mastalerz et al. described the influence of

inclination on muscular activity of the lower extremities [8]. Our findings are in agreement with the results of Bobet et al. who described significant changes in muscle activity of the upper trapezius caused by variable load positions on the back, though in our investigation we observed a ventral inclination of the body [16].

## 5. Conclusions

The presented data indicate that weight and distribution of equipment influence muscular activity and posture in specific ways. Unbalanced load distribution can lead to increased vertical forces and the resultant enhanced trunk muscle activation of the dominant side may be a compensation mechanism. Muscular activation and orientation of body axis interact with each other to compensate for equipment loads. Development of load carriage equipment should consider possibilities for equal load distribution.

### Competing interests

The authors declare that they have no competing interests.

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