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Title: Electromyography patterns of trapezius muscles and rectus abdominis during prolonged walking on treadmill with different backpack loads in 6-year-old children

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Abstract: This study investigated the electromyography patterns of shoulder and abdominal muscles during prolonged walking with loads in children. Fifteen Chinese children aged six performed four 20-minute walking trials on treadmill (speed = 1.1 ms-1) with different backpack loads (0%, 10%, 15% and 20% bodyweight). Electromyography signals from upper trapezius (UT), lower trapezius (LT) and rectus abdominis (RA) were recorded at time intervals (0, 5, 10, 15 and 20 minutes), and were normalized to the signals collected during maximum voluntary contraction. Integrated EMG signal (IEMG) was calculated to evaluate the muscle activity. Power spectral frequency analysis was applied to evaluate muscle fatigue by the shift of median power frequency (MPF). Overall results showed that 15% and 20% loads increased IEMG at UT and both UT and LT respectively. In prolonged walking, 15% and 20% loads increased IEMG at UT from 15 and 5 minutes respectively. With a 20% load, muscle fatigue was found at UT from 10 minutes and at LT from 15 minutes. No muscle activity changes or muscle fatigue was found in RA. It is suggested that a load within 15% of the body weight in a backpack was acceptable to children aged six for walking within 20 minutes.

Abstract

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CONFLICT OF INTEREST STATEMENT

Ref: submission of the paper titled "Electromyography patterns of trapezius muscles and rectus abdominis during prolonged walking on treadmill with different backpack loads in 6-year-old children"

We declare no conflict of interest including employment, consultancies, stock ownership, honoraria, paid expert testimony, patent application/registrations, and grants or other funding.

Youlian Hong

Jing-Xian Li

Daniel Tik-Pui Fong

15 January 2007

* Cover Letter

Dear Editor of Journal of Electromyoraphy and Kinesiology,

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We would like to submit the captioned manuscript to the Journal of Electromyography and Kinesiology, Elsevier. All authors have read and approved the content of this manuscript as submitted. This manuscript has not been published and will not be simultaneously submitted to other journals.

Youlian Hong

Jing-Xian Li

Daniel Tik-Pui Fong

15 January 2007

*** Manuscript**

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Electromyography patterns of trapezius muscles and rectus abdominis during prolonged walking on treadmill with different backpack loads in 6-year-old children

Abstract:

This study investigated the electromyography patterns of shoulder and abdominal muscles during prolonged walking with loads in children. Fifteen Chinese children aged six performed four 20-minute walking trials on treadmill (speed = 1.1 ms^{-1}) with different backpack loads (0%, 10%, 15% and 20% bodyweight). Electromyography signals from upper trapezius (UT), lower trapezius (LT) and rectus abdominis (RA) were recorded at time intervals (0, 5, 10, 15 and 20 minutes), and were normalized to the signals collected during maximum voluntary contraction. Integrated EMG signal (IEMG) was calculated to evaluate the muscle activity. Power spectral frequency analysis was applied to evaluate muscle fatigue by the shift of median power frequency (MPF). Overall results showed that 15% and 20% loads increased IEMG at UT and both UT and LT respectively. In prolonged walking, 15% and 20% loads increased IEMG at UT from 15 and 5 minutes respectively. With a 20% load, muscle fatigue was found at UT from 10 minutes and at LT from 15 minutes. No muscle

activity changes or muscle fatigue was found in RA. It is suggested that a load within 15% of the body weight in a backpack was acceptable to children aged six for walking within 20 minutes.

1. Introduction:

Concerns have been raised over recent decades about the backpack or school bag weight of children in worldwide countries. The heavy weight of school bad has been reported as 17.7% in the United States (Pascoe et al., 1997), 20% in Italy (Negrini and Carabalona, 2002) and 20% in Hong Kong (Hong Kong Society for Child Health and Development, 1988). In Italy, Negrini and Carabalona (2002) reported that among 115 children aged 11.7 years old surveyed, 79.1% felt that they backpacks were heavy, 65.7% reported that the backpack introduced fatigue to them, and 46.1% developed back pain from daily backpack carriage. In Hong Kong, the Hong Kong Society for Child Health and Development (1988) reported that 45 out of 812 (5.5%) surveyed children had spinal deformity. The mean weight of their school bags was found to be higher than the mean of the school bag weight of all 812 children. In 61 children investigated in Pascoe's study (1997), the most commonly reported symptoms included muscle soreness (67.2%), back pain (50.8%), numbness (24.5%) and shoulder pain (14.7%). In investigating the risk factors, Grimmer et al (1999) found significant strong association between overweight backpacks and spinal symptoms. In addition, Sheir-Neiss et al reported (2003) that heavy use of backpacks was independently associated with back pain. Therefore, orthopaedics and biomechanics specialists believed that habitual heavy backpack loads carriage may cause spinal symptoms, low back pain and musculoskeletal disorder.

However, the cause-and-effect relationships between heavy backpack load and the related syndromes can hardly be established by these prospective cohort studies alone. Therefore, biomechanists and physiologists worked on different randomized controlled trials to help understanding the effect and mechanism introduced by load carriage. The oldest documented study was a physiology study conducted in 1965 in India, which investigated the metabolic cost of carrying book bags weighing 2.6 kg on six school boys aged from 9 to 15 years old (Malhotra and Sen Gupta, 1965). In 1977, Voll and Klimt (1977) reported the common weight of school bags (11.1% to 14.3%) and the common distances the children walked to school (28.5 minutes), which served as references for future researchers to determine representative loads and testing time in experiment. After that, numerous biomechanics and physiology studies emerged to reveal the effects of load carriage on energy expenditure (Hong et al., 2000), cardiorespiratory response (Li et al., 2003), lung volume and ventilation restriction (Lai and Jones, 2001), gait kinetics (Hong and Li, 2005), trunk posture (Chansirinukor et al., 2001), and gait kinematics (Kinoshita, 1985). Various settings of load carriage were studies, including the position of load placement (Bobet and Norman, 1984, Cook and Neumann, 1987), weight of loads (Johnson et al., 1995), carrying method (Hong et al., 2003), walking speed (Charteris, 1998), age difference (Li and Hong, 2004), level walking (Hong and Cheung, 2003) and stair walking (Hong and Li, 2005). These studies in general suggested that a load of 15% bodyweight triggered significant trunk inclination (Li and Hong, 2004), gait alternation (Hong and Brueggemann, 2000), prolonged blood pressure recovery time (Hong et al., 2000), larger energy expenditure (Hong et al., 2000), increased ventilation frequency (Li et al., 2003), as well as moments and power at hip, knee and ankle joints (Chow et al., 2005).

While numerous studies on load carriage on children were found, none of them reported the effect on muscle fatigue. In lower extremity, muscle fatigue leads to postural control and balance impairment (Gribble and Hertel, 2004). In trunk and upper extremity, muscle fatigue has significant effect in decreasing shoulder proprioception (Carpenter et al., 1998) and hampered glenohumeral proprioception

(Voight et al., 1996). As Pascoe et al (1997) mentioned that the reported symptoms from load carriage in children included muscle soreness (67.2%) and also shoulder pain (14.7%), it is necessary to have some investigations on shoulder muscle fatigue. Trapezius muscles were selected as they were found to be sensitive to the changes of load carriage in backpack (Bobet and Norman, 1982). Moreover, backpackers often reported fatigue and soreness in trapezius muscles (Bjelle et al., 1981). Rectus abdominis, which was located anterior to the human trunk, was a representative of trunk flexor muscle. As Cook and Neumann (1987) reported that the lumbar paraspinal muscles were less activated when a load was added posterior to the body, and were more activated when a load was added anterior, it is expected that the antagonistic muscles in the trunk should be activated in a reverse way to compensate. When loads are added posterior to the human body, it is expected that the rectus abdominis might play an important role to bring the body back to an upright position. Previous study showed that abdominis muscle was found significant to contribute in spine stabilization, and a delayed onset of abdominis contraction results in a lack of control of trunk muscles and develops low back pain (Hodges and Richardson, 1996). Muscle fatigue in abdominis may also result in a lack of control of trunk muscle. Therefore this muscle is also selected. In this study, the effect of prolonged load carriage in walking on muscle activity and fatigue in children was investigated. The main effects investigated included the loads and the time of walking.

2. Method:

2.1. *Subjects*

Fifteen Chinese male children (Age = 6 years) participated in this study. The subjects were recruited from local primary schools. They used to carry two-strap backpack to school daily. An orthopaedics physician examined all subjects to ensure that they were free of musculoskeletal injury and pain before each trial. The procedures of the whole experiment were introduced to the subjects and their parents before the test. Informed consents from the subjects and their parents were obtained. The university ethics committee approved the study.

Subjects were asked to come to the laboratory on four different days. There were a total of four trials with different backpack loads for each subject. In each testing day, each subject performed one trial in the morning. Before the trial, the subjects were requested not to participate in any physical activities which may introduce tiredness. The order of the trials was randomized for each subject.

2.2. *Procedure*

Before each trial, the subject was requested to wear black and tight shorts and no shirt. Disposable silver/silver chloride preamplified bipolar surface electrodes (Medicotest T-00-S, Denmark) were attached to upper trapezius (UT), lower trapezius (LT) and rectus abdominis (RA) (Figure 1). All electrodes were placed on the right side of the body. The electrode location was in the midline of the muscle belly between the nearest innervation zone and the myotendinuous junction as suggested by De Luca (De Luca, 1997), and was located and marked on the skin with ink by an orthopaedics physician. A common ground electrode was attached to the anterior aspect of the articular capsule of the sternoclavicular joint. Before electrode attachment, the skin surface was slightly abraded with sandpaper and wiped with rubbing alcohol to facilitate better attachment with reduced skin-electrode impedance (Boone and Holder, 1996). In each trial, new electrodes were attached again on the ink mark.

Maximum voluntary isometric contraction test

After the preparation of electrodes, a maximum voluntary isometric contraction test followed, which act as a reference to reflect the percentage of muscle contraction performance capacity (Yang and Winter, 1984) for later comparison within subject. Each subject was instructed to perform maximum voluntary contraction (MVC) on the selected muscles. Firstly, the subject was instructed to stand up and perform maximum shoulder elevation, while the shoulder motion was restricted by depression force on both shoulders provided by two adult research assistants to ensure an isometric muscle contraction at upper and lower trapezius. Secondly, the subject was instructed to lie supine on the floor, and perform upward and forward trunk flexion. The trunk flexion motion was again restricted by two adult research assistants by applying downward forces at both shoulders to ensure an isometric muscle contraction at rectus abdominis.

Each MVC test trial lasted for 10 seconds. During each trial, loud, strong and continuous verbal encouragement was initiated by the same research staff, in order to reduce the limitation of muscle contraction capacity by lack of motivation and inhibitory effects (Vollestad, 1997). Three trials of shoulder elevation and three trials of trunk flexion were performed, with a 3-minute rest in between each trial. The MVC test was done before each of the four walking trials for all subjects to reduce the effect introduced by new electrodes, by different testing day and time, and perhaps by slightly different electrode attachment locations.

Treadmill walking test

After the MVC test, subject was asked to take a 30-minute rest to remove any muscle fatigue. The resting time was to ensure the subject did not feel jaded prior to the treadmill walking test. All subjects reported that they did not feel fatigue after the rest and did not require extra resting time. A two-strap backpack was prepared with the testing load by filling with objects that students usually bring to school, such as books, pencil box, sweater, water bottle, sports wear and shoes. The fillings were arranged symmetrically inside the backpack. The four testing loads equaled 0%, 10%, 15% and 20% of the subject body weight. Percentage weight instead of absolute weight was used to provide normalization across subjects.

The subject was allowed to practice walking on the treadmill without the testing backpack until he felt familiar and secure. Then the subject put on the backpack and performed a 20-minutes walking on treadmill with a speed of 1.1 ms^{-1}. EMG signals were collected during the walk at different time points (0, 5, 10, 15 and 20 minutes). The duration of the EMG signal collection at each time point is one minute.

Data collection and processing

The electromyography (EMG) signals during MVC test and during treadmill walking test were collected, amplified and transmitted by BTS EMG system (Bioengineering Technology & Systems, Italy) at 2000 Hz to a computer via a 12-bit A/D conversion board (National Instruments, USA). LabView (National Instruments, USA) was used to view and trim the collected EMG signals. For each MVC performance, five two-second EMG samples were trimmed during the whole 60-second sample at the position of 10, 20, 30, 40 and 50 seconds. All these five samples were processed to obtain the mean value. This was to avoid the effect introduced by trimming at different duration within the raw sample. For each load and each time point in the treadmill walking test, the same data trimming procedure was employed.

BioProc EMG Data Processing System (University of Ottawa, Canada) was used to process the trimmed EMG signals. Each trimmed signal was band-pass filtered 20-300 Hz, and was full-wave rectified. The filtered and rectified EMG signal was then integrated (IEMG), and was normalized to the IEMG values of the corresponding muscles recorded from the MVC test (%MVC). The trimmed EMG signal was also filter again and was further processed for power spectrum analysis by Fourier Transform method with 1000 Hz harmonics. Median power frequency (MPF) was recorded to evaluate muscle fatigue. In quantifying muscle fatigue, researchers investigated the drop of mean, median and mode of frequency spectrum. In this study, median power frequency was used for muscle fatigue analysis as it is less sensitive to noise and more sensitive to the biochemical and physiological processes that occur within the muscles during sustained contraction (De Luca, 1997). Since the EMG responses have a great degree of between-muscles, inter-individual and intra-individual variation, the relative changes in the frequency were used for comparison (Bobet and Norman, 1984). In demonstrating load effect, the MPF at 10%, 15% and 20% load were normalized to that at 0% load. In demonstrating the time effect, the MPF at 5, 10, 15 and 20 min were normalized to that at 0 min. A shift of MPF of the EMG signal to the low end indicated muscle fatigue (De Luca, 1997).

Statistical analysis

Two-way multivariate analysis of variance (load by time) with repeated measures (MANOVA) was applied on EMG patterns at all three selected muscles to see significant effects by load and time. To determine load effect, ANOVA (Analysis of variance) and Tukey pairwise comparisons were conducted to determine any significant changes on IEMG and MPF at each muscle. To determine time effect, analysis was done at each load separately. ANOVA and Tukey pairwise comparison was conducted between all selected time points at each load for both IEMG and MPF. Statistical significance was set at 95% level of confidence.

3. Results:

The integrated electromyography (IEMG) and the median power frequency (MPF) of each muscle at each load and time point were shown in Figure 2 and Figure 3 respectively. MANOVA showed significant effects by both load (Wilk's lambda = 0.216, F = 2.206, p = 0.005) and time (Wilk's lambda = 0.159, F = 2.794, p = 0.000).

3.1 Load effect

As shown in Figure 2, there are increasing trends of IEMG with increasing load in general. Significant increase in IEMG was found when the load was 20% in T1 (p < .05) and when the load was 15% and 20% in T4 (p < .05). The load effect was not significant in RA. For MPF, significant effect was found at 20% for both T1 and T4 (p

$< .05$), but not in RA.

3.2 Time effect

ANOVA showed that the time effect was significant in changes in IEMG in T4 and RA ($p < .05$) but not T1 when load was not taken in account. Time effect was also significant in introducing MPF changes in T1 and T4 ($p < .05$) but not in RA. The time effect was further evaluated at different load, and was represented in Figure 3 for IEMG and in Figure 4 for MPF.

There were increasing trends of muscles activity with increasing walking time for all muscles at all loads. When muscle activity (IEMG) was evaluated at different load, no significant changes were found in T1 and RA. For T4, at 0% load, IEMG significantly increased from 4.5% MVC at 0 min to 18.2% MVC at 20 min ($p < .05$). At 10% load, no significant changes were found. At 15% load, IEMG significantly increased from 7.1% MVC at 0 min to 22.3% MVC at 15 min ($p < .05$) and to 25.8% MVC at 20 min ($p < .05$). At 20% load, IEMG significantly increased from 4.3% MVC at 0 min to 18.8% MVC at 5 min ($p < .05$), to 19.4% MVC at 10 min ($p < .05$), to 22.6% MVC at 15 min ($p < .05$), and to 21.6% MVC at 20 min ($p < .05$).

In muscle fatigue, there were general decreasing trends of the MPF with time. The only significant changes were found when the load was 20% body weight. MPF at T1 significantly dropped to 85.8% at 10 min ($p < .05$), to 83.6% at 15 min ($p < .05$) and to 83.9% at 20 min ($p < .05$). At T4, MPF significantly dropped to 79.0% at 15 min ($p < .05$) and to 77.9% at 20 min ($p < .05$).

4. Discussion

There are two main types of electrodes used for electromyography (EMG) studies, the fine electrode and the surface electrodes. Fine electrodes, also called fine-wire electrodes, is a kind of invasive electrodes which are inserted to the muscle fibers during EMG recording. The electrode placement often requires invasive procedure performed by physician specialized in neurology. The procedure may introduce discomfort or pain to the subject, and may also interfere with the human motion analyzed. As the authors expected that there will be difficulties in recruiting children subject for invasive EMG study, a non-invasive surface EMG protocol was employed instead. Surface EMG is a safe and easy method commonly used in ergonomics and biomechanics studies (De Luca, 1997). The most useful applications of EMG are to estimate muscle activity and act as an index of muscle fatigue.

A treadmill was used as an experimental instrument in this study. It allowed control of walking speed to facilitate removal of the effect introduced by different walking speed. In this study, the subject walking speed was set at 1.1 ms^{-1}, a comfortable speed of walking for children (Hong and Brueggemann, 2000, Hong et al., 2000). Previous studies showed significant differences between treadmill and floor walking on some gait biomechanics measurements including double-limb support (Murray et al., 1985) and knee motion (Strathy et al., 1983). However in general, Murray et al (Murray et al., 1985) showed that treadmill walking does not differ from floor walking in EMG patterns at slow (0.80-0.83 ms^{-1}), free (1.38-1.42 ms^{-1}) and fast speed (1.92-1.93 ms^{-1}). As the selected walking speed in this study lied between the ranges reported by Murray et al, the results obtained from this study are likely to reflect the general tread of EMG patterns in level ground walking.

Previous studies investigated EMG on different shoulder and trunk muscles in related to load carriage by arms or backpack. In studying shoulder muscle fatigue during prolonged arm elevation, Hagberg investigated the EMG of upper trapezius, infraspinatus, deltoid and biceps brachialis muscles (Hagberg, 1981). In studying the muscle fatigue during load carriage in backpack, Bobet and Norman (1984) analyzed the EMG of trapezius and erector spinae muscles. Cook and Neumann found that the muscle activity decreased in lumbar paraspinal muscles when a load was carried in backpack position when compared with a load anterior to the chest carried by arms (1987). After reviewing the muscle selection in previous studies, upper trapezius, lower trapezius and rectus abdominis were selected in this study.

The electrode placements were determined by an orthopaedics physician. As backpack load is a symmetrical carriage method, electrodes were only attached to the right side of the trunk in this study. An assumption was made that EMG patterns on muscles on both side of the trunk were similar. The trapezius is the largest and most superficial of the upper back muscle group, which is divided into upper, intermediate and lower functional components. The origins of the lower trapezius are from the spinous processes of the seventh cervical down to the twelfth thoracic vertebrae (Wiater and Bigliani, 1999). Above the seventh cervical vertebrae, the upper trapezius takes its origin from the ligamentum nuchae and as far superior as the external occipital protuberance (Mercer and Bogduk, 2003). The upper trapezius inserts on the posterior border of the lateral third of the clavicle, while the lower trapezius inserts on the base of the spine of the scapula (Wiater and Bigliani, 1999). The orthopaedics physician first located the trapezius muscles origin border by palpation and then identified the mid-point along this border. Then the orthopaedics physician palpated the insertion position. Electrodes were attached at the middle position of the line joining the mid-point of origin border and the insertion position. Rectus abdominis has its origin at pubis crest and its insertion at xiphoid process and anterior ribs. The orthopaedics physician again palpated the origin and insertion and determined the mid-point in between, which was near the umbilicus position (Stokes et al., 1989). Electrodes were attached at this mid-point.

Before each trial, the subjects were asked to take a 30-minute rest to remove muscle fatigue. After the rest, the removal of any fatigue was confirmed by verbal feedback by the subjects. There was no fatigue test, biomechanical or physiological, to determine if the muscle was really free of fatigue at that moment. In reviewing the literature about muscle fatigue studies, it was found that the researchers often just described that the subjects have taken a certain period of resting time before the trial. Only verbal feedback but no quantitative measurements were done to confirm this. Physiologically, researchers may collect blood sample and check for the lactate (Douris, 1993) or creatine phosphate concentration (Westerblad et al., 2002). Another method is muscle biopsy analysis (Weston et al., 1999). However these methods are invasive and may cause wounds and bleeding to the subjects. As children subjects were recruited in this study and they were less tolerant to invasive experiment procedure, these methods were not employed. A 30-minute resting time plus a verbal feedback was used to ensure the removal of fatigue before each trial.

Previous studies (Asmussen, 1979, Westerblad et al., 1998) showed that in muscle fatigue, the decline of forces in muscle fibers showed a three-phase pattern, which usually lasts for less than ten minutes. In the first phase, the force fell rapidly to about 80% of the initial. In the second phase, there was a relatively stable force production period. In the last phase, the force dropped rapidly again. However, in some less demanding exercise where fatigue developed more slowly, this three-phase pattern of force decline was not observed. In other words, if such pattern was observed within ten minutes, the exercise task could be too demanding physically (Vollestad et al., 1988).

In this study, a load of 15% bodyweight introduced significant increased activity in lower trapezius, and a load of 20% bodyweight introduced significant increased activity and muscle fatigue in both upper and lower trapezius (Figure 2). When the load was 0%, 15% and 20%, increased muscle activity was found at 20, 15-20, and

5-20 minutes respectively (Figure 3). When the load was 20%, muscle fatigue was found in upper trapezius and lower trapezius at the time point of 10 and 15 minutes respectively (Figure 4). This indicated that a load of 20% resulted in a too demanding task to the children participating in this study. Although loads of 0% and 15% also introduced significant increase in muscle activity in lower trapezius, no muscle fatigue was found within the 20 minutes walking time period.

Chansirinukor et al (2001) suggested that a 15% bodyweight load is too heavy to maintain standing posture for adolescents. In level walking, other previous studies suggested a 15% or 20% load introduced trunk forward lean (Hong and Brueggemann, 2000, Hong and Cheung, 2003, Li and Hong, 2004, Li et al., 2003) and increased ventilation frequency (Li et al., 2003). A 10% or more load introduced prolonged blood pressure recovery time (Hong and Brueggemann, 2000, Hong et al., 2000) and changes in gait kinematics and kinetics parameters (Chow et al., 2005). In stair walking, a 10% or more load caused trunk inclination and increased plantar force exertion in ascending stairs (Hong et al., 2003, Hong and Li, 2005). In general, these studies suggested the limit of backpack load for children to be 10% body weight, which is similar to the 10%-12% suggested weight recommended by Malhotra and Sen Gupta in 1965 (Malhotra and Sen Gupta, 1965). From the results in this study, a

15% load or more introduced significant increased muscle activity. However such increase does not necessary mean any harmful effect to the children. A load of 20% load significant introduced muscle fatigue in upper trapezius in 10 minutes and in lower trapezius in 15 minutes. No fatigue was found when the load was within 15% bodyweight. Therefore, a load within 15% of the body weight in a backpack was determined to be an acceptable task to children aged six, if only muscle fatigue is to be prevented. If the load is 20%, the walking time should not exceed 5 minutes.

5. Conclusion

Overall results showed that a 15% body weight load significantly increased muscle activity at upper trapezius and a 20% load significantly increased muscle activities at both upper and lower trapezius. In prolonged walking, a 15% load significantly increased muscle activity at lower trapezius from 15 minutes, and a 20% load significantly increased it from 5 minutes. When walking with a 20% load, muscle fatigue was found at upper trapezius from 10 minutes and at lower trapezius from 15 minutes. No increased muscle activity or muscle fatigue was found in rectus abdominis within the 20% load range and 20 minutes walking period.

It is suggested that for children aged six to walk within 20 minutes, while carrying load of 15% of body weight, no muscle fatigue on upper trapezius, lower trapezius and rectus abdominis could occur.

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Figure 1 – Subject performing treadmill walking test with electrodes attached on upper trapezius, lower trapezius and rectus abdominis

Figure 2 – IEMG and MPF of each muscle at each load (load effect)

Figure 3 – IEMG of each muscle at each load and time point (time effect on each load)

Figure 4 – MPF of each muscle at each load and time point (time effect on each load)

Figure 1
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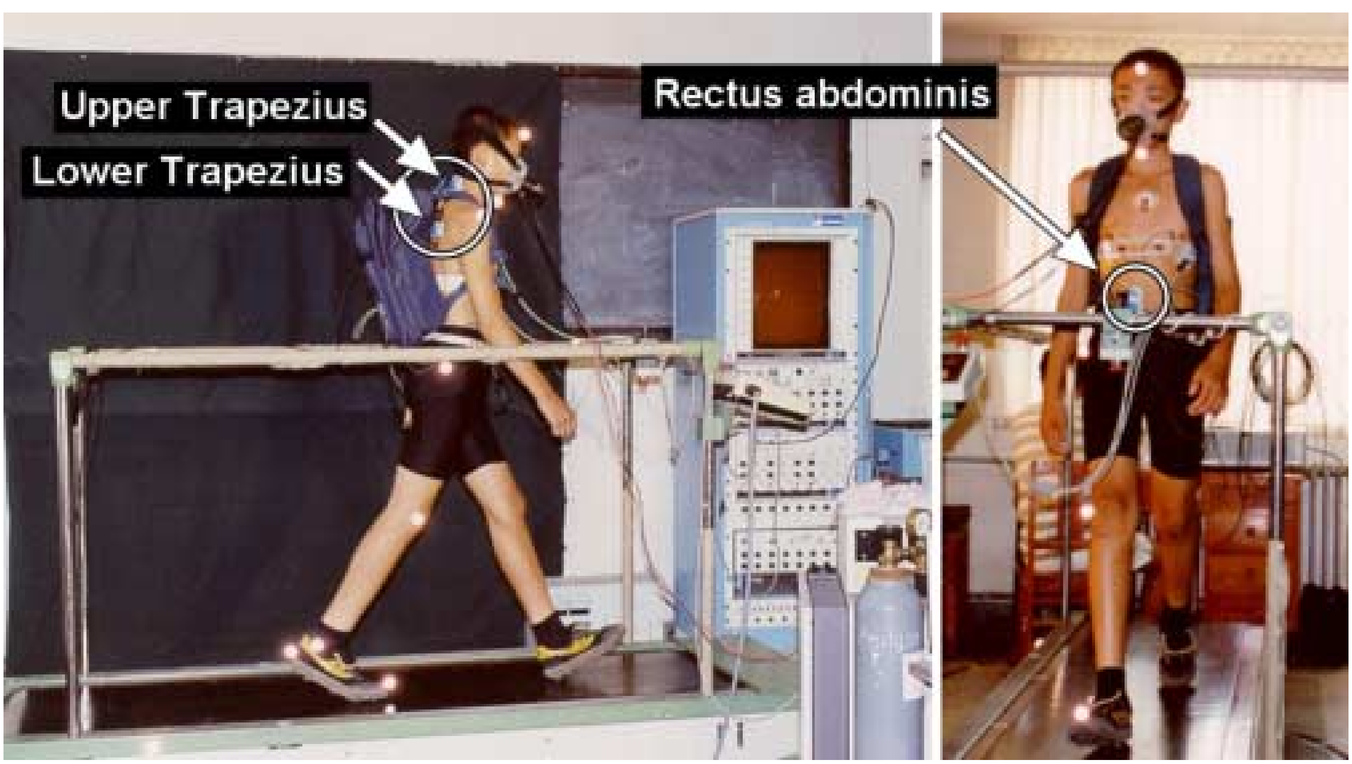

Figure 2

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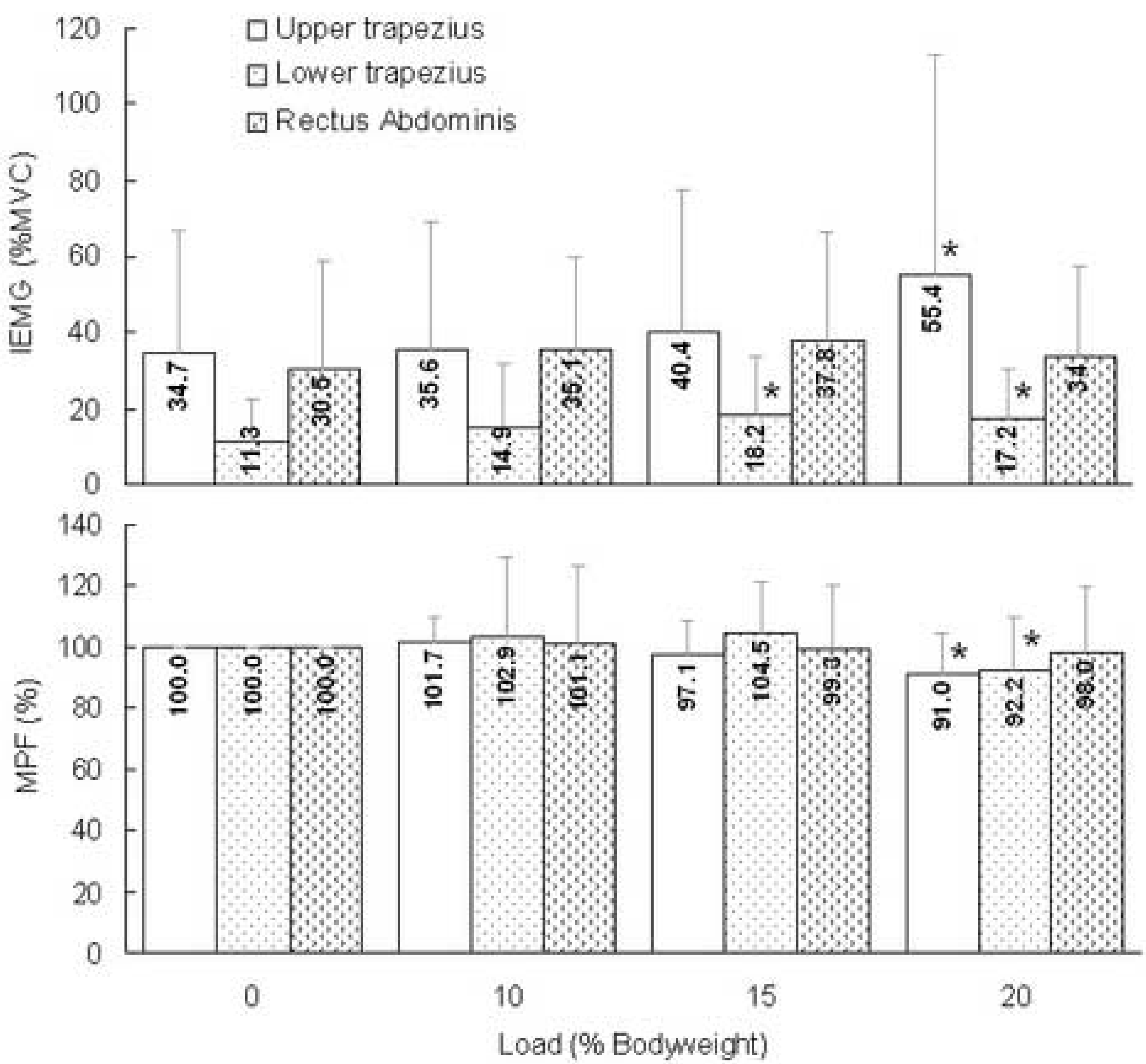

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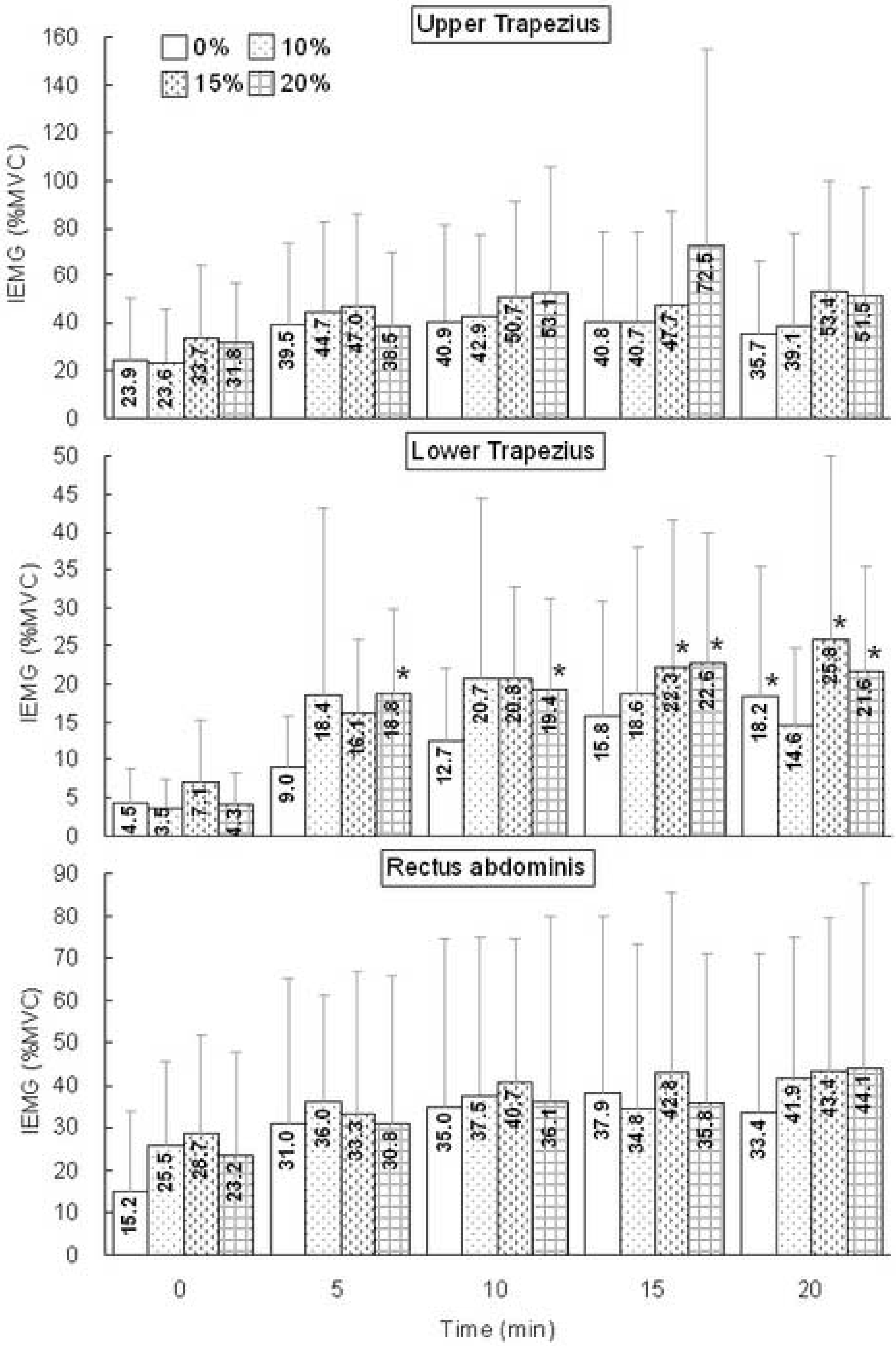

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