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External torque as a factor to modify load in abdominal curl-up exercises

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Summary

Study aim: the aim of our study was to evaluate electromyography (EMG) activity in exercises where the load to the muscles is determined by the external torque. In a part of the exercises, we changed the value of the external force, while in the other we modified the length of the lever arm at which the force was applied.

Material and methods: the study was carried out on a group of 12 subjects (21 ± 2 years, 61 ± 4.8 mass, 172 ± 5 cm height). Electromyographic activity of the rectus abdominis (RA) muscle was evaluated by recording the EMG signal. The length of the lever arm of the external force was changed by using four different positions of the upper limbs, whereas the magnitude of the external force was changed through adding the weights of 0.5, 1.0, and 1.5 kg. The data recorded were normalized with respect to EMG activity measured under maximum voluntary contraction (MVC) conditions.

Results: it was found that the change of the lever arm at which the force was applied (any change in the position of the upper limbs) causes a change in EMG activity in each part of the RA muscle from ca. 50% to ca. 100% MVC ($p < 0.001$). Further, the change in the external load changes statistically significantly the EMG activity only in the left upper part of the RA muscle ($p < 0.05$).

Conclusions: activity in the RA muscle that increased for longer lever arms of the external force, offers opportunities for changing the load used during the exercise in a manner that is safe for the vertebral column.

Keywords: EMG, external torque, prevention of LBP

Introduction

Analysis of literature concerning the contribution of muscles in abdominal muscle strength exercises shows that there have been numerous hypotheses that proposed how to modify the exercises in order to obtain specific effects. Many authors have examined changes in the load to abdominal muscles and contribution of hip joint flexors in exercises with the lower limbs bent or extended [1]. Other researchers have pointed to varied contribution of abdominal muscles depending on the method and range of bending the body trunk [3, 18, 19]. Studies have also demonstrated that, contrary to popular belief, more substantial activity of the abdominal muscles is observed for exercises whose aim is to develop strength of the arms and the muscles of the pectoral girdle (front and side support) compared to conventional exercises for this muscle group [3]. Furthermore, studies on the use of different types of training devices are being carried out in order to reduce the contribution of hip flexors (particularly the iliopsoas muscles) during abdominal muscle exercises, and, on the other hand, to improve the effectiveness of abdominal exercises [19, 20]. Although the findings have not been unequivocal, researchers have demonstrated that exercises using training devices should be more beneficial for people with back pain symptoms. The abdominal exercises analysed in the above mentioned studies differ in contribution of the lower limbs, range of motion in the hip and knee joints, and range of trunk flexion.

The main reason for performing exercises to strengthen abdominal muscles is the fact that they play an important role in stabilization of the vertebral column. This explains the interest of coaches [15] and physical therapists [8] in such exercises. Especially in low back pain (LBP) prevention, abdominal exercises should be performed in positions that prevent overload to the lumbar region of the vertebral column. In order to avoid the overload, trunk flexion motion should be performed in such position that the pressure applied to intervertebral discs is distributed evenly across the discs. Curl-up exercises meet the above criterion. Another benefit of this type of exercises is that it engages abdominal muscles rather than hip flexors. The load in the exercise can be changed by different positions

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of the lower and upper limbs. External load in the form of weights with different mass can also be used, similar to different types of training devices and equipment.

In our study, we propose a biomechanical approach to the choice and variation of the load, resulting from the principle that says that the external torque acting on the human motor system is always compensated by the muscle torque. Therefore, the aim of our study was to evaluate EMG activity in the exercises where the load to the muscles is determined by the external torque. In a part of the exercises, we changed the value of the external force, while in the other we modified the length of the lever arm at which the force was applied. Changes in the lever arm were obtained through varied positions of the upper limbs with respect to the long axis of the body and therefore by the shift in the centre of gravity (COG) of the person who performs the exercise. Further, the magnitude of the external force (body mass) changes with the external load added in the form of weights held by the exercising person. We assume that both changes in the lever arm for the external force (changes in position of the upper limbs) and changes in the magnitude of the external force substantially modify the load applied to abdominal muscles during curl-up exercises.

Material and methods

Participants

Twelve women aged 19 to 25 years (21 ± 1.8) with mean body mass of 61.2 ± 5.0 kg and mean body height of 172.3 ± 5.0 cm took part in the experiment. All subjects gave consent to participate in the experiment. The subjects were students from the University School of Physical Education, who were characterized by similar parameters of body build and a high level of physical activity and fitness. All subjects were physically active, healthy, and had never experienced disabling low back pain. All subjects had been informed about the experimental risk, and they signed an informed consent document before the test.

Procedures

The experiment was carried out in the Biomechanical Analysis Laboratory with ISO certificate (PN-EN ISO 9001:2001). The study was approved by the local Research Bioethics Commission. Before the measurements, the subjects performed a 5-minute warm-up procedure. Following the principles described in the literature, EMG activity was measured during isometric maximum voluntary contraction (MVC) before the main measurements [6, 9]. During the MVC measurements, the upper limbs were bent at the elbow joints and placed at the height of the chest, with body trunk raised so that the lower angle of the scapulae was adjacent to the ground. The assistant who participated in the measurement stood behind the head of the exercising person and resisted the body trunk motion against the extension movement. The value of bioelectrical activity was approached as the maximum value and used for further analysis as a reference value in order to normalize signal.

The surface electromyography method was used for recording muscle activity. Action potential was recorded in the right and left (in both upper and lower parts) RA muscles. Rectangular (22.5 × 46 mm) surface electrodes R-LFR-310 with solid gel Ag/AgCl (Bio Lead-Lok, Poland) were used by placing them on the skin along the muscle fibres in a bipolar configuration. The reference electrode was placed in an electrically neutral place (the lateral epicondyle of the femur).

The choice of the right and left and upper and lower parts of the RA muscle resulted from the specific build of this muscle. A similar approach to examination of the activity in this muscle has also been adopted by other researchers [2, 3]. Distribution of the electrodes was based on the principles of best reception of the EMG signal demonstrated in the literature and with respect to the location of the muscles and individual anatomical body build of the subject [6, 7, 14]. EMG data were collected with an eight-channel electromyograph Bortec "Octopus" (Bortec Electronics Inc., Calgary, Alberta; CA). The amplifier bandwidth ranged from 10 to 1000 Hz. The input impedance of the amplifier was 10 GΩ whereas the common-mode rejection ratio was 115 dB. EMG signals were sampled at 1000 Hz by using an analogue-to-digital converter based on a 16-bit analogue-to-digital board. EMG signals were collected simultaneously from all electrodes in order to record the activity level of the selected muscles.

The raw EMG signal was recorded using a personal computer (PC) with BioWare software. The data were exported to files with "*tbd" format and then analysed using Analizator software used for numerical analysis of continuous signals recorded with Bioware. Analizator software allowed for determination of the module of the electrical signal and computation of a moving average with a step of 101 samples. The moving average can be regarded as a result of low-pass filtration. Subtraction of this value from the original signal causes elimination of the slow-changing component that represents the redundant noise in the frequency analysis.

Description of exercises

Each subject performed abdominal curl-up exercises with four locations of the upper limbs and four external loads with dumbbells, thus making 16 combinations of this exercise. The initial position was similar for all the combinations: lying on the back, lower limbs bent at the hip and knee joints, and feet placed on the elevated platform.

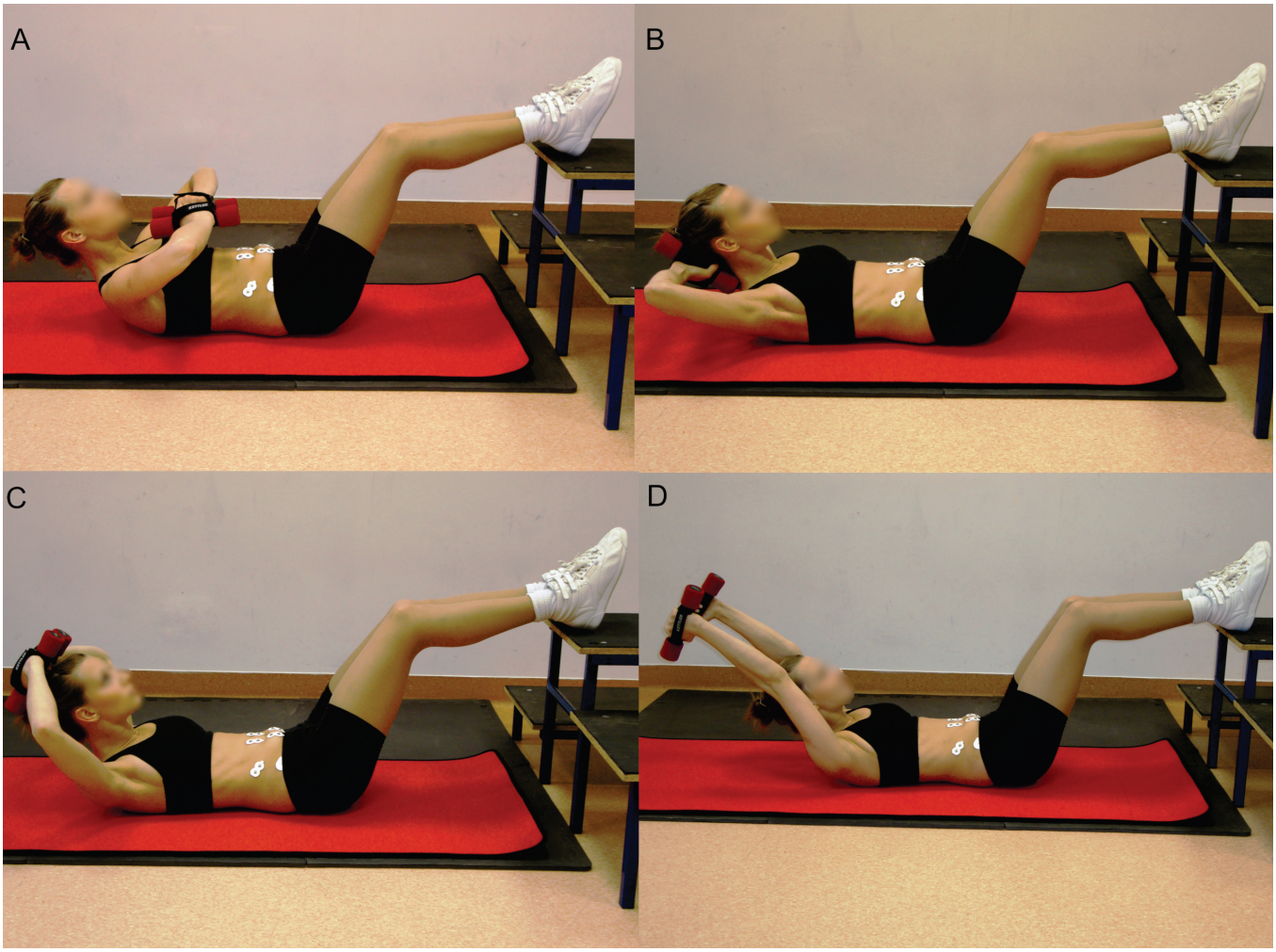


Fig. 1. Positions of the upper limbs during exercises: A) upper limbs bent in the elbow joints, hands placed on the chest; B) upper limbs bent in the elbow joints, hands placed on the occipital protuberances; C) upper limbs bent in the elbow joints, hands placed behind head; D) upper limbs extended in elbow joints, arms adjacent to ears

Curl-up exercises consisted of lifting the head and pectoral girdle over the ground, without losing contact with the inferior angle of the scapula (Figure 1). The external load was dumbbells with mass of 0.5 kg, 1.0 kg, and 1.5 kg held in the hands by the subjects in four positions of the upper limbs: A) upper limbs bent at the elbow joints, hands placed on the chest; B) upper limbs bent at the elbow joints, hands placed on the occipital protuberances; C) upper limbs bent at the elbow joints, hands placed behind head; D) upper limbs extended at elbow joints, arms adjacent to ears.

The duration of the exercise was 5 seconds. A 1-minute rest break was used between individual exercises. The order of performing individual tests was randomly selected, which meant a different order of the exercises for each person studied.

Statistical analysis

The results of computations were exported from the Analizator software to a Microsoft Excel spreadsheet, where the data were processed for statistical analysis performed by means of the Statistica 8.0 software package. Statistical analysis used multivariate analysis of variance MANOVA with multiple comparison post hoc test (least significance difference test, LSD). The level of significance was set at á = 0.05.

Results

Analysis of the data showed that changes in the upper limb position (from position at the height of the chest to the position of the arms extended behind the head), which increased the length of the lever arm for the external force, caused an increase in electrical activity in all parts of the RA muscle. The differentiation of the group of the exercising subjects was also reflected by SD values. The highest variability among the subjects studied was observed for the exercise with the load of 1.5 kg held in the hands, with arms extended behind the head (Figure 2).

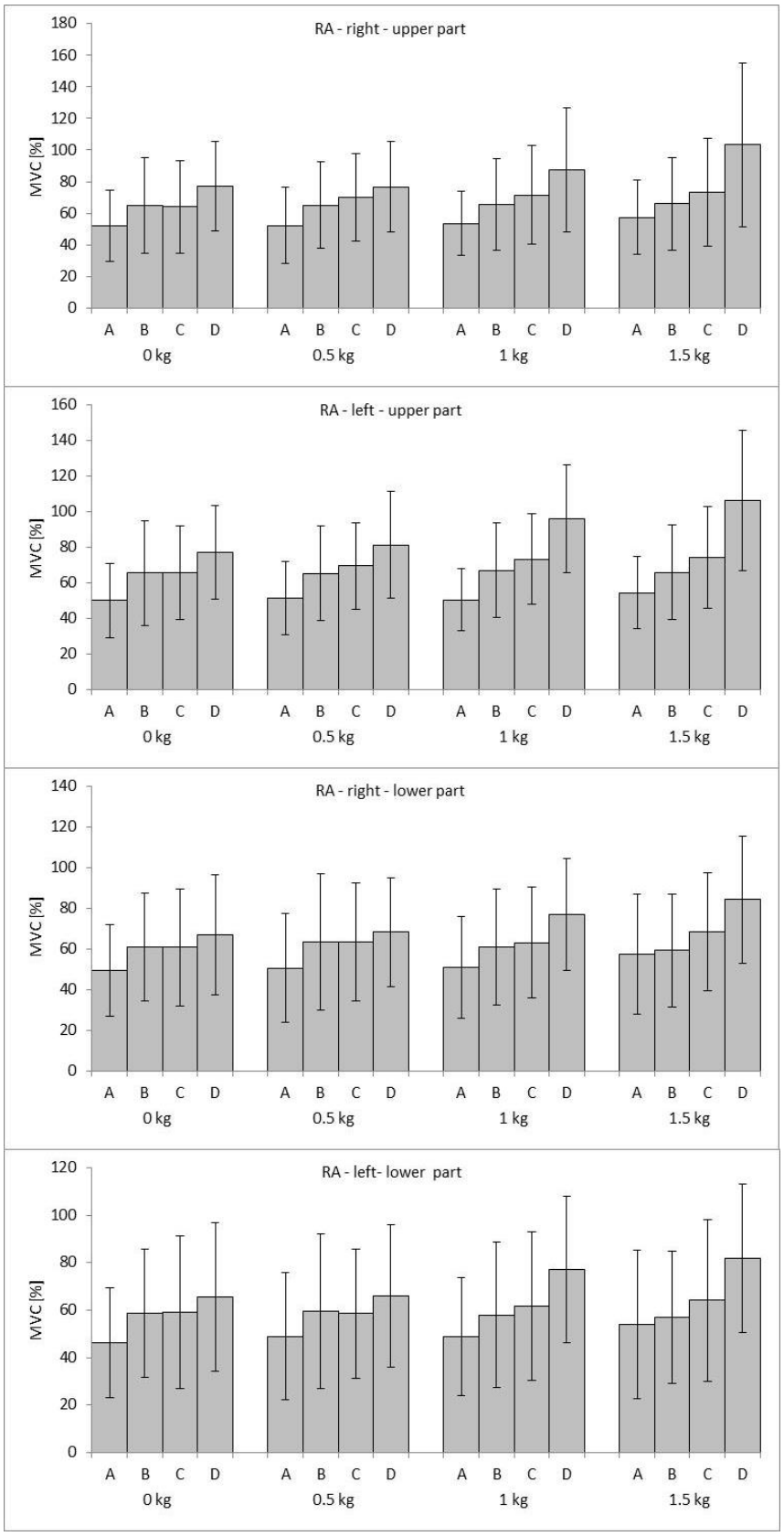


Fig. 2. EMG activity (upper left and right, lower left and right part) RA normalized under MVC conditions. A) upper limbs bent in the elbow joints, hands placed on the chest; B) upper limbs bent in the elbow joints, hands placed on the occipital protuberances; C) upper limbs bent in the elbow joints, hands placed behind head; D) upper limbs extended in elbow joints, arms adjacent to ears

Table 1. Results of multivariate analysis of variance (Test F); p – probability level, RA – rectus abdominis muscle

Experiment	RA – **right** upper		RA – **left** upper		RA – **right** lower		RA – **left** lower	
	F	p	F	p	F	p	F	p
Position of upper limbs	17.999	0.000	33.976	0.000	9.725	0.000	9.764	0.000
External load	2.155	0.092	3.026	0.03	1.272	0.284	0.987	0.399

The use of multivariate analysis of variance (MANOVA) points to the relationship between the position of the upper limbs and electromyographic activity of all parts of the RA muscle. Furthermore, increasing the value of the external force through adding weights did not cause statistically significant changes in electrical activity of the RA muscle. Only the upper and left part of the RA muscle caused a statistically significant change in activity under conditions of changing the external load (Table 1).

Discussion

There are over 200 modifications of abdominal exercises described in various guidebooks for people of different age and with different strength abilities. Studies have shown that, apart from the benefits of these exercises that help develop muscles which stabilize the vertebral column, there are some drawbacks, especially when the exercises are not adjusted to strength abilities of the exercising person. During certain abdominal exercises, a substantial (even doubled) increase in pressure in the intervertebral discs can be observed [13], which represents a contraindication for performing these exercises by people with LBP. Increased pressure in the intervertebral discs is caused by high compressive forces on the lumbar spine that exceeded even 3000 N [3]. This means that these exercises can be dangerous for older people and those with weak muscles that stabilize the vertebral column. The exercise which can be performed by these persons without causing any problems consists of bending the thoracic region of the vertebral column (lifting the body trunk off the ground so that the lumbar region remains in contact with the ground) and is performed by lying on the back with the lower limbs bent at the hip and an angle joint of at least 90°, and supported by an elevated platform. Under these conditions, the pressure in the intervertebral discs is minimized and represents merely 40% of this value compared to the standing position. Therefore, curl-up exercises are performed under conditions of reduced load to the lumbar region of the vertebral column. Furthermore, one benefit of this exercise is that EMG activity in the muscles that stabilize the vertebral column is comparable [20] and even greater [4] compared to the exercises performed on training devices. Another cause of searching for safe exercises to strengthen muscles that stabilize the vertebral column is that the problem of LBP affects an increasing number of persons in adult populations (ca. 31–40%) and the majority of pain occurs in the younger age groups – 25–40 years of age [5, 10].

Thus, the question remains how to modify the external load used in these exercises in order not to change the conditions of reduced load to the lumbar section while changing the load to the muscles. The idea adopted in the study consists of increasing the load to the muscles through changing the external torque. It was supported by previous results where contribution of body trunk flexors and hip extensors in abdominal exercises performed in different angular positions of the lower and upper limbs was examined [16, 17]. These studies have found that the change in position of the upper and lower limbs (change in length of the lever arm) and the change in the muscle torque (through changing the angle of the joint) cause a change in abdominal muscle activity. Conventionally, curl-up exercises are performed with the upper limbs bent at the elbow joints and hands placed on the chest. Studies have found that activity in the RA muscle varies for this version of the exercise from 50% [9] to 60% [11] of MVC, and is similar in both the lower and upper part of this muscle [12]. A similar result was obtained for this version of the exercise in our study. Vera-Garcia et al. [21] recorded activity of the upper part of RA in dynamic curl-up exercises performed at varied velocity. The recorded activity of the RA muscle for the exercises performed at maximum velocity was 49.6 ± 19.0% MVC and was similar to our data obtained for exercises with the upper limbs placed on the chest. Furthermore, exercises which were performed slowly activated the muscle in the range from ca. 23–39% MVC, thus substantially less than during the isometric exercises analysed in our study.

Activity in the RA muscle that increased for longer lever arms of the external force offers opportunities for changing the load used during the exercise in a manner which is safe for the vertebral column. It should be noted that although the study examined young people with over-average physical fitness, the exercise with the upper limbs extended behind the head doubled muscle activity in some subjects, compared to the exercise where the upper limbs were bent and the hands rested on the chest.

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