MUSCLE ACTIVATION IN HEALTHY SUBJECTS DURING SINGLE STEP UP

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BACKGROUND: The single step up is an integral movement performance for functional mobility and activities of daily living. During this activity the body has to be able to keep its balance and maintain a stable upright posture for performing voluntary movement. For this purpose the central nervous system creates different motor programs specific to the task. A motor programme is believed to contain the pre-programmed sequence of muscle activity prior to the initiation of the task, and includes both the muscle activity for the task, as well as postural muscle activity.

OBJECTIVE: The aim of this paper was to examine the sequence of muscular activation, and to determine the timing of the involvement of selected trunk and leg muscles whilst stepping up. The further aim was to find out the most common muscle patterns in this model of motor activity in healthy subjects.

METHODS: The bilateral electromyographic (EMG) signal from the gluteus maximus, biceps femoris and erectores spinae muscles were recorded using surface electromyography. The visual record of the step up performance was registered simultaneously with surface electromyography. The tested group consisted of 16 healthy (5 men with an average age of 23.6, 11 women with an average age of 23.2). They were monitored during the motor task – the step up task, that is which was performed by the dominant leg. The subject stood facing the step (height of the step = 20 cm). Upon request he/she stepped up with the right leg at a spontaneous speed. The motor task was completed by bringing the left leg up onto the step.

RESULTS: During this task, we registered the activation of the right erector spinae muscle, right biceps femoris muscle, left erector spinae muscle and left biceps femoris muscle before the beginning of the visually recognizable movement. The most frequently registered pattern of activation on the side that carried out the step was: right biceps femoris muscle → right erector spinae muscle → right gluteus maximus muscle. Greater differences in the sequence of the muscle involvement were found on the side of the supporting leg.

CONCLUSIONS: In conclusion, the findings have indicated that there exists variability in patterns of muscle activation during the step up task.

Keywords: Stepping, surface electromyography, muscular activity, timing.

INTRODUCTION

The single step up is an integral movement performance for functional mobility and activities of daily living. During this activity the body has to be able to keep its balance and maintain a stable upright posture for performing voluntary movement. Imbalance in the performance of this functional task may cause falls with various undesired consequences (Mercer et al., 1999; Shumway-Cook & Woollacott, 2007). The point in time at which subjects fall has not yet been identified, but investigating the anticipatory period prior to the initiation of the stepping is valuable. This is because it can lead to insight concerning the priority of the organization of the task by the central nervous system, particularly with regard to motor programmes. A motor programme is believed to contain the pre-programmed sequence of muscle activity prior to the initiation of the task, and includes both the muscle activity for the task as well as postural muscle activity.

According to Gélat and Brenière (2000) the performance of a single step can be divided into four phases. The first phase, which is called the anticipatory phase, starts at the onset of the dynamic phenomena and it finishes at the moment when the heel breaks contact with the support surface (heel off). The second phase is the performance of the movement itself. It starts with the heel off, and finishes at the moment when the leading limb again makes contact with the ground. The third phase is the stage of double stance, which starts with the contact of the leading limb with the ground and finishes at the moment the backward limb leaves the ground (toe off). The fourth phase of the movement starts with the toe off from the support surface and finishes by putting it down next to the other limb.

The aim of this paper was to examine the sequence of muscular activation, and to determine the timing of the involvement of selected trunk and leg muscles whilst stepping up. The further aim was to find out the most

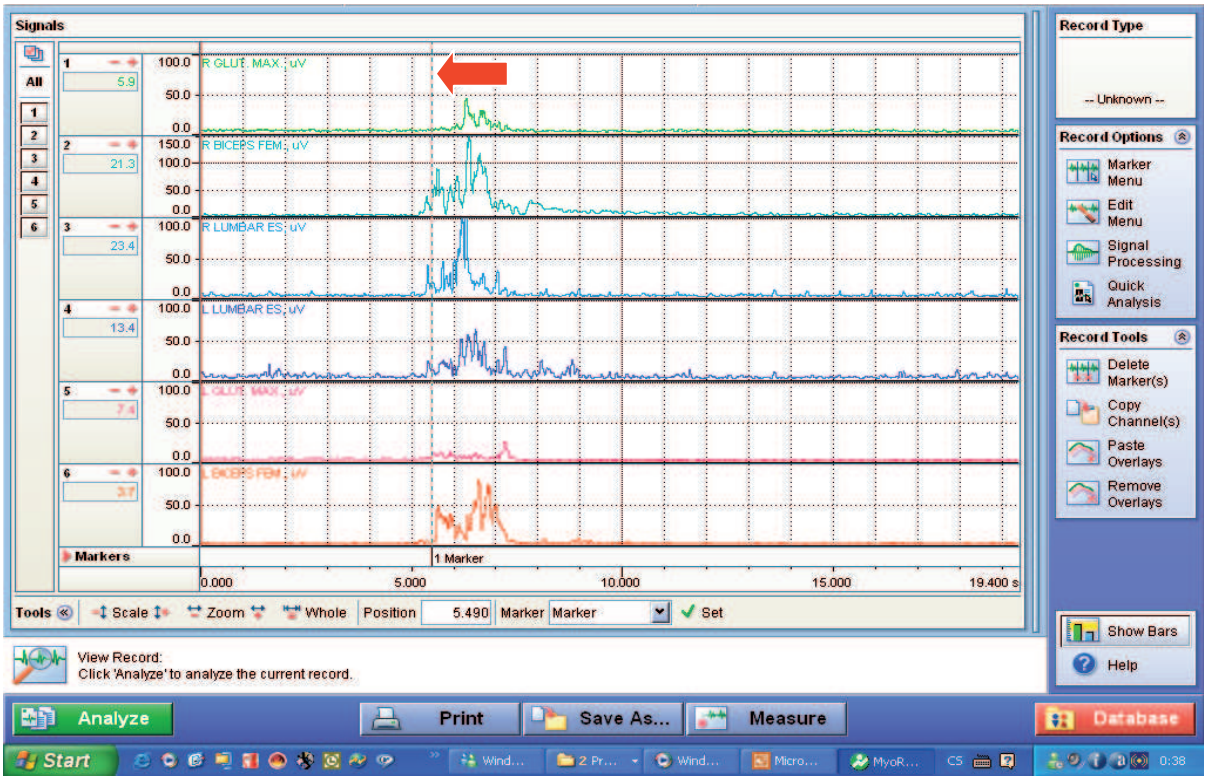
common patterns for the involvement of muscles in this model of motor activity in healthy subjects.

MATERIAL AND METHODS

The tested group consisted of 16 healthy subjects (5 men with an average age of 23.6, 11 women with an average age of 23.2), who were examined by an experienced physiotherapist. No important muscular imbalances were found. They were monitored during the motor task – in this case the step up task which was performed by the dominant leg. All subjects were right footed persons. A Czech translation of the Footedness Questionnaire was used to determine limb dominance (Wai-Hang, 2004).

The surface EMG Myosystem 1400A was used for the presented study. The surface EMG involved using 6 EMG channels, with a frequency bandwidth of 10 Hz – 500 Hz, an input impedance of 10 MΩ and a CMMR (Common Mode Rejection Ratio) of 130 dB. For scanning we used the surface electrodes Kendall ARBO silver-silver chloride with fixed hydrogel, with an electrode size of 10 mm and oval in shape. The inter electrode distance was 20 mm. The surface electrodes were put onto pre-cleaned skin and positioned parallel to the muscle fibres: over the right and left gluteus maximus muscles at the line between the os sacrum and trochanter major, at the point of the muscle's greatest prominence; on the right and left biceps femoris muscles at the line between the tuber ischiadicum and condylus lateralis tibie, and finally, on the right and left erectores spinae muscles, placed at a two finger widths distance laterally from the processus spinosus of L2 (Hermens, 2000). The reference electrode was placed over the spina iliaca posterior superior. The visual record of the step up performance was registered together with the surface electromyography. A SONY – DCR-TR V900E digital camera was used to scan the picture.

Fig. 1
Surface electromyographic record of muscular activity during the step up task



Legend:
R GLUT MAX – right gluteus maximus muscle
R BICEPS FEM – right biceps femoris muscle
R LUMBAR ES – right erector spinae muscle
L GLUT MAX – left gluteus maximus muscle
L BICEPS FEM – left biceps femoris muscle
L LUMBAR ES – left erector spinae muscle
uV – mikrovolt
Arrow indicate the beginning of the step up motor task.

The subject stood facing the step (height of the step = 20 cm). Upon request he/she stepped up with the right leg at spontaneous speed. The motor task was completed by bringing the left leg on up onto the step.

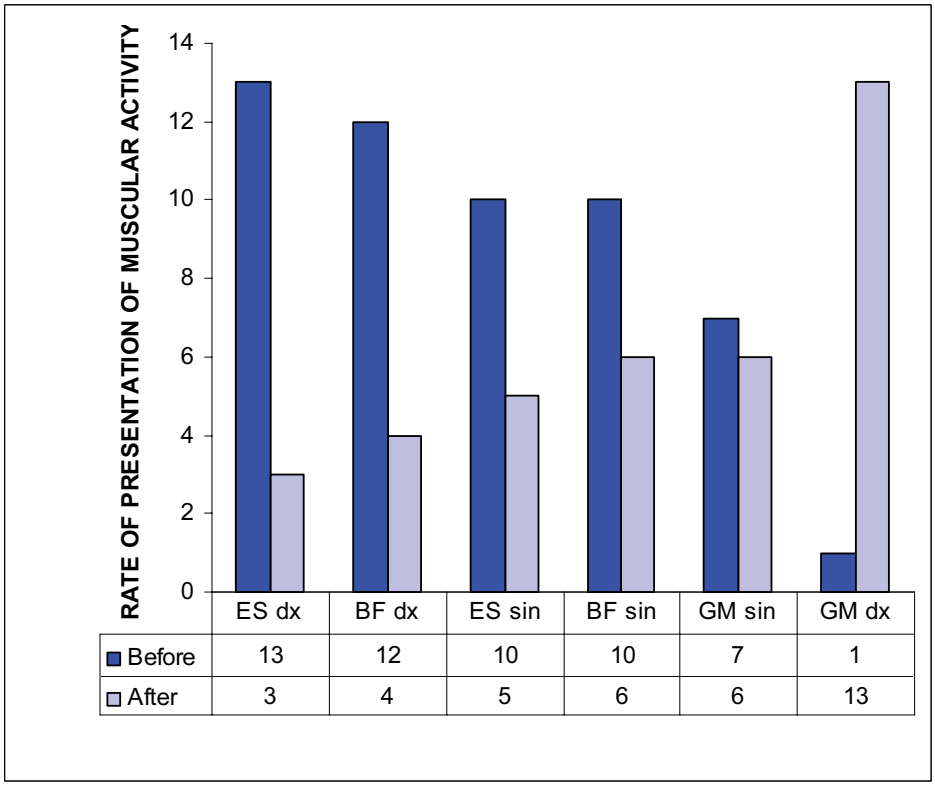
Full wave rectification and smoothing were used for processing the EMG signal. The root mean square (RMS) parameter was evaluated. The part of the EMG record from the verbal command for the performance of the motor task, until the right leg made contact with the contact sensor on the step, was evaluated. This section was divided into two parts. The first one started with the command request and ended with the beginning of the movement. The first observed movement (heel off) of the right leg on the video was indicated as the beginning of the movement (t = 0). The second part lasted from this movement (t = 0) until the first contact of the foot with the step. To detect the onset of muscle activity in individual muscles, we stated a moment, when the amplitude of the EMG signal went above the defined threshold. The threshold for each muscle was determined by calculating the sum of the mean voltage value plus 3 standard deviations from the relative baseline activity (threshold = mean + 3 SD above baseline activity) (Chung & Giuliani, 1996; Soderderg & Knutson, 2000). The onset times of all the muscles were compared to each other. The value of 10 ms was chosen for distinguishing the intervals in different muscle connections. If the time calculations were to differ by more than 10 ms, then a different sequence of muscle time activation would be registered. In the case that the beginning of the activity was equal to or less than 10 ms, then the same sequence of muscle time activation would be registered (De Luca, 1997; Rodová, 2002).

RESULTS

The activation of selected muscles in relation to visually initiated movement was evaluated in a single step up task from the beginning of the movement (t = 0). Registration of the multi-channel EMG signal provided the sequence of an activation of the selected trunk and leg muscles whilst stepping up (Fig. 1).

The findings are presented according to the frequency of the activity of single muscles before and after the beginning of the visually registered movement of the

Fig. 2
Frequency of the registered manifestation of the muscular activity of the studied muscles before and after the visually recognizable beginning of the step up task

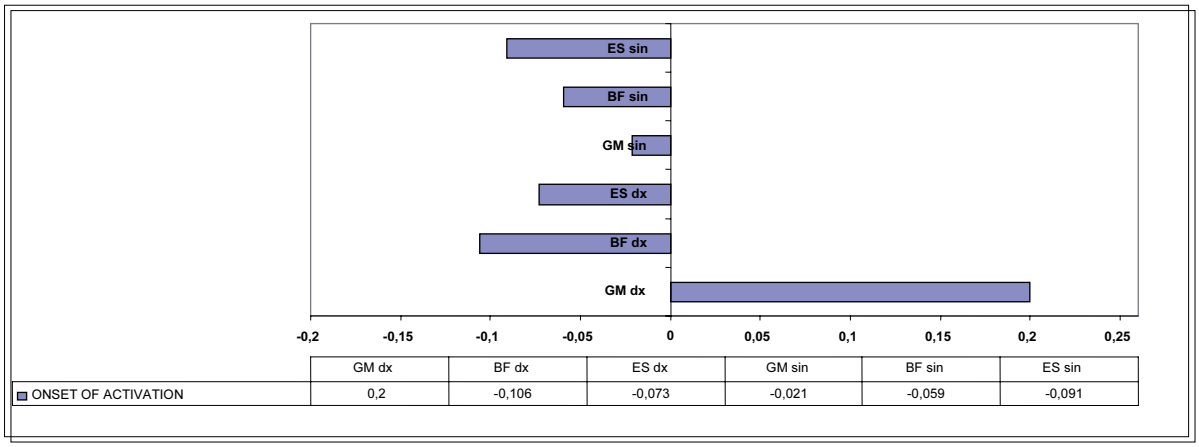


	ES dx	BF dx	ES sin	BF sin	GM sin	GM dx
Before	13	12	10	10	7	1
After	3	4	5	6	6	13

Legend:
ES dx – right erector spinae muscle
BF dx – right biceps femoris muscle
ES sin – left erector spinae muscle
BF sin – left biceps femoris muscle
GM sin – left gluteus maximus muscle
GM dx – right gluteus maximus muscle
Total number of persons – 16

step up task. The results of the muscular activation of particular muscles during the step up task were as follows: the right erector spinae muscle was activated in all examined persons (i.e. 100% – exactly 13 times before and 3 times after the beginning of the movement). The right and left biceps femoris muscles were activated in all persons (i.e. 100%) – exactly the right biceps femoris muscle 12 times before and 4 times after the beginning of the movement and the left biceps femoris muscle 10 times before and 6 times after the beginning of the movement. Activity of the left erector spinae muscle was recognised in 15 persons of 16 (i.e. 93.75%) – exactly 10 times before and 5 times after the beginning of the movement. The right gluteus maximus muscle (on the side which performs the step up movement) was activated in 14 persons of 16 (i.e. 87.5%) – exactly once before and 13 times after the beginning of the movement. The left gluteus maximus muscle (on the supporting side) was activated in 13 persons of 16 (i.e. 81.25%) – exactly 7 times before and 6 times after the beginning of the movement. There was no muscular activity recorded during this task in 3 persons (Fig. 2).

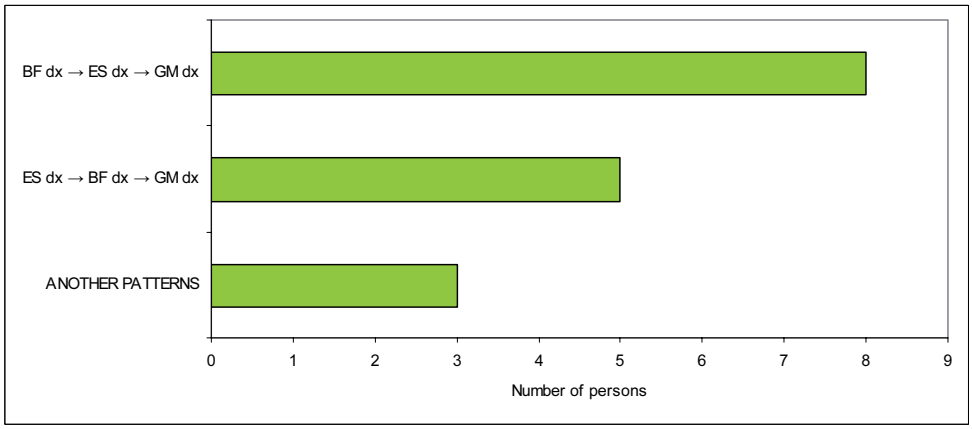
Fig. 3
The onset of the activation of single muscles in relationship to the visually registered beginning of the step up (mean values expressed in seconds)



	GM dx	BF dx	ES dx	GM sin	BF sin	ES sin
ONSET OF ACTIVATION	0,2	-0,106	-0,073	-0,021	-0,059	-0,091

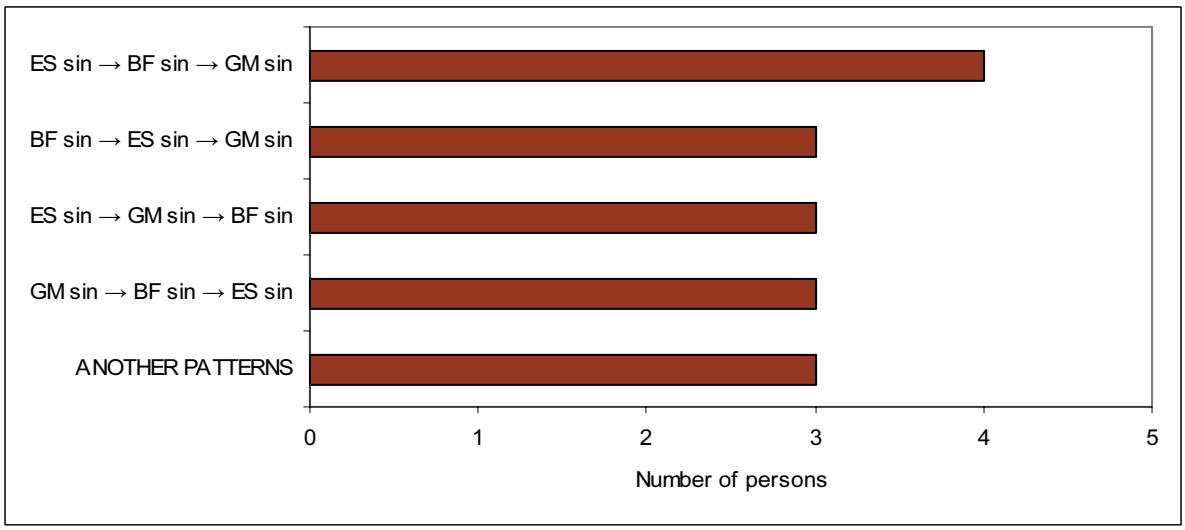
Legend:
ES dx – right erector spinae muscle
BF dx – right biceps femoris muscle
ES sin – left erector spinae muscle
BF sin – left biceps femoris muscle
GM sin – left gluteus maximus muscle
GM dx – right gluteus maximus muscle
0 – the beginning of the movement visually registered from the video record

Fig. 4
The most common patterns in the sequence of muscle activation on the right leg during the step up task



Legend:
BF dx – right biceps femoris muscle
ES dx – right erector spinae muscle
GM dx – right gluteus maximus muscle
Total number of persons – 16

Fig. 5
The most common patterns in the sequence of muscle activation on the support (left) leg during the step up task



Legend:
BF dx – left biceps femoris muscle
ES dx – left erector spinae muscle
GM dx – left gluteus maximus muscle
Total number of persons – 16

Figures 3, 4 and 5 show the mean activation time of the studied muscles and their sequence of involvement during the step up movement.

DISCUSSION

The aim of this paper was to examine the sequence of the muscle activation in the lumbopelvis area during the step up movement. During this task, we registered the activation of the right erector spinae muscle, right biceps femoris muscle, left erector spinae muscle and left biceps femoris muscle before the beginning of the visually recognizable movement. We presume that this early muscle activation may be associated with the anticipatory activity of the muscular system for stabilizing and postural functions. In accordance with Satoru et al. (2008), it is known that the muscles involved in the stabilizing action become anticipatorily active prior to the muscular activity of the prime mover. They found anticipatory activity in the left gluteus medius muscle, left obliquus internus abdominis muscle and left multifidus muscle when subjects performed three right hip flexions to 90 degrees of flexion whilst standing. Perturbations to upright posture can be counteracted by postural adjustments that occur simultaneously with, or just before, the initiation of voluntary movement. The general mechanism of postural regulations involves anticipating the effect of the movement on posture and coordinating the activation of postural adjustments with the intended movement to minimize the postural disturbance (Frank & Earl, 1990). According to Gélat and Brenière (2000), the anticipatory postural preparation during initiation of gait in healthy adults enables the movement of the centre of mass of the body forward and towards the standing foot. Muscular activity starts at the beginning of this anticipatory phase.

The next aim of this study was to find out the most frequently registered patterns of muscle activation in the model motor activity of healthy people. The most frequently registered pattern of activation on the side that carried out the step was: the right biceps femoris muscle → right erector spinae muscle → right gluteus maximus muscle. Greater differences in the sequence of the muscle involvement were found on the side of the supporting leg, not only during the whole task, but also before the beginning of the movement.

Mercer and Sahrmann (1999) studied whether consistent sequences of postural muscle activation exist when lifting the right foot onto a step from a standing position. The muscles selected were the tibialis anterior muscle, gluteus medius muscle, hamstrings, the gastrocnemius-soleus muscles of the supporting limb and the rectus femoris muscle of the moving limb. The authors found that the first muscle to activate in 93% of total trials was the tibialis anterior muscle. The sequence of muscles activated subsequent to the tibialis anterior muscle, but before the onset of lifting the right foot onto the step, was more variable. The most common muscular pattern was the tibialis anterior muscle followed by the gluteus medius muscle, without activi-

tation of any other postural muscles before movement onset. Another relatively common sequence was: tibialis anterior muscle → hamstrings → gastrocnemius-soleus muscles.

CONCLUSION

We found that during the step up task, the activation of the right erector spinae muscle, right biceps femoris muscle, left erector spinae muscle and the left biceps femoris muscle occurred before the beginning of the movement. The most frequently registered pattern of muscle activation on the side that carried out the step was: right biceps femoris muscle → right erector spinae muscle → right gluteus maximus muscle. Greater differences in muscle activation patterns were found on the side of the supporting leg. In conclusion, the findings have indicated that variability in patterns of muscle activation during the step up task does exist. It may be a reflection of the ability of the central nervous system to prepare different motor programs (in the meaning of the varying involvement of different muscles) for any given motor task. This situation requires further study for an explanation of registered differences among individual subjects and furthermore, to compare the results obtained between healthy subjects with ones obtained from subjects with diseases or disturbances of the locomotor system.

ACKNOWLEDGEMENT

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AKTIVACE SVALŮ U ZDRAVÝCH OSOB PŘI NÁKROKU NA SCHOD

(Souhrn anglického textu)

VÝCHODISKA: Nákrok na schod je součástí běžných denních motorických aktivit. Při jeho provádění musí být tělo schopno udržovat rovnováhu a stabilní vzpřímenou posturu za současného průběhu volního pohybu. K tomuto účelu vytváří centrální nervová soustava různé motorické programy, specifické pro daný úkol a obsahující předem programované sekvence zapojování svalů k zajištění provedení vlastního pohybu a k udržení postury během vykonávaného pohybu.

CÍLE: Cílem práce bylo určení časové posloupnosti zapojení vybraných svalů trupu a dolních končetin při nákroku na schod. Dalším cílem bylo zjištění nejběžnějšího vzoru zapojování svalů v této modelové pohybové aktivitě u zdravých osob.

METODIKA: U této práce byla snímána bilaterálně elektromyografická aktivita m. gluteus maximus, m. biceps femoris a m. erector spinae (v jeho lumbální části). Spolu s elektromyografickým signálem snímaným povrchovými elektrodami byl zaznamenáván i vizuální záznam provedení nákroku na schod. Soubor tvořilo 16

zdravých mladých probandů, všichni praváci (5 mužů, průměrný věk 23,6 let a 11 žen, průměrný věk 23,2 let), u kterých byly anamnesticky vyloučeny úrazy dolních končetin a páteře. Na povel nakročili probandi spontánní rychlostí na schod (výška schodu = 20 cm) pravou dolní končetinou. Pohybový úkol končil došlápnutím levou dolní končetinou na schod. Elektromyografické záznamy jednotlivých svalů byly hodnoceny z hlediska časového nástupu aktivace svalů ve vztahu k začátku pohybu pravé dolní končetiny, který byl určen podle videozáznamu. Časy nástupu aktivace jednotlivých svalů byly mezi sebou porovnány k určení časové posloupnosti zapojení svalů a k určení nejběžnějšího vzoru svalového zapojení při tomto úkolu.

VÝSLEDKY: Při úkolu nákroku na schod jsme zaregistrovali aktivaci pravého m. erector spinae, pravého m. biceps femoris, levého m. erector spinae a levého m. erector spinae již před začátkem pohybu pravé dolní končetiny. Dále jsme pozorovali jako nejčastější svalovou sekvenci na nákročné (pravé) straně: pravý m. biceps femoris → pravý m. erector spinae → pravý gluteus maximus. Větší rozdíly v sekvenci zapojování svalů jsme zachytili na stojné (levé) dolní končetině.

ZÁVĚRY: Výsledky naší studie prokazují variabilitu vzorů zapojování svalů při studovaném úkolu nákroku na schod u zdravých jedinců.

Klíčová slova: nakročení, povrchová elektromyografie, svalová aktivace, timing svalů.

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