Age and sex differences in leg strength in stepping up movements

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Introduction

Stepping up movements are very important forms of human everyday life motor behaviour. We perform the movements getting on the train, bus, etc. or walking up the stairs. Aging processes cause a decrease in the strength of muscles (Izquierdo, 1999; Lexell, 1995; Hakkinen, 1991), which in seniors is demonstrated by slowing the movements (St George et al., 2007; Latecka et al., 2006, Metter et al., 2005).

In the presented study we have applied the step-test to examine the relative strength of legs. Many researchers (Barry et al., 2005; Simonneau et al., 2005) test age and sex differences in strength on the basis of absolute strength (maximum strength abilities). Relative strength expresses human strength abilities with respect to the mass of the subject’s body and therefore is stronger related to the human motor efficiency, which determines the effectiveness in everyday activities.

The main aim of our studies is to show to what degree the aging process causes a decrease of relative leg strength in women and men and whether any sex differences occur in the strength in young and elderly people. We have put forward a hypothesis that the age differences are greater in the female than in the male group, and the sex differences may occur only in the elderly group. Our studies are also directed to showing the need and sense of practising the strength of legs in seniors.

Step-tests that require the performance of stepping up movements were usually used to test the energetic possibilities of the human motor system. In this application the most popular step-tests are Harward (Meyers, 1969) and Margaria-Kalamén’s test (Margaria, 1966). The former enables the estimation of aerobic, the latter the anaerobic efficiency of the human energetic system.

The total strength of extensors in stepping up movements consists of explosive (initiation of the movement) and dynamic (speed of performing movements) muscles strength. Researchers with respect to human strength very often measure the maximum explosive, dynamic and isometric strength. The explosive maximum relative leg strength is usually tested by vertical (jumps upwards) and horizontal jumps (jumps forwards). The jump method was often used in sport. Subjects were asked to perform a series of jumps on tensometric platforms (Bosco, 1992) or upon step-box (Giovanis, 2008; Giovanis et al. 2006). Giovanis and co-workers (2006) used the step-test to study the explosive strength and strength endurance in skiing. The jump method is not safe for seniors.

Stepping up and down movements in everyday life pose a risk of falling down for seniors. Our another study
has shown a very strong correlation between the leg strength (Lapszo et al., 2010), speed of locomotion and rotation movements (Lapszo et al.,2008) and the balance control ability in elderly people. These findings indicate that the strength of legs, the speed of locomotion and rotation movements determine the safety (the fall risk) of everyday movements performance with respect to balance control in seniors. Greater strength of legs and speed of locomotion and rotation movements might reduce the risk of falls. In the further research we are going to use the research method presented in this paper to show how much active lifestyle (biking, jogging, walking, dancing, hiking, etc.) in seniors can improve the strength of legs and how large are the differences between physically active and inactive elderly people. We have found such differences with respect to the speed of locomotion and rotation movements (Łapszo et al., 2006). We would like to show the forms of senior physical activity that engages the lower part of body and markedly improves the strength of legs, the speed of locomotion and rotation movements and in this way increases the balance control ability and safety of everyday motor behaviour in seniors.

28 young (13 female and 15 male – av. age 22.5 years, SD = 0.84) and 15 elderly (7 female and 8 male – av. age 67.1 years, SD= 7.1) subjects participated in the study. The elderly subjects did not report any CNS and movement disorder diseases or any falling down accidents. The Human Research Consultants had no objections to the measurement procedure in the experiment applied in the study.

Method
A psychomotor timer (Łapszo, 2002) was used in conjunction with a measurement station to test stepping up movements. The measurement station is a part of leg and arm strength timer, which we have constructed to test the relative strength of muscle groups fundamental for every day motor activities (Prusik et al., 2010).

The measurement station consisted of a step-box and four tactile leg sensors located on two platforms (Fig.1). Two leg sensors were placed on a platform on the floor and the other two on a 30.5 cm (12 inches) high step-box. Each sensor consisted of two circle, tiny, resistance plates. In the stepping-up task, subjects walked up and down as quickly as possible on the step-box in response to two lights placed on the shoulder level in front of the subject. Left light stimulated stepping up and down with the left leg, while the right light with the right leg.

Subjects were stepping up and down with the right and the left leg irregularly in a series of 20 stepping up movements (each leg 10 times). The leg strength was measured indirectly by the time elapsing from the instant of releasing the floor leg sensor to the instant of putting the leg on the step-box leg sensors by the other leg than the one which was just put on the box. Straightening of the leg put on the step-box caused taking off the foot of another leg from floor and displacing the foot on the step box. The faster the subject was able to straighten the leg put on the step-box, the shorter was the time of putting of another leg on the box.

The measured time reflected the explosive (fast initiation of movements) and dynamic (fast performing of the stepping up movements) leg strength together. The average for 5 measurements of stepping up time of the right leg (STr) and the left (STl) leg reflects the total strength (explosive and dynamic strength together) of the left and the right leg in the stepping-up task respectively.

During the experiment subjects could put (not support) their hands on handrails located on the right and the left side of the step-box. In this way the elderly people were protected against the falls and were able to perform the tested movements with maximum speed.

Results
Three-way Anova (age x sex x leg) was used to analyse the respective differences in leg strength with the “p” value set up at 0.05. Table 1 presents the average values of stepping up time of the right leg (STr) and the left (STl) leg reflects the total strength (explosive and dynamic strength together) of the left and the right leg in the stepping-up task respectively.

The analysis of age differences has shown that the relative leg strength was smaller in the elderly subjects, compared to the young ones. The age absolute and relative differences were as follows: for the left leg 0.277 s and 21.3 %, 0.291 s and 21.8 % for the right leg.

We have found the largest age differences in leg strength between female elderly and young subjects for
The left leg (0.352 s, 26.9 %), big and similar in female (0.308 s and 22.6 %) and male (0.284 s and 21.7 %) older subjects for the right leg and the smallest for left leg in older men (0.201 s and 15.4 %).

The research has shown that the aging process impaired more the strength of legs in women (av. 24.8 %) than in men (av. 18.6 %). The right leg is impaired by 6.3 % more than the left leg by the aging process in men, while in women the left leg is impaired by 4.3 % more than the right leg.

With respect to sex differences our study has shown that elderly female subjects have demonstrated smaller than males relative strength of the left leg by 10.3 %.

**Discussion and conclusions**

The analysis of obtained results has shown that aging causes a decrease in strength of leg muscles. The age differences in strength have been found by many researchers who usually measured maximum dynamic and isometric strength of muscles in an isolated way (the strength of a chosen muscle group) in biomechanical laboratories and rehabilitation centres with using different sort of dynamometers, tensometric devices (Kubo et al., 2007; Barry et al., 2005) and sometimes very complicated measurement equipment (Petrella et al., 2005).

To measure the leg strength in the presented study we have used a computed method, which can be applied to test the explosive and dynamic strength together (total strength) in an indirect way by measuring the time of stepping up movements in response to audio-visual stimuli.

Motor reacting (responding to stimuli) in a natural way forces subject to perform movements as fast as possible. The dynamometric and tensometric methods require generating high motivation to demonstrate the maximum strength abilities in elderly subjects. Therefore, the method applied in the presented study seems to be more useful to test strength in seniors. Furthermore, the obtained results of strength measurements presented in time units are easier to transfer into everyday life activities than surmounted resistance of external mass expressed in kilograms. Elderly subjects who have a shorter time of stepping up movements obtain information that they are able to get on the train, bus, tramway easier and walk up the stairs faster.

Other researchers used stepping task on a flat surface (stepping back and forward or to the sides; Demura et al., 2008; George et al., 2007) or up and down but at small elevations of the step (5 cm, Demura et al., 2008) to examine the age differences. These studies were directed to testing leg reaction and response time, the influence of disturbing factors (split attention) on stepping movements in seniors in the aspect of the risk of falls. In this study elderly subjects could not demonstrate the maximum strength (speed of movements) because of the inertia of the body, which could cause falls in a situation of very fast reacting. Furthermore, in stepping task on a flat surface (in the horizontal plane) different muscles took part than in stepping up (in the vertical one) movements. Summing up, the stepping up method applied in the presented study

<table>
<thead>
<tr>
<th>Groups</th>
<th>Left leg strength</th>
<th>Right leg strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Times M SD ST</td>
<td>Times M SD ST</td>
</tr>
<tr>
<td>Elderly</td>
<td>1.579 0.221</td>
<td>1.629 0.305</td>
</tr>
<tr>
<td>Young</td>
<td>1.302 0.192</td>
<td>1.338 0.214</td>
</tr>
<tr>
<td>Female Elderly</td>
<td>1.656 0.209</td>
<td>1.668 0.261</td>
</tr>
<tr>
<td>Female Young</td>
<td>1.304 0.243</td>
<td>1.360 0.272</td>
</tr>
<tr>
<td>Male Elderly</td>
<td>1.502 0.208</td>
<td>1.590 0.338</td>
</tr>
<tr>
<td>Male Young</td>
<td>1.301 0.151</td>
<td>1.306 0.136</td>
</tr>
</tbody>
</table>

**Table 1**

The speed of stepping up movements (ST, relative leg strength) for left and right leg in tested groups.

<table>
<thead>
<tr>
<th>Differences</th>
<th>Absolute differences [s]</th>
<th>Relative differences [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Left leg</td>
<td>Right leg</td>
</tr>
<tr>
<td>Times</td>
<td>ST right leg</td>
<td>ST left leg</td>
</tr>
<tr>
<td>Elderly-Young</td>
<td>0.277 0.291</td>
<td>21.3 21.8</td>
</tr>
<tr>
<td>Female Elderly-Young</td>
<td>0.352 0.308</td>
<td>26.9 22.6</td>
</tr>
<tr>
<td>Male Elderly-Young</td>
<td>0.201 0.284</td>
<td>15.4 21.7</td>
</tr>
<tr>
<td>Female-Male Elderly</td>
<td>0.154 0.078</td>
<td>10.3 4.9</td>
</tr>
<tr>
<td>Female-Male Young</td>
<td>0.003 0.054</td>
<td>0.2 4.1</td>
</tr>
</tbody>
</table>

x – statistically insignificant differences

The right leg is impaired by 6.3 % more than the left leg by the aging process in men, while in women the left leg is impaired by 4.3 % more than the right leg.

With respect to sex differences our study has shown that elderly female subjects have demonstrated smaller than males relative strength of the left leg by 10.3 %.
enables reacting with the maximum speed (small risk of falls) and is related to a different kind of motor responses than the horizontal stepping method.

Our study has shown that the aging process slows down the stepping up movements to a high degree. We have found not only age but also sex differences in the elderly in the speed of stepping up. Our findings support results of Demura et al. (2008) with respect to age differences in stepping task in elderly subjects. Demura et al. (2008) did not find sex differences in stepping tests in older people, while we have found such a difference in the speed of stepping up for the left leg. We have hypothesised larger leg strength in male than female subjects. The results obtained support our hypothesis with respect to leg strength. The male elderly group demonstrated the left leg markedly stronger than right one in stepping up movement speed. Therefore, the stepping up method seems to be more discriminative with respect to sex and leg differences than the horizontal stepping method.

We have found relative strength for the left and the right leg on average smaller by 21.6 % in elderly than in young subjects. Our earlier study (Latecka et al., 2006) showed 42 % slower locomotion of elderly people in comparison to the young ones. We think that elderly subjects perform locomotion than stepping up movements almost twice slower in comparison to young subjects not because of the greater aging changes in the structure of leg muscles but because of the horizontal stepping experiments elderly subjects did not perform the movement with maximum speed being afraid of falls. (inertia of the body).

The 21.5 % (on average for both legs) age difference in the leg strength obtained in this study is also observed in real life. Elderly people walk up the stairs and get on a bus, tramway or train much more slowly than young ones. In our earlier study we have found that inactive older people were by 22 % slower in locomotion and rotation movement than active older people (Lapszo et al., 2006). Cunha and co-workers (2010) have shown that a walking intervention program improves the distance traveled by elderly women in a 6-minute walking test. Hökelmann (2006) applied a music and movement intervention program in seniors, which allows improvement in cardiovascular endurance, rhythmic abilities, balance, reaction time and power in this group. The intervention programs improving the motor abilities in seniors were also conducted by vibration muscles training (Niewiadomski et al., 2005). On the basis of the studies we suppose that various intervention programs that require producing fast leg movements (dancing, nordic walking, jogging) or large leg strength (biking, hiking, strength training) can also significantly reduce the age differences in the speed of stepping up movements. The effects of different intervention programs can be controlled by using motor tests (as the test presented in this study) and also by measuring biochemical, physiological and mental factors (Gault et al., 2009; Niewiadomski et al., 2007; Borcz et al., 2006; Blaser and Hökelmann, 2009).

In the analysis of leg strength lateral differences we have found that the aging process causes a greater decrease in leg strength for the right (21.7%) than the left leg (15.4 %) in male elderly subjects. The obtained results suggest that aging impairment may cause lateralization in leg strength in older men. The difference of the age changes of the strength between the left (26.9 %) and the right (22.6 %) leg occurs also in female elderly subjects, but they are not so marked (not statistically significant) as in male seniors. The obtained results show that male subjects are more efficient in stepping up movement with the left (Tab. 1) than the right leg and suggest that elderly women might have stronger right than the left leg. Further research is necessary with respect to aging and sex lateralization of leg strength in older people.

In young subjects we did not find lateral differences in leg strength, although the 4.1 % leg difference in female young subjects suggests a possibility of such lateralization also in the young group. It is reported that the leg strength lateralization in young people can be caused by practising specific sports. The research on students who studied skiing specialisation at the university of Athens showed lateralization in the static strength of legs (Giovanis et al., 2006). The students demonstrated the right leg was stronger than the left one. These findings suggest that the practice of skiing may improve the strength of the right more than the left leg. Concluding, our study has not shown the lateral differences in leg strength in youth, but has shown such differences in male elderly subjects and indicates a possibility of leg strength lateralization in female young and older women if larger groups be tested.

Other researchers who concentrated on testing the initiation and speed of stepping movements on flat surfaces (George et al., 2007; Berg & Blasi, 2000) and in conditions in which attention was split (Ashton-Miller et al., 2005; Melzer & Oddsson, 2004; Chen et al., 1996) also showed age differences in most of the tested factors. The conditions of such studies are more related to the walking situation than stepping up stairs or getting on the bus, train, or tramway. So our studies are related to a vertical stepping up situation (the relative height of the step – 30.5 cm, 12 inches) and in this sense are different from the earlier horizontal stepping (walking) studies. The presented studies on age, sex and leg differences in vertical stepping task explore the human motor behaviour which is less known than horizontal stepping movements but not less important in the aspect of safety in performance of different movements.

The presented study and the previous ones (Lapszo et al., 2008, Lapszo et al. 2006, Latecka et al., 2006) are directed to the elaboration a multidimensional test of fundamental motor efficiency for everyday activity, in which the presented step-test will be used. We are also planning to use the method to test the initiation (explosive strength), execution (dynamic strength) and total (explosive and dynamic strength together) time in stepping up movements of older people who systematically participate in organised (intervention programs; Cunha et al., 2010; Hökelmann, 2006) recreational forms of motor activity (walking, jogging, biking, dancing, hiking) to evaluate the influence of different forms of motor activity on fundamental for everyday activity motor and mental (feeling of high fitness, motor safety and movement confidence) efficiency.
References:

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Came to edition 07.09.2011.

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Came to edition 07.09.2011.