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THE EFFECT OF BACK MUSCLE FATIGUE ON POSTURAL SWAY

VPLIV UTRUJENOSTI HRBTNIH MIŠIC NA GIBANJE SREDIŠČA PRITISKA

ABSTRACT

The purpose of this study was first to determine the effect of lumbar extensor muscle fatigue on the movement of the centre of pressure (CoP) in young and elderly subjects. The second purpose was to determine if there is any difference between age groups in the response to such fatigue. Fourteen elderly (72 ± 7.2 years) and 16 young (27.5 ± 4.1 years) male subjects stood on a force platform with their eyes open and closed before, immediately after and 10 minutes following a fatiguing exercise protocol for back muscles. The force platform was used to measure the CoP movements and six variables of postural sway were chosen for the analysis.

The results showed a difference in the movement of the CoP between the age groups standing with their eyes open and standing with their eyes closed. However, the lumbar extensor muscle fatigue did not affect the movement of the CoP in the young and elderly subjects. There was also no difference in the response to the back muscle fatigue between the age groups.

The results suggest that fatigue of the lumbar extensor muscles does not lead to a different response among younger and elderly individuals. However, there was a tendency to adopt different strategies to maintain quiet standing between the young and elderly subjects, with increased movement of the CoP in the young compared to the elderly. Further, there were differences in the direction of the CoP movement, with the young subjects moving more in a medio-lateral direction and the elderly subjects in an antero-posterior direction.

Key words: muscle fatigue, postural sway, elderly, balance

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IZVLEČEK

Namen raziskave je bil ugotoviti vpliv utrujenosti hrbtnih mišic pri skupini mlajših in starejših preiskovancev na gibanje središča pritiska (SP) in ugotoviti ali med starostnima skupinama obstaja kakšna razlika v odzivu na utrujenost. 14 starejših (72 ± 7,2 let) in 16 mlajših (27,5 ± 4,1 let) preiskovancev je stalo na pritiskovni plošči, z odprtimi in zaprtimi očmi pred, po in 10 minut po izvedbi utrujanja hrbtnih mišic. Merili smo silo reakcije podlage (SRP) na pritiskovni plošči, na osnovi katere smo izračunali šest parametrov gibanja SP.

Med starostnima skupinama so se pokazale statistično značilne razlike v gibanj SP pri stoji z odprtimi in z zaprtimi očmi. Utrujenost hrbtnih mišic pa ni imela statistično značilnega vpliva na gibanje SP ne pri skupini mlajših in ne pri skupini starejših preiskovancih. Ravno tako pa ni bilo videti statistično značilnih razlik v odzivu na utrujenost hrbtnih mišic med starostnima skupinama.

Na podlagi rezultatov naše raziskave lahko sklepamo, da utrujenost hrbtnih mišic ni povzročila različnega odziva med mlajšimi in starejšimi preiskovalci. Kaže se pa tendenca o uporabi različnih strategijah ohranjanja mirne stoje med mlajšimi in starejšimi preiskovanci, kar lahko sklepamo iz povečanega gibanjem SP po utrujanju pri mlajših in zmanjšanega gibanje SP pri starejših preiskovancih in iz razlik v smeri gibanja SP in sicer pri mlajših v medio-lateralni smeri in pri starejših preiskovancih v antero-posteriorni smeri.

Ključne besede: mišična utrujenost, gibanje SP, starejši, ravnotežje

INTRODUCTION

More than one-third of elderly people aged over 65 falls at least once a year and half of them fall several times a year. With age the number of falls increases; every other person over 85 years falls at least once a year (Blake et al., 1988; Tinetti, Speechley, & Ginter 1988). Most of these falls are the result of a loss of balance in a forward direction such as stumbling while walking (Blake et al., 1988). In 2010 in Slovenia, 16 per 1,000 people aged between 60 and 64 were hospitalised due to a fall, 20 per 1,000 among those aged between 65 and 74, 33 per 1,000 among those aged between 75 and 84, and 57 per 1,000 among those older than 85 (IVZ, 2010).

Fatigue of the back muscles has been found to be an important factor in the increased movement of the body's CoP and a predictor of falls (Pline, Madigan, & Nussbaum 2006) since lumbar extensors have the largest impact of all studied muscle groups on the movement of the CoP (Lin et al., 2009). Davidson, Madingen, and Nussbaum (2004) found that the increased movement of the CoP was the result of reduced muscle proprioceptive flow. Lattanzio, Petrella, Sproule, and Fowler (1997) and Björklund, Crenshaw, Djupsjöbacka, and Johansson, (2000) also found that lower limb muscle fatigue reduces the final proprioceptive flow. Ng, Parnianpour, Richardson, and Kippers. (2003) pointed out that the fatigue of back muscles leads to less smooth muscle force production, which means poor control of body movements and the consequent increased movement of the CoP. Davidson et al. (2004) also studied how breathing affects the motion of the CoP. Increased breathing, as a result of fatigue, has not been shown to be an important factor in the increased movement of the CoP. Fatigue of the lumbar extensor muscles increases the movement of the CoP and subjects have to adopt a postural strategy (Madingan, Davidson, & Nussbaum 2006). Back muscle fatigue also has an effect on the postural strategy in response to balance perturbation (Wilson, Madigan, Davidson, & Nussbaum 2006), as young subjects often use the hip strategy. The hip strategy is often used by people with a greater likelihood of falling (Maki, Edmondstone, & McIlroy, 2000). Muscle fatigue has a different impact on maintaining balance in young subjects compared to elderly ones (Mademli, Arampatzis, & Karamanidis, 2008; Wojcik, Nussbaum, Lin, Shibata, & Madigan 2011). Davidson, Madingen, Nussbaum, and Wojcik (2009) found that the elderly have more problems with balance when their back muscles are fatigued than younger subjects.

The fatigue of back muscles has proven to be a significant factor in the increased movement of the CoP and various authors have pointed out that between the young and elderly there are differences in response to such fatigue, among different muscle groups. We therefore decided to firstly investigate how back muscle fatigue influences the movement of the CoP and compare the responses between young and elderly subjects and, secondly, to investigate if there are any differences in response to fatigue between these two age groups. Our hypotheses were that fatigue of the back muscles will cause a statistically significant: (1) increase in CoP movement among young subjects; (2) an increase in CoP movement among elderly subjects; and (3) difference in the response of the postural sway between elderly and young subjects while standing.

METHODS

Subjects

Sixteen young (age: 27.5 ± 4.1 years, height: 178 ± 5 cm, mass: 74.5 ± 8.1 kg) and 14 elderly (age: 72.0 ± 7.2 years, height: 172 ± 6 cm, mass: 77.9 ± 13.5 kg) active men participated. All subjects were healthy at the time of the measurement, active on average three times a week and were able to independently perform all of the tasks in the experiment. All subjects signed an informed consent form. The study was in accordance with the Helsinki-Tokyo Declaration and the Slovenian Medical Ethics Committee approved the study.

Experimental design

At the beginning of the experiment the subjects were informed about the purpose of the study. First, we attached the appropriate measuring devices to each subject, and then they warmed up (6 minutes of stepping on a 20 cm high bench with a frequency of 0.5 Hz). We continued with initial measurements on the force platform, which was followed by a fatiguing protocol and then all the measurements were repeated on the force platform immediately and 10 minutes after fatigue. The subjects were asked to stand quietly on the force platform for 30 seconds with their feet together, without shoes, their hands at their sides, first with their eyes open and second with their eyes closed.

The subjects' back muscles were fatigued using a modified Sorensen test (Figure 1) (Dedering, Nkmeth, & Harms-Ringdahl 1999). The subjects were positioned prone on a bench, and the anterior iliac spine was positioned on the edge of the bench, supporting the pelvis and legs. The lower body was stabilised on the bench with straps and the arms were crossed over the chest. The subjects were instructed to maintain a horizontal trunk position until either they were unable to voluntarily maintain the position or the position deviated from horizontal, which was controlled by a band that had been stretched between bars and positioned over the subjects' backs. When the subjects moved away from the position for more than 10 seconds, the test was terminated and fatigue declared. Verbal encouragement was given during the fatigue test. We used an 11-point Borg scale (0–10) to measure subjective estimates of fatigue (Borg, 1982).

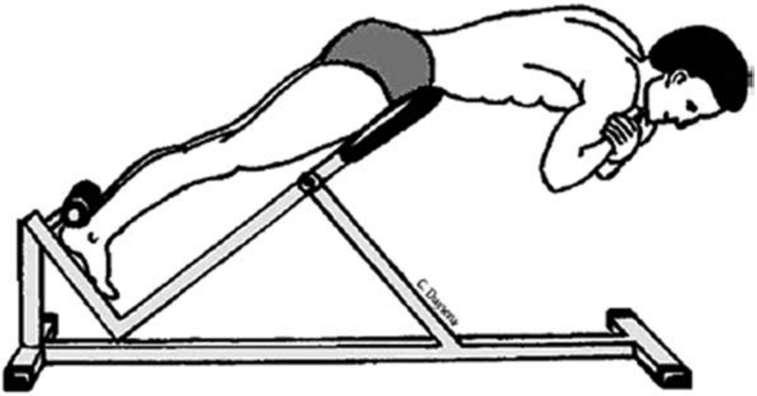


Figure 1: Modified Sorensen test (Dedering et al., 1999)

Measuring Instruments

The measurements were performed in the Laboratory of Kinesiology at the Faculty of Sport in Ljubljana. We measured the CoP position during standing with a force platform (Kistler 9286AA, Winterthur, Switzerland) supported by a computer system and software (DasyLab MCC, Norton, USA). Data were processed and analysed with a program for processing stabilometric data that is accessible through a web server (Sevšek, 2009). The analysis of the stabilometric data started by smoothing the acquired CoP positions in medio-lateral and antero-posterior directions using Gaussian averages over three adjacent points. Six sway parameters were chosen for this analysis: (1) medio-lateral (ML path) and (2) antero-posterior (AP path) path lengths, variability of the (3) medio-lateral (ML variability) and (4) antero-posterior (AP variability) sways, (5) CoP mean velocity and (6) sway area, which was calculated by Fourier coefficients. The exact method of calculation is described in Rugelj and Sevšek (2007).

Statistical analysis

For the statistical analysis we used the SPSS.17 program (SPSS Inc., Chicago, IL USA) and Microsoft Excel 2010 (Microsoft Inc., Redmond, WA, USA). All dependent variables were visually inspected for normality, which was found in all cases. A 3x2 mixed-design ANOVA was calculated to determine the effect of fatigue of the back muscles and age on the sway variables. Statistical significance was accepted at a 5-percent error alpha.

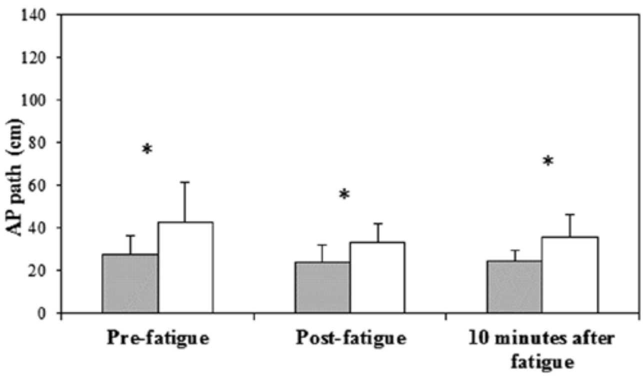
To determine differences between individual measurements within a group we needed to perform protected t tests, for which we used paired t tests. Statistical significance at a 1.7-percent error alpha (5% / 3) was used.

RESULTS

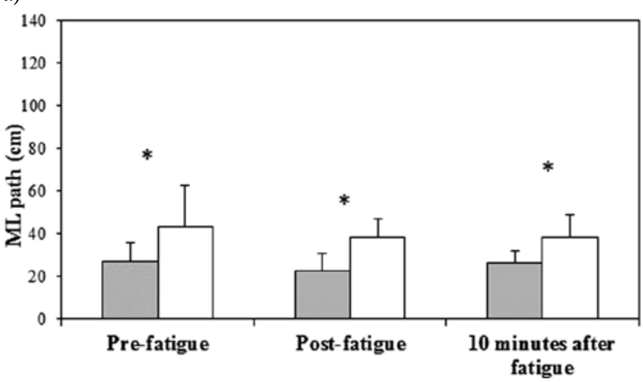
A 3x2 mixed-design ANOVA was calculated to determine the effect of back muscle fatigue (before, immediately after and 10 minutes following a bout of fatiguing exercise) and age (young and elderly subjects) on the sway variables.

No significant interactions between group × measurements were found. The value of F (2, 56) ranged from a minimum of 0.57 in AP variability in standing with eyes closed to a maximum of 2.37 in AP variability in standing with eyes open. Alpha ranged from a minimum of 0.103 in AP variability in standing with eyes open to a maximum of 0.568 in AP variability in standing with eyes closed.

The mean effect for age was significant in standing with eyes open in the AP path (F (1,28) = 12.12, p = 0.002), ML path (F (1,28) = 12.37, p = 0.002 (Figure 2), ML variability (F (1,28) = 5.74, p = 0.023) and mean velocity (F (1,28) = 13.19, p = 0.001), while in AP variability (F (1,28) = 0.86, p = 0.77) and sway area (F (1,28) = 3.87, p = 0.059) the main effect for age was not statistically significant.



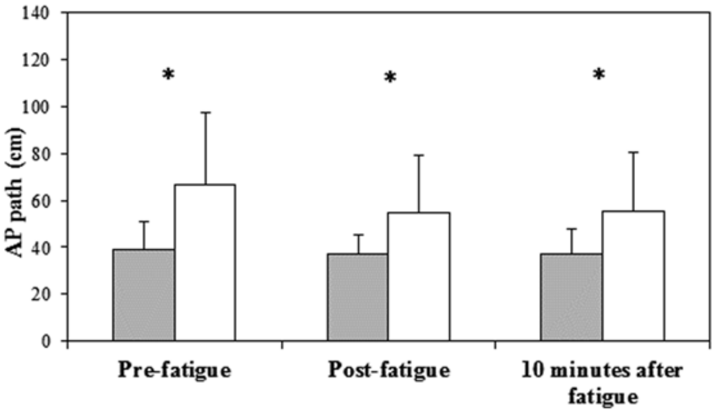
a)



b)

Figure 2: Effect of back muscle fatigue on AP path (a) and ML path (b) during quiet standing with open eyes open in young (grey) and elderly (white) men. *- p<0.05

The mean effect for age was significant in the standing with eyes closed condition in the AP path (F (1,28) = 10.70 p = 0.003), ML path (F (1,28) = 7.00, p = 0.013) (Figure 3), AP variability (F (1,28) = 3.99, p = 0.055), mean velocity (F (1,28) = 9.64, p = 0.004) and sway area (F (1,28) = 4.27, p = 0.048), while in the ML variability (F (1,28) = 3.38, p = 0.077) the mean effect for age was not significant.



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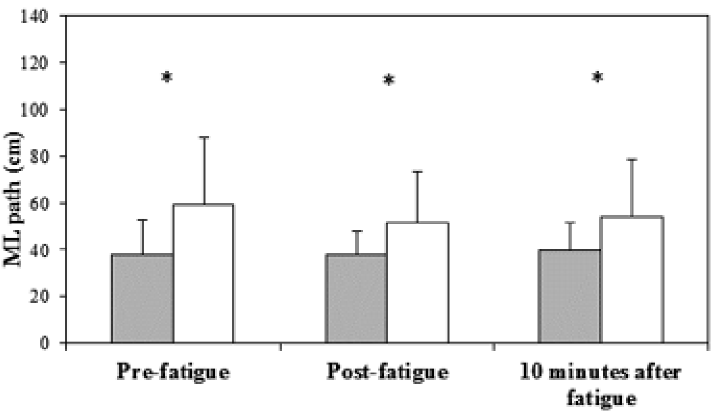

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Figure 3: Effect of back muscle fatigue on AP path (a) and ML path (b) during quiet standing with eyes closed in young (grey) and elderly (white) men. *- $p<0.05$

To determine the mean effect for fatigue of the back muscles (before, immediately after and 10 minutes following a bout of fatiguing exercise) on individual sway parameters, a 3x2 mixed-design ANOVA was first performed, followed by post hoc t tests for which we used paired t tests.

The mean effect for fatigue was significant in the AP path (F (2, 56) = 7.95, p = 0.009) when standing with eyes open. However, the post hoc t tests showed no significant difference between pre-fatigue, post-fatigue and 10 minutes after fatigue (Tables 1 and 2).

The mean effect for fatigue was significant in mean velocity ($F (2, 56) = 4.60$, $p = 0.014$) when standing with open eyes. Again, post hoc t tests showed no significant difference between prefatigue, post-fatigue and 10 minutes after fatigue (Tables 1 and 2).

The results showed there was no significant mean effect for fatigue in the ML paths ($F (2, 56) = 2.39$, $p = 0.10$), AP variability, $F (2, 56) = 0.75$, $p = 0.477$), ML variability $F (2, 56) = 2.79$, $p = 0.07$) and sway area ($F (2, 54) = 1.26$ $p = 0.27$) when standing with eyes open.

The mean effect for fatigue was significant in the AP path ($F (2, 56) = 4.068$, $p = 0.022$) when standing with eyes closed. The post hoc t tests showed no significant difference between pre-fatigue, post-fatigue and 10 minutes after fatigue (Tables 1 and 2).

In the ML path ($F (2, 56) = 0.903$, $p = 0.411$), AP variability ($F (1, 56) = 0.46$ $p = 0.632$), ML variability $F (2, 56) = 1.579$, $p = 0.219$), the mean velocity ($F (2, 56) = 2.407$, $p = 0.132$) and sway area ($F (2, 54) = 1.698$, $p = 0.192$) there was no significant mean effect for fatigue when standing with eyes closed.

Detailed values for the younger subjects are given in Table 1 and those for the elderly subjects in Table 2.

Table 1 Centre of pressure movement in the younger subjects (n = 16) before, immediately after and 10 minutes after fatigue of the lumbar extensor muscle group

Parameters				*p* values		
	Pre-fatigue	Post-fatigue	10 min after fat.	pre: post	post:10po	pre: 10po
AP path (cm)	27.39 ± 8.57	23.68 ± 7.83	24.09 ± 5.20	0.094	0.772	0.129
AP path EC (cm)	39.14 ± 11.64	37.08 ± 8.32	36.94 ± 10.80	0.501	0.959	0.373
ML path (cm)	26.82 ± 10.35	22.71 ± 6.63	26.32 ± 6.41	0.091	0.044	0.851
ML path EC(cm)	38.00 ± 14.76	38.08 ± 9.47	39.37 ± 12.21	0.981	0.614	0.671
AP variability	0.50 ± 0.18	0.53 ± 0.16	0.51 ± 0.23	0.584	0.638	0.867
AP variability EC	0.53 ± 0.13	0.55 ± 0.13	0.55 ± 0.17	0.699	0.962	0.721
ML variability	0.42 ± 0.17	0.38 ± 0.10	0.40 ± 0.09	0.391	0.204	0.822
ML variability	0.50 ± 0.19	0.47 ± 0.11	0.58 ± 0.22	0.721	0.522	0.037
Mean velocity	1.42 ± 0.47	1.27 ± 0.30	1.32 ± 0.28	0.147	0.42	0.406
Mean velocity EC	2.02 ± 0.61	1.97 ± 0.44	2.00 ± 0.58	0.748	0.781	0.916
Sway area (cm²)	3.14 ± 2.20	3.00 ± 1.54	2.61 ± 0.91	0.832	0.549	0.395
Sway area EC (cm²)	4.65 ± 2.41	4.19 ± 1.52	5.03 ± 2.92	0.439	0.213	0.590

Mean ± SD from AP path – antero-posterior path lengths with eyes open, AP path EC – antero-posterior path lengths with eyes closed, ML pathpot – medio-lateral path lengths with eyes open, ML path EC – medio-lateral path lengths with eyes closed, AP variability – variability of antero-posterior sways with eyes open, AP variability EC – variability of antero-posterior sways with eyes closed, ML variability – variability of medio-lateral sways with eyes open, ML variability EC – variability of medio-lateral sways with eyes closed, Mean velocity – mean velocity with eyes open, Mean velocity EC – mean velocity with eyes closed, Sway area – sway area with eyes open, Sway area EC – sway area with eyes closed, pre:post – difference between the measurements before and immediately after fatigue, post:10po – difference between the measurements immediately after and 10 minutes after fatigue, pre: 10po – difference between the measurements before and 10 minutes after fatigue.

Table 2 Centre of pressure movement in the older subjects (n = 14) before, immediately after and 10 minutes after fatigue of the lumbar extensor muscle group

Parameters				*p* values		
	Pre-fatigue	Post-fatigue	10 min after fat.	pre: post	post:10po	pre: 10po
AP path (cm)	42.26 ± 19.18	32.94 ± 8.62	35.29 ± 10.63	0.028	0.175	0.048
AP path EC (cm)	66.71 ± 30.45	55.03 ± 24.44	55.32 ± 25.33	0.033	0.948	0.071
ML path (cm)	43.15 ± 20.88	38.00 ± 15.00	38.08 ± 14.99	0.256	0.974	0.259
ML path EC(cm)	59.38 ± 28.89	51.90 ± 21.46	54.40 ± 24.41	0.234	0.437	0.33
AP variability	0.56 ± 0.17	0.43 ± 0.10	0.50 ± 0.16	0.005	0.104	0.018
AP variability EC	0.68 ± 0.31	0.64 ± 0.25	0.70 ± 0.24	0.421	0.296	0.744
ML variability	0.61 ± 0.33	0.50 ± 0.15	0.45 ± 0.17	0.227	0.039	0.07
ML variability	0.69 ± 0.39	0.62 ± 0.19	0.64 ± 0.23	0.324	0.547	0.402
Mean velocity	2.24 ± 1.01	1.86 ± 0.57	1.92 ± 0.63	0.081	0.506	0.106
Mean velocity EC	3.31 ± 1.52	2.81 ± 1.10	2.87 ± 1.25	0.086	0.717	0.12
Sway area (cm²)	2.67 ± 0.66	2.27 ± 1.04	1.76 ± 1.20	0.281	0.185	0.443
Sway area EC (cm²)	10.26 ± 12.13	7.19 ± 5.66	8.06 ± 5.55	0.228	0.27	0.32

Mean ± SD from AP path – antero-posterior path lengths with eyes open, AP path EC – antero-posterior path lengths with eyes closed, ML pathpot – medio-lateral path lengths with eyes open, ML path EC – medio-lateral path lengths with eyes closed, AP variability – variability of antero-posterior sways with eyes open, AP variability EC – variability of antero-posterior sways with eyes closed, ML variability – variability of medio-lateral sways with eyes open, ML variability EC – variability of medio-lateral sways with eyes closed, Mean velocity – mean velocity with eyes open, Mean velocity EC – mean velocity with eyes closed, Sway area – sway area with eyes open, Sway area EC – sway area with eyes closed, pre:post – difference between the measurements before and immediately after fatigue, post:10po – difference between the measurements immediately after and 10 minutes after fatigue, pre: 10po – difference between the measurements before and 10 minutes after fatigue.

There was no significant difference in time to exhaustion (modified Sorensen test) between the younger and older subjects (Mean ± SD: 4.2 ± 1.2 minutes for the younger group and 3.1 ± 1.8 minutes for the older group, p=0.82).

DISCUSSION

The purpose of this study was to determine the effect of back muscle fatigue on postural sway and to assess potential differences between young and older subjects in the response to such fatigue. We found statistically significant differences between the younger and older subjects in the individual measurement conditions (before, immediately after and 10 minutes after fatigue) in most variables of postural sway, indicating the likely impact of ageing on the movement of the CoP.

The ability to maintain an upright posture decreases with age due to the reduced efficacy of the sensory, motor and cognitive systems (Rose, 2003), while fatigue has been suggested not to reduce this ability in older more than in younger subjects (Mademli et al., 2008; Granacher, Gruber, Förderer, Strass, & Gollhofer 2010). Delgado, Coghlin, Earle, Holek, and O´Hare (2010) found that trunk extensor fatigue does not affect balance differently for young and middle-aged subjects. The present study indicated there are differences in the amount of CoP movement when measured before, immediately after and 10 minutes after fatiguing of the back muscles in each age group, although these differences did not reach a statistically significant level. Therefore, based on these results we cannot confirm the impact of back muscle fatigue on movement of the CoP in either younger or older men. However, based on the reported data it can be assumed that the younger subjects and older subjects employed different balance strategies. Similar differences between young and elderly subjects were reported by Davidson et al. (2009). They studied the effect of local muscle fatigue on recovery from a postural perturbation without stepping, and in 3 of the 13 parameters they found differences between younger and elderly subjects. Elderly subjects were more challenged during recovery than the young subjects in the following parameters: peak CoP velocity, time-to-peak velocity and time-to-return to the original CoP position. Yet Lin et al. (2009) reached the opposite conclusion, indicating that fatigue had a greater impact on the movement of the centre of gravity while standing among younger subjects compared to elderly subjects. They concluded that this was a result of the use of a different balance strategy.

Elderly people more often use the hip strategy to maintain balance after fatigue than younger people (Maki et al., 2000). During quiet standing, without the presence of fatigue, young people mainly use the ankle strategy (Horak & Nashner, 1986), while elderly people generally use the hip strategy (Woollacott, Shumway-Cook, & Nashner 1986) to maintain the desired quite standing position. The same happens in the case of a narrow support surface (Amiridis, Hatzitaki, & Arabatzi 2003) and in the case of a moving support surface (Okada, Hirakawa, Takada, & Kinoshita 2001). The hip strategy enables elderly people to reduce the influence of muscle fatigue on the CoP compared to young people when fatigue is not related to hip muscle performance (Lin et al., 2009), as was the case in the present experiment. With longer durations and levels of fatigue, the postural sway increases (Pline et al. 2006) and it might be reasonable to expect that in our study the extension of fatigue resulted in a statistically significant difference between the age groups. The reasons for the reduced strength of muscle contractions due to fatigue can be attributed to both metabolic and non-metabolic processes (central nervous system). The longer the effort, the greater the influence of non-metabolic processes, which means a longer time between stimulation and contraction (Edwards, Hill, Jones, & Merton 1977). With prolonged activity, especially at higher loads, a large amount of micro-damage in the muscles was found, which means a lower muscle response and increases in the postural sway (Pline et al., 2006).

After fatigue, the younger subjects demonstrated an increase in the value of CoP movements in a medio-lateral direction and in the sway area while standing quietly with their eyes closed. On the other hand, the values of the other analysed variables decreased. In the elderly subjects the values of all variables decreased compared to the measurements before the fatiguing protocol. Lin et al. (2009) also found a statistically significant acute effect of fatigue on balance in young people only. Young people increased the movement of their CoP, while the elderly decreased the movement of their CoP. We can therefore assume that elderly people employ alternative strategies, which probably leads to a reduction of CoP movement. Taimela, Kankaanpää, and Luoto (1999) reported a reduced potential to detect changes in the position of the spine after fatigue of the back muscles. In the case of back muscle fatigue, it can be expected that an increase occurs in the detection threshold in the joints of the spine. In the event of fatigue a person may only detect larger movements so it may cause a delay in stabilisation, which results in an increase in postural sway (Davidson et al., 2004). The results of our study indicate that in elderly subjects the postural sway was larger even before the fatigue, which may lead to earlier and more intense stabilisation reactions after an exercise fatiguing the back muscles, which are reflected as a reduction of CoP movement. While the younger group detects a movement of the spine later, this leads to increased movement of the CoP after fatigue. This is also in line with the opinion that elderly people should be more resistant to fatigue than young people (Kent-Braun, Ng, Doyle, & Towse 2002) due to the lower percentage of type II muscle fibres (fast contraction/rapid fatigue) (Lexell, 1995; Kent-Braun, 2009) as well as thinner muscle membranes, the small part of the active muscle volume and forces produced, and consequently to the lower energy consumption (Mademli and Arampatzis, 2008).

Based on the present results we can reject our hypotheses, namely that fatigue of the back muscles did not cause a statistically significant: (1) increase in CoP movement among the young subjects; (2) am increase in CoP movement among the elderly subjects; and (3) a difference in the postural sway response between the elderly and young subjects while standing.

CONCLUSION

Young and elderly subjects responded similarly to a fatiguing back muscle protocol. However, there was a tendency towards the different use of strategies to maintain quiet standing between the young and elderly subjects after fatigue. The young subjects increased the movement of their CoP after fatigue, while the elderly subjects decreased their movement of their CoP. Another difference between the two groups is seen in the direction of the CoP motion, namely in the young group the ML direction was pronounced while in the elderly group the AP direction was more pronounced. In order to confirm this trend, it would be necessary to increase the sample size or increase the level of fatigue .

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