Acta of Bioengineering and Biomechanics
Vol. 13, No. 1, 2011

Original paper

Changes of bioelectrical activity in cervical paraspinal muscle during gait in low and high heel shoes

ANNA MIKA[1]*, ŁUKASZ OLEKSY[2], EDYTA MIKOŁAJCZYK[3], ANNA MARCHEWKA[1], PIOTR MIKA[1]

[1] Department of Clinical Rehabilitation, University School of Physical Education in Kraków, Poland.
[2] Zen Machines Poland.
[3] Department of Physiotherapy, University School of Physical Education in Kraków, Poland.

High heel footwear may be destructive for the spine because of an increased erector spinae muscle bioelectrical activity and increased ground reaction forces affecting lower limbs and the spine. The aim of this study was to evaluate the changes of bioelectrical activity in cervical paraspinal muscle during gait in low and in high heel shoes in different age groups. In 31 women aged 20–25 years and in 15 women aged 45–55 years without neck pain, the bioelectrical activity of the cervical paraspinal muscle was assessed during gait on flat surface with natural speed in three conditions: without shoes, in low (4 cm) and in high (10 cm) heel shoes. Higher bioelectrical activity cervical paraspinal muscle was noted during gait in high heel shoes in comparison to gait without shoes. The changes were more pronounced in the group of subjects aged 45–55 years. The prolonged wearing of shoes with stiletto type heels by individuals without neck pain is not safe for their spine and may lead to chronic paraspinal muscle fatigue.

Key words: *surface electromyography, cervical spine, gait, heel shoes, RSI*

1. Introduction

Neck pain is a common occurrence in our society and constitutes significant social and economic burden [1]. It is recognized that all soft tissues, including muscle, tendon, ligament, fascia, synovia, cartilage and nerve, will fail when sufficient force is applied. Activities at work, daily living and recreation may often produce biomechanical forces upon the body that approach the limits of the mechanical strength of soft tissue. This phenomenon is described as Repetitive Strain Injury (RSI) and is linked with a variety of musculoskeletal disorders, especially those affecting the neck and upper limb [2].

In the age of Louis XIV in France, women started to wear high-heeled shoes [3]. At present, high-heeled shoes are routinely used by women of all ages, in work and other settings. However, there are consequent negative side effects, such as sprained ankles, lower back pain (LBP), and leg pain, shortened Achilles tendon, increased oxygen consumption, decreased stride length and other changes in the gait pattern, walking speed and mobility and even, potentially, an increased predisposition towards knee degenerative osteoarthritis [4]–[6].

Previous research has shown that the height of a heel directly affects the spine as well as other parts of a body [7]. Unfortunately, many of these studies aimed only at gait kinematic analysis, a few dealt with low back electrical activities. Some authors have indicated that wearing high-heels not only increases the loading of the erector spinae, but could also be a cause for low back pain [3], [8]. Low back pain as a result of increased heel height may be the result of increased ground reaction force (GRF), which has been reported

* Corresponding author: Anna Mika, Department of Clinical Rehabilitation, University School of Physical Education in Kraków, al. Jana Pawła II 78, 31-571 Kraków, Poland. Tel. +48126831134, e-mail: anna.mika@awf.krakow.pl

Received: May 30th, 2010
Accepted for publication: January 15th, 2011

when comparing high-heeled shoes to flat heeled sports shoes [5]. There does not appear to be any previous literature evaluating the influence of high-heeled shoes on cervical paraspinal muscles activity during gait.

Research into trunk muscle activity during gait has indicated that erector spinae activity increases during ipsilateral and contralateral swing phases of gait, and decreases during double stance (following heel strike) [9], [10]. KAVANAGH et al. [11] have suggested that the muscles of the low back are activated at corresponding heel contacts of the feet [12], possibly increasing the stiffness of the spine to better attenuate the transmitted ground reaction forces [13], [14]. Therefore this attenuation of increased GRF by high-heeled shoes may be considered as a protective mechanism preventing spine overload.

It has been suggested that the biomechanics of the spinal movement is affected by abnormal patterns of muscle activity that could result in mechanically induced pain. Some authors have demonstrated that cervical pain may be attributed to dysfunctional cervical posture, disturbance in movement, and the associated sEMG recruitment of the cervical region, and high heel shoes may be considered as one of the factors leading to these ailments [15]. It was observed that even small, but prolonged increase in bioelectrical activity of paraspinal muscles may lead to their chronic overload and fatigue [15], [16].

To our knowledge, there has been no previous study to quantify the effects of heel lifts on cervical paraspinal muscle activity during gait. Moreover, this study is the first to examine the effects of heel lifts on paraspinal muscle activity in either a young or middle-aged asymptomatic population.

The aim of this study was to evaluate the changes of bioelectrical activity in cervical paraspinal muscle during gait in low and in high heel shoes in different age groups.

2. Material and methods

2.1. Subjects

In 31 women aged 20–25 years (Group 1) (body height of 167.6 ± 5.8 cm; body mass of 60.35 ± 6.49 kg) and in 15 women aged 45–55 years (Group 2) (body height of 161.3 ± 4.2 cm; body mass of 65.8 ± 6.2 kg), without neck pain either in the past or currently, the bioelectrical activity of the cervical paraspinal muscle was assessed with surface electrodes. Those with confirmed overloading changes in the cervical spine or with other pathologies which could have affected the research and its results were not qualified for participation. All those tested wore high-heeled shoes occasionally, not more frequently than once a month. For the purpose of familiarizing all the subjects were asked to use stiletto type shoes one hour a day during one week before starting the study protocol.

All measurements were taken during one day, threefold for each subject. The test was conducted without footwear, in shoes of the stiletto heeled type with 4 cm heels (low heels) and in shoes of the stiletto heeled type with a height of 10 cm (high heels). The heels had a base of 1 cm^2.

All the participants were informed in detail about the research protocol and gave their informed consent to participate in the study. Local Ethical Committee approval was obtained for this study.

2.2. Study protocol

2.2.1. Procedure

Surface electromyography (sEMG) of cervical paraspinal muscle was measured using POCKET EMG (BTS, Bioengineering) according to SENIAM guidelines [17], [18]. The analysis of the sEMG signal was conducted with the SMART ANALYZER application (BTS, Bioengineering).

Fig. 1. Electrode location during measurement

The skin in the place where the electrode was attached was degreased with alcohol. The surface electrodes (Ag/AgCl) *(BIO LEADLOK)* with the 2-cm center-to-center distance were attached along the direction of the muscle fibers on the belly of the cervical paraspinal muscle at the neck on the right and left sides 2 cm from and along the spine [17], [18] (figure 1).

Muscles bioelectrical activity was measured during gait on flat surface with natural speed in three conditions: without shoes and in low (4 cm) and in high (10 cm) heel shoes. In each study condition, subject was asked to walk 6 times along walkway.

Before the test the person examined performed 2–3 walking trials with and without shoes with the aim of becoming fully familiar with the nature of the measurement.

2.2.2. Data analysis

sEMG data were recorded with 10-KHz sampling and processed according to SENIAM guidelines [17], [18]. The sEMG signal was filtered with Butterworth high-pass filter (with a cutoff frequency of 10 Hz) and a low-pass filter (with a cutoff frequency of 500 Hz). Then signal was rectified and the sEMG signal was RMS (Root Mean Square – the square root of the mean square value) smoothed with mobile window 300 ms [17], [18]. Using kinematic data obtained by six-camera BTS motion-analysis system (BTS, Bioengineering) according to Davis protocol, gait cycle events were set, heel strikes and toe off events for each gait trial for each side [19]. Using those events, smoothed RMS values (μV) were obtained for both ipsi- and contralateral sides for each event – heel strike value (HSV) and toe off value (TOV) [9], [18]–[21].

2.2.3. Statistical analysis

The statistical analysis was conducted using the STATISTICA Pl. The ANOVA test with repeated measurements was employed for the evaluation of the significance of the differences in the tested trails from amongst the measurements without footwear, in footwear with a low heel and with a high heel. The differences were considered as statistically significant if the level of test probability was lower than the assumed level of significance ($p < 0.05$).

3. Results

There was observed a higher value in cervical paraspinal muscle activity in the measurement in high heel shoes in comparison to low heel and barefoot, and this tendency was noted in both groups (the table).

In Group 1 (20–25 years old), the activity of the evaluated muscle during gait differed significantly between women in high heel shoes and those without footwear both in HSV as well as in TOV (figures 2a and 3a). In both instances, the cervical paraspinal muscle activity was higher in women wearing high heel shoes compared to barefoot ones. We did not find significant difference in muscle activity between women in low heel shoes and without shoes both in HSV and TOV ($p > 0.05$).

In the Group 2 (45–55 years old), also higher cervical paraspinal muscle bioelectrical activity was noted during gait in high heel shoes compared to gait without shoes. Moreover, in subjects aged 45–55 years, significant differences in HSV were observed

Table. Differences in cervical paraspinal muscles activity (RMS) between all study conditions in both groups

		F	*p*		*p* (post-hoc)
Group 1 20–25 years old	HRV	3.61	0.007	without shoes	–
				low heels	n.s.
				high heels	0.003
	TOV	5.96	0.001	without shoes	–
				low heels	n.s.
				high heels	0.008
Group 2 45–55 years old	HRV	4.90	0.001	without shoes	–
				low heels	0.02
				high heels	0.001
	TOV	3.77	0.003	without shoes	–
				low heelas	n.s.
				high heels	0.006

n.s. – nonsignificant, HRV – heel strike value, TOV – toe off value, *F* – ANOVA test *F*, *p* – level of statistical significance.

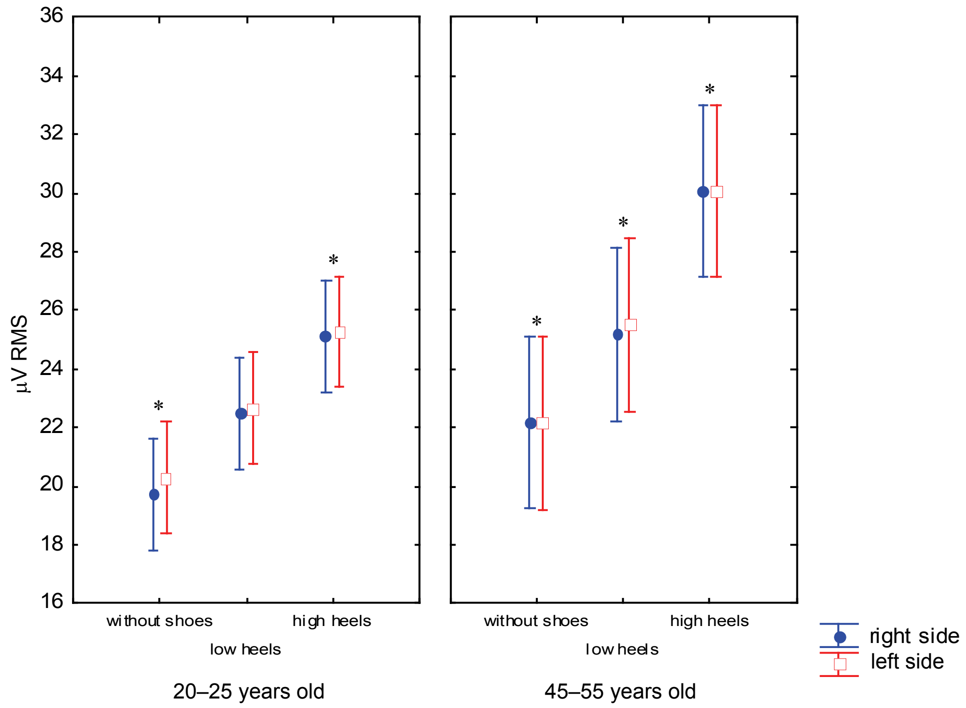

Fig. 2. RMS value of cervical paraspinal muscles at heel strike (HSV).
* $p < 0.05$

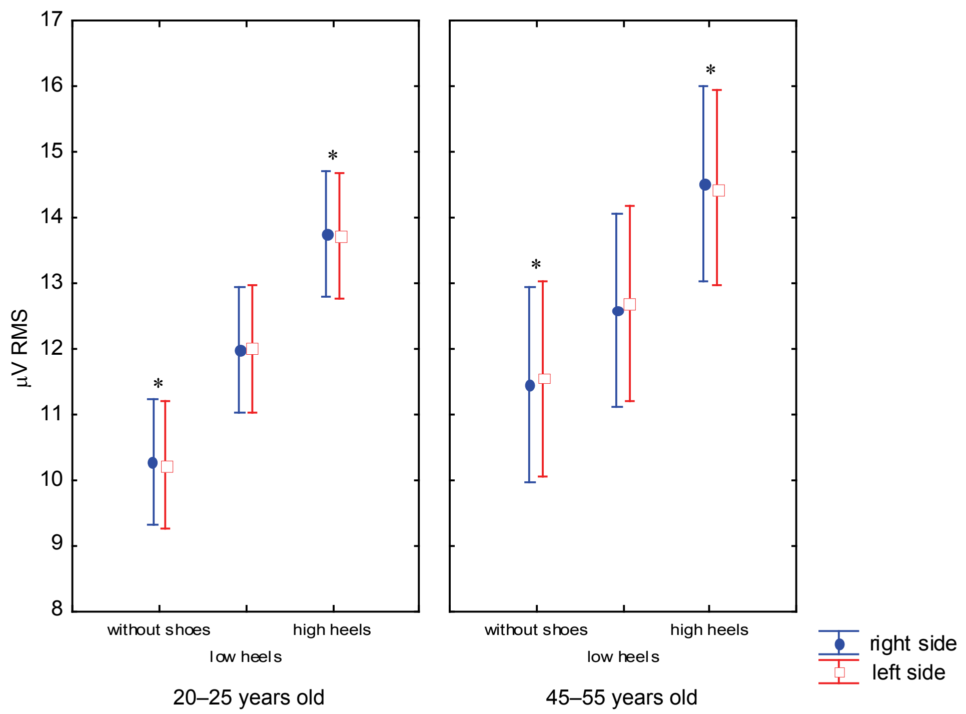

Fig. 3. RMS value of cervical paraspinal muscles at toe off (TOV).
* $p < 0.05$

both during the measurement without footwear and in footwear with low and high heels. In the subjects aged 45–55 years, a significant increase in evaluated muscle activity even for women in low heel shoes compared to barefoot ones may indicate that the changes in paraspinal muscle due to heeled shoes were more pronounced in this age group. Whereas TOV of cervical paraspinal muscle activity differed significantly in this group only in high heel gait in comparison to barefoot gait (figures 2b and 3b).

4. Discussion

The most important information revealed by the tests conducted is that footwear of the stiletto type of a height of 10 cm significantly increases the activity of the cervical paraspinal muscles and this effect is observed in both young and middle-aged women. To the author's knowledge, no previous study has examined the effects of heel lifts on cervical paraspinal muscles activity during gait.

Wearing footwear with increased heel height such as high-heeled shoes has been linked with low back pain etiology [8]. LEE et al. [3] observed 200 females who regularly wore high-heeled shoes, and found 58% of this population experienced low back pain whilst wearing the shoes.

Previous research into trunk muscle activity during gait has indicated an increase during ipsilateral and contralateral swing phases of gait, and a decrease during double stance (following heel strike) [9], [10]. Also VINK and KARSSEMEIJER [22] investigated low back muscle activity in a normal population during walking and noted higher bilateral activity of those muscles around heel contact. LEE et al. [3] reported a significant increase in the amplitude of lumbar erector spinae around heel strike in five female participants when walking in high-heeled shoes (45 mm and 80 mm) compared to bare feet. Higher levels of erector spinae activity around heel strike reported by LEE et al. [3] and earlier erector spinae onsets found by BIRD et al. [23] may be produced by the body's central nervous system (CNS) to compensate for postural disturbances due to high heels shoes. Those observations are in agreement with our findings, revealing cervical paraspinal activity during heel strike (HSV), which proves that cervical trunk muscles activity pattern is consistent with this observed in the lumbar region by other researchers.

EBBELING et al. [5] reported an increase in vertical and anterior–posterior GRF when comparing walking in high-heeled shoes to walking in flat heeled sports shoes. They suggested that an increase in proximal ground reaction force (GRF) could in part explain the mechanisms behind lower back pain (LBP) development as a result of tissue overloading due to wearing high-heeled shoes. Unfortunately, there is no information about the relationship between GRF and heeled shoes in the literature for cervical muscles. So, if GRF increased by heeled shoes has been linked with spinal pain and dysfunction, we may expect that due to age-related changes in spinal disc and paraspinal soft tissues this harmful effect of GRF on spine may be stronger in older women than in younger ones. This may partially explain the significant difference found in our study in cervical paraspinal muscle activity at heel strike between low and high heels' gait in the group of middle-aged women. We did not observe this rapid increase in muscle activity at heel strike during gait in high heeled shoes in young subjects, and based on that observation we may hypothesize that age-related changes in spine are important and may intensify the symptoms of neck overload and fatigue due to wearing high stiletto type heeled shoes.

BARTON et al. [24] have showed that peak EMG value of the trunk muscles activity increased significantly as heel height increased. This data is similar to our findings where showing that both HSV and TOV sEMG activities were higher in high heels than in low heels and barefoot gait, respectively.

Findings from previous studies [3], [23] indicate that some compensation for muscle activation occurs with an increase in to heel height. They suggest that the wearing of high heels causes several deleterious effects. An increase in heel height results in the shift in the height of the center of body mass. The upper body becomes heavier which creates additional compressive forces in the spine. In addition, there is a compensatory increase in erector spinae activity to maintain the abnormal posture. All these effects can significantly increase discomfort and fatigue levels in women wearing high heels. However, there may be a heel height at which trunk muscle activation is no longer able to adequately compensate for potentially increased GRF or center of mass (COM) positional changes [23].

The observations from our study have demonstrated in both study groups a gradual increase in the activity of cervical paraspinal muscles during heel strike with the rising of heel height. The significant differences in cervical muscles' activity in high heels compared to low heels in Group 2 may suggest that compensatory mechanisms observed by other authors become less efficient with age. So the harmful effect of high-heel shoes on posture and spinal tissues may be more pronounced in middle-aged women and may quicker contribute to pain and neck problems.

Some authors have demonstrated that cervical pain may be attributed to dysfunctional cervical posture, disturbance in movement, and the associated sEMG recruitment of the cervical region [15]. The injuries are surmised, leading to overexertion of the musculo-ligamentous structure of the neck [25]. This mechanism resulting in repetitive strain injury may lead to cervical spine dysfunctions [2], [26].

In a voluntary cervical motion, the neuromotor control exercised by the central nervous system determines the time, intensity, and a nature of excitation of agonists and antagonist muscles. In symptomatic subjects, due to pain, the pattern of the neuromotor control may be disrupted, altering the relationship between the muscle excitation, regional muscle balance, and resultant mechanical output [26]. Possible pathways involved in the development of neck musculoskeletal disorders have been described by ARMSTRONG et al. [27]. This model is useful for describing the cumulative nature of disorders whereby muscles activity produces internal forces acting upon body tissue. Those forces cause a response from the body such as increased circulation, local muscle fatigue and other various responses of a physiological and biomechanical nature. If the time necessary for regeneration of body tissue capacity is insufficient then a series of responses may further reduce the available capacity. This cumulative cycle may continue until o structural tissue deformation f some type occurs, e.g., pain, swelling, limited movement. This phenomenon is called [2] *repetitive strain injury* (RSI) and consist of a variety of musculoskeletal disorders, generally related to tendons, muscles, or joints, as well as some common peripheral nerve entrapment and vascular syndromes. These disorders generally affect the back, neck, and upper limbs, although lower limbs may also be involved. These injuries result from repetitive and forceful motions, awkward postures, and other overloading conditions [2], [26].

In our study, the increased cervical paraspinal muscles activity was observed in low and in high heel shoes in comparison to barefoot gait and this increase was observed in both young and middle-aged women. Based on these findings we may suggest that permanent wearing of heeled footwear may lead to neck muscles overuse and fatigue, and in those women the RSI symptoms may appear. Additionally those symptoms may be more pronounced in unstable balance when the shoes have stiletto type of the heel. KAVANAGH et al. [11] observed gait kinematics before and after fatigue onset of the cervical and lumbar erector spinae during static sub-maximal efforts, and they found oscillatory differences in trunk and neck sagittal movements during gait when cervical and lumbar muscles were fatigued. These observations may suggest that the fatigue of both trunk and neck muscles may be an additional factor which disturbs t body balance during gait and may intensify tissue overload in the condition of heeled shoes [11], [28].

McGILL et al. [16] evaluated the level of back muscle oxygenation during prolonged isometric contractions at intensities from 2 to 30% of maximum voluntary contraction (MVC). They observed that tissue oxygenation in the lumbar extensor musculature was reduced as a function of contraction intensity, even at the levels as low as 2% of MVC. They concluded that their findings had implications for prolonged work, where postures requiring isometric contractions were sometimes held for hours, and where musculoskeletal illness was linked with prolonged contraction levels above 2% of MVC. This situation occurs when the activity of trunk muscles is increased by compensatory mechanism working due to high heeled shoes, especially when this type of footwear is used for a long time. So based on McGILL study [16] and on our observations we may suggest that prolonged, increased muscles activity may lead to insufficient oxygenation and contribute to neck dysfunctions.

Several limitations of this study need to be addressed. First, the population examined consisted of healthy subjects only, without any ailments located in cervical spine, so future research should be conducted with a group of patients with cervical dysfunctions. Further, the surface EMG signals may vary, depending on electrode placement, different impendance due to insufficient skin preparations, so the appropriate condition for sEMG signal detection should be the main interest of the researcher. Moreover, circadian variation of the sEMG signal is the reason that the sEMG data in the assessment of muscle activity should be always considered with caution.

Thus, in conclusion, women should be discouraged from wearing high heels for prolonged time. There is a need for further research with the aim of defining whether there is a threshold heel height the compensatory mechanisms of the body become insufficient to counteract the excessive activeness of the cervical paraspinal muscles, the changes in GRF and shifting of the COM. It seems desirable to extend the research to a larger number of people in the population tested and to incorporate a group comprised individuals with pain symptoms in the cervical spine and other age groups.

5. Conclusion

1. The use of shoes with stiletto type heels increases activity in cervical paraspinal muscles, so this observation may suggest that prolonged wearing this type of footwear even by individuals without neck pain is not safe for their spine and may lead to chronic paraspinal muscle fatigue resulting in the neck repetitive strain injury.

2. Age-related changes in musculoskeletal system, especially in spine, may interfere with the disturbance in posture, balance and muscles activity resulting from stiletto type heeled shoes and may contribute in middle-aged women to quicker and more pronounced symptoms of neck overload and repetitive strain injury than in young women.

References

[1] KUMAR S., NARAYAN Y., PRASAD N., SHUAIB A., SIDDIQI Z.A., *Cervical electromyogram profile differences between patients of neck pain and control*, Spine, 2007, 32(8), E246–E253.

[2] YASSI A., *Repetitive strain injuries*, Lancet, 1997, 349, 943–47.

[3] LEE C.M., JEONG E.H., FREIVALDS A., *Biomechanical effects of wearing high-heeled shoes*, Int. J. Indust. Ergonom., 2001, 28, 321–326.

[4] NIETO E., NAHIGIAN S.H., *Severe ankle injuries while wearing elevated platform shoes*, Ohio Medicine, 1975, 71, 137–141.

[5] EBBELING C.J., HAMILL J., CRUSSEMEYER J.A., *Lower extremity mechanics and energy cost of walking in highheeled shoes*, Journal of Orthopedics Sports Physical Therapy, 1994, 19, 190–196.

[6] de LATEUR B.J., GIACONI R.M., QUESTAD K., KO M., LEHMANN, J.F., *Footwear and posture: compensatory strategies for heel height*, American Journal of Physical Medicine and Rehabilitation, 1991, 70, 246–254.

[7] OPILA-CORREIA K.A., *Kinematics of high-heeled gait with consideration for age and experience of wearers*, Arch. Phys. Med. Rehabil., 1990, 71, 905–909.

[8] BIRD A., PAYNE C.B., *Foot function and low back pain*, The Foot, 1999, 9, 175–180.

[9] ARENDT-NIELSEN L., GRAVEN-NIELSEN T., SVARRER H., SVENSSON P., *The influence of low back pain on muscle activity and coordination during gait: a clinical and experimental study*, Pain, 1995, 231–240.

[10] LAMOOTH C., DAFFERTSHOFER A., MEIJER O., MOSELEY G., WUISMAN P., BEEK P., *Effects of experimentally induced pain and fear of pain on trunk coordination and back muscle activity during walking*, Clin. Biomech., 2004, 19, 551–563.

[11] KAVANAGH J.J., MORRISON S., BARRETT R.S., *Lumbar and cervical erector spinae fatigue elicit compensatory postural responses to assist in maintaining head stability during walking*, J. Appl. Physiol., 2006, 101, 1118–1126.

[12] PRINCE F., WINTER D.A., STERGIOU P., WALT S.E., *Anticipatory control of upper body balance during human locomotion*, Gait Posture, 1994, 2, 19–25.

[13] VOLOSHIN A.S., MIZRAHI J., VERBITSKY O., ISAKOV E., *Dynamic loading on the human musculoskeletal system – effect of fatigue*, Clin. Biomech., 1998, 13, 515–520.

[14] VOLOSHIN A., WOSK J., *An in vivo study of low back pain and shock absorption in the human locomotor system*, J. Biomech., 1982, 15, 21–27.

[15] CRAM J.R., KNEEBORN W.J., *Cervical flexion: a study of dynamic surface electromyography and range of motion*, J. Manipulative Physiol. Ther., 1999, 22(9), 570–575.

[16] MCGILL S.M., HUGHSON R.L., PARKS K., *Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work*, Ergonomics, 2000, 43, 486–493.

[17] The SENIAM project (*Surface electromyography for the non-invasive assessment of muscles*).

[18] MERLETTI R., PARKER P., *Electromyography: Physiology, Engineering, and Non-Invasive Applications*, Wiley, IEEE Press, 2004.

[19] DAVIS R.B., OUNPUU S., TYBURSKI D., GAGE J.R., *A gait analysis data collection and reduction technique*, Human Movement Science, 1991, 10, 575–587.

[20] VINK P., DAANEN H.A.M., VERBOUT A.J., *Specificity of surface EMG on the intrinsic lumbar back muscles*, Human Movement Science, 1989, 8, 67–78.

[21] WINTER D.A., YACK H.J., *EMG profiles during normal walking: stride-to-stride and inter-subject variability*, Electroenceph. Clin. Neurophysiol., 1987, 67, 402–411.

[22] VINK P., KARSSEMEIJER N., *Low back muscle activity and pelvic rotation during walking*, Anat. Embryol., 1988, 178, 455–460.

[23] BIRD A.R., BENDRUPS A.P., PAYNE C.B., *The effect of foot wedging on electromyographic activity in the erector spine and gluteus medius muscles during walking*, Gait Posture, 2003, 18, 81–91.

[24] BARTON C.J., COYLE J.A., TINLEY P., *The effect of heel lifts on trunk muscle activation during gait: A study of young healthy females*, Journal Electromyogr. Kinesiol., 2009, 19(4), 598–606.

[25] KUMAR S., NARAYAN Y., AMELL T., *An electromyographic study of low-velocity rear-end impacts*, Spine, 2002, 27, 1044–1055.

[26] BUCKLE P.W., DEVEREUX J., *The nature of work-related neck and upper limb musculoskeletal disorders*, Applied Ergonomics, 2002, 33, 207–217.

[27] ARMSTRONG T.J., BUCKLE P., FINE L.J., HAGBERG M., JONSSON B., KILBOM A., KUORINKA I., SILVERSTEIN B.A., SJOGAARD G., VIIKARI-JUNTURA E., *A conceptual model for work-related neck and upper-limb musculoskeletal disorders*, Scand. J. Work Environ. Health, 1993, 19, 73–84.

[28] OLSON M.W., *Trunk extensor fatigue influences trunk muscle activities during walking gait*, Journal of Electromyography and Kinesiology, 2010, 20, 17–24.