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Effect of physical activity on the locomotive system and plantar pressure patterns

Theses of Doctoral (PhD) Dissertation

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1. Introduction

Thorough understanding of physical activity is getting more important as its effect on health status is gaining more evidence. Apart from the operation of the locomotive system, it support almost all physiological procedures. However, Europeans' life-style indicators are troubling, indicators of physical activity are extremely low. Hungary is at the bottom of the list of European nations, 53% of Hungarians never does any sports (*Eurobarometer, 2014*).

Scientific clarification on the correlation of physical activity and health of joints is yet to be made. The healthy amount and quality of physical activity for joints is yet unclear. The neuromuscular system maintains its joint-protective function through movement and mechanical triggers, but we know about certain long-term, one-sided movements or regular overloading movements in connection with work or sports, in which case the protection reduces and joint impairment begins.

Feet are the only part of the body that is directly connected to the ground during movement. It has a significant role in alleviating the hit coming from the ground, while it also protects joints from mechanical energy, and it has an important role in stabilizing and moving the body. Preventive examinations seem to prove that insufficient quality or quantity of physical activity may initiate functional or structural modification of the foot, which may cause pain for the patient. Foot pain occurs relatively often (20-25%) among general public (*Thomas et al, 2011).*

My goal in this work was to provide a more accurate picture about one aspect of the diverse effect of physical activity; and to examine its connection with joint pain and plantar pressure patterns in light of anthropometric and socio-demographic data.

2. Aim of research

The aim of this work was to determine the level of physical activity in the sample, analyse the effect of physical activity on the foot by evaluating plantar pressure patterns and examine the occurrence of locomotive pain among patients with different levels of physical activity. All this is analysed in light of age, gender, and body mass index (BMI), to provide a more complex understanding about the connection between physical activity and the locomotive system.

This thesis describes three examinations including the given sample. The first examination describes the sample population's physical activity. The second part examines the evaluated plantar pressure samples. In the third part I analyse the location and frequency of joint pain and its connection to age, gender and BMI.

To reach the goals of this thesis I raised the following research questions:

1. What is the distribution of various levels of physical activity in the given sample, and how frequent is the appearance of physical inactivity?
2. What is the relationship of groups with different physical activity to age, gender and BMI?
3. How does individual physical activity influence plantar pressure patterns?
4. What is the relationship between plantar pressure patterns to age, gender and BMI?
5. Does individual level of physical activity have a role in appearance or localisation of pain in larger joints or the spine?
6. Does age, gender and BMI have a role in appearance or localisation of pain in larger joints or the spine?

3. Methods

3.1 Sample

I analyse individual physical activity on our healthy sample members, who are able to work. According to my aims I defined the individual's total weekly physical activity that covers all possible domains such as activity at work, commuting, leisure and household work.

The research included healthy people with various levels of physical activity at work: postmen and -women walking several hours on a workday; health visitors with combined sedentary and active work; and sedentary workers at a post office. Participants were employers of the Health Visitor Service of Central Health Service in Pécs, Hungary, and the Pécs office of Hungarian Post Office's Western Hungary Area Headquarters. Aim of the research was total sampling. Total sample included 439 workers: 123 person did not wish to participate in the research, and 316 worker completed the questionnaire. Due to data collection errors, I analysed the data of 309 persons: 114 male and 195 female. The average age of participants was 39.98±10.3 years, and the average level of BMI was 25.11±4.36 kg/m^2 (Table 1.).

According to the inclusion criteria of the research, physical activity was analysed among employees between the age of 18 and 65 years. I excluded people with foot under the following direct or non-direct, non-static pathological issues: congenital foot- or lower limb deformity, diabetes-related foot problem, rheumatic foot, pathologic varicose vein or vein deformity, any type of neurological disease, or previous surgical intervention or trauma on the foot.

Plantar pressure and physical activity was analysed for the same sample. From the total sample of 258, 309 employees met the analytical criteria for plantar pressure analysis. I analysed the same 309 participants as the sample for examining the frequency of joint pain frequency.

Table 1. Sample features: gender, age, BMI according to levels of weekly total amount of physical activity (low, medium, high), average and standard deviation (n=309)

	Total sample	**Low physical activity**	**Medium physical activity**	**High physical activity**	***p***
Gender	male:114; female:195	male:2; female:9	male:8; female:90	male:104; female:96	***<0.001***
BMI – (kg/m²)	25.11±4.36	27.8±5.2	23.5± 3.8	25.8±4.4	***<0.001***
Age - (years)	39.98±10.3	37.6±13.1	40.7±10.4	39.8±10.1	0.593
Total physical activity –(MET-minutes per week)	6633.1 ± 5316.7	577.0± 318.7	1887.7± 689.3	9291.4 ±4826.5	***<0.001***

3.2 Method of examination

Individual ***amount of physical activity*** was defined based on the total physical activity of the previous week, measured by the long form International Physical Activity Questionnaire (IPAQ). We applied the questionnaire to evaluate the level of one week's physical activity as high, medium or low. The questionnaire evaluates possible domains of daily physical activity such as workplace, commuting, household and free time. The basis of the evaluation was energy usage, measured in MET minutes per week. The questionnaire evaluated the duration, frequency and intensity of the given physical activity, providing a standardized overview of the individual's level of weekly total physical activity.

Plantar pressure distribution was measured by digital dynamic pedobarograph type Novel 101B EMED SF. To complete measurements I used the 102 H (4 sensor/cm², 50 measurement/s) platform or sensor, and applied the mid-gait method (*Wearing et al, 1999*). During evaluating, the dynamics of the walking was steady, without any change in direction, stopping or slowing down. In any other case the change in walking speed may influence plantar pressure for at least 7% (*Hennig and Rosenbaum, 1995*). Measurements were made without shoes on. One record was made of each correct step and foot. Plantar pressure parameters were analyzed by the EMED software.

I divided the plantar tract to 9 areas: lateral heel (LH), medial heel (MH), lateral midfoot (LMF), medial midfoot (MMF), lateral metatarsus (LMT), medial metatarsus (MMT), lateral toes (LT), medial toes (MT) and full plantar area (FPA). These areas were analyses according to the following aspects: contact area (cm^2; %), peak pressure (N/cm^2), maximum force (N), contact time (ms;%), integral amount of pressure-time (Ns/cm^2).

For a complex examination of ***locomotive pain,*** we applied a self-developed, structured questionnaire. The following categories explained the frequency of joint pain: does not hurt; hurts sometimes; hurts every day for at least the last six months (chronic pain). To localize pain, I analyzed the following anatomic domains: shoulder joint, cervical spine, posterior spine, hip joint, knee joint, ankle, foot.

3.3 Method of data analysis

One-way ANOVA analysis was carried out to compare the sample's anthropometric and socio-demographic features and the levels of physical activity. Multinomial logistic regression was applied to model 3-level category variable of physical activity, the reference group being the medium physical activity group in each case (*Hajdu, 2003).* One-way ANOVA analysis was applied to compare various sample groups' plantar pressure patterns and to examine correlations. Post-hoc test was applied to identify significant differences between groups with different levels of physical activity, BMI, age and gender. Multinomial logistic regression was applied to model 3-level category variable of joint pain (does not hurt; hurts sometimes; chronic pain), the reference group in each anatomic region being the lack of pain category. Data analysis was carried out by SPSS 20.00 software. Null hypothesis (assuming independence) was rejected when the significance level was $p<0.05$ (*Pintér and Rappai, 2007)*.

4. Results

4.1 Examination of physical activity

The examined sample consisted of 309 people: 195 female (63.1%) and 114 male (36.9%). 64.7% pf the sample belonged to the high physical activity group, 31.7% belonged to the medium physical activity group and 3.6% belonged to the low physical activity group (inactive).

Table 2. Results of multinominal logistic regression on factors influencing physical activity (PA) – BMI, age, gender (reference group: medium physical activity)

Level of physical activity	Determining variable	OR	CI		*p*
Low PA	BMI	1.22	1.07	1,.39	***0.004***
	Age	0.95	0.89	1.02	0.176
	Male	2.51	0.43	14.51	*0.304*
High PA	BMI	1.12	1.04	1.2	***0.002***
	Age	0.99	0.96	1.02	0.585
	Male	12.36	5.38	28.38	***<0.001***

Looking at the correlation between physical activity and all the examined variables, I may claim that it if an individual is a men, then it is 12.36-times more probable that he has high level of physical activity compared to the medium level of physical activity. 1 unit increase of BMI makes it 1.12-times more probable, that the individual has high level of physical activity, and 1 unit increase of BMI makes it 1.22-times more probable that level of physical activity is low compared to the reference group (medium physical activity). This sample showed no significant correlation between age and the level of physical activity (Table 2.).

4.2 Pedobarographic examination of the foot

In this chapter I use only peak pressure values from the five different plantar pressure parameters to highlight pressure relations of various plantar areas in connection the examined variables (age, gender, physical activity, BMI).

In terms of age, the level of peak pressure at the medial heel is significantly lower in the older age group compared to the younger age group (p=0.003; -11%). Peak pressure is significantly higher at the lateral metatarsus in the younger age group compared to the older age group (p=0.012; 12.5%).

In terms of gender, peak pressure is significantly higher at the lateral heel area among men compared to women (p=0.043; 5%). No significant difference was found among the two genders in any other plantar area.

Table 3. Differences in peak pressure values (mean, standard deviation) by age groups, BMI groups (normal, obese), categories of physical activity (medium level of physical activity, high level of physical activity), indicated by significance value (p value) according to the 9 examined plantar areas

Plantar area	Young and old age group	Genders	Medium and high pyhsical activity	Normal and obese BMI
Total	0.348	0.677	0.269	***0.009***
LH	0.095	***0.043***	0.191	***<0.001***
MH	***0.003***	0.586	0.609	0.216
LMF	0.834	0.377	***0.002***	***<0.001***
MMF	0.672	0.579	***0.001***	***<0.001***
LMT	***0.012***	0.260	***0.016***	***<0.001***
MMT	0.883	0.293	***0.050***	***<0.001***
LT	0.289	0.588	0.055	0.353
MT	0.331	0.312	0.678	0.099

Influence of *physical activity* showed significantly higher values in case of high physical activity groups at the middle, lateral areas of the foot (p=0.002; 20.5%) and at the medial midfoot with 10.75% (p=0.001; 11%), but also at the lateral metatarsus (p=0.016; 9%).

At examination of *BMI* the peak pressure was significantly higher at the total plantar area in case of the obese group compared to the normal weight group (p=0.009; 8.5%,). Also, higher peak pressure was detected at the middle areas of the foot (lat.: p<0.001; 33.5%, med.: p<0.001; 34%) and at the metatarsus (lat.: p<0.001; 22.5%, med.: p<0.001; 15%) in case of the overweight participants. Significantly higher pressure was detected in the overweight group at the lateral heel area (p<0.001; 17.5%) (Table 3)

4.3 Examination of joint pain

8% of our sample reported no joint pain, 54% reported rare joint pain and 38% reported chronic joint pain (Table 4).

The frequency of one joint's chronic pain is 9.5%; the frequency of one joint's rare pain is 10%, and the the frequency of several joint's rare pain is 42%. 30.5% of our sample reported simultaneous chronic pain in multiple joints. Highest frequency of chronic joint pain occurs at the lumbar territory (18.6%). Rare joint pain is also the most frequent at the waist and the back region (17.8%). Co-analysis of the two pain categories highlight that the frequency of waist pain is 36.4%, and the frequency of the posterior spine pain is 36%. Pain in the knee and hip joints were the least frequent in the current sample.

Table 4. Distribution of pain regarding gender, age, BMI and physical activity categories (N=309)

		n	All joints		
			No pain	Rare pain	Chronic pain
	Male	114	8 (7.0)	71 (62.3)	35 (30.7)
	Female	195	17 (8.7)	95 (48.7)	83 (42.6)
Gender	*p*			0.068	
	-29	68	6 (8.8)	78 (70.6)	14 (20.6)
	30-49	162	12 (7.4)	86 (53.1)	64 (39.5)
	50-	69	5 (7.2)	29 (42.0)	35 (50.7)
Age	*p*			***0.008***	
	Normal	167	17 (10.2)	94 (56.3)	56 (33.5)
	Overweight	96	4 (4.2)	53 (55.2)	39 (40.6)
	Obese	46	4 (8.7)	19 (41.3)	46 (50.0)
BMI	*p*			0.131	
	Low	11	2 (18.2)	3 (27.3)	6 (54.5)
	Medium	98	8 (8.2)	53 (54.1)	37 (37.8)
Total physical activity	High	200	15 (7.5)	110 (55.0)	75 (37.5)
	p			0.438	
Total		**309**	**25 (8.1)**	**166 (53.7)**	**118 (38.2)**

Looking at all joints, significant correlation was detected only regarding age (p=0.008). Occurrence of chronic pain was highest (50.7%) in the age group 50 years and above, while 'rare joint pain' occurs the most often (70.6%) in the age group 29 and below (Table 4).

Evaluation of the correlation coefficients, age significantly correlates with pain in the ankle (p=0.013), knee- (p<0.001) and hip joints (p=0.003) and the shoulders (p=0.006) (Table 5).

Significant correlation between gender and joint pain was detected only in case of chronic pain in the posterior spine area (women: 20%; men: 7.9%; p=0.016) (Table 5).

Examined as a categorical variable, no significant correlation was detected between joint pains and physical activity categories. Examined as a continuous variable, significant correlation was detected in between weekly physical activity and pain in the shoulder joints ($p<0.001$) and pain in the ankle ($p=0.029$) (Table 5).

Evaluation of correlation coefficients revealed that significant correlation can be found between BMI and the ankle (p=0,003) and the foot (p=0,018) (Table 5).

Table 5. Correlation between BMI, physical activity, age, gender and various joint pain; p values (variance analysis, Chi-square test (n=309)

	BMI	Total physical activity	Age	Gender
Neck	0.291	0.785	0.059	0.175
Ankle	***0.003***	***0.029***	***0.013***	0.918
Knee	0.141	0.391	***<0.001***	0.801
Hip	0.151	0.067	***0.003***	0.463
Shoulder	0.089	***<0.001***	***0.006***	0.170
Waist	0.577	0.575	0.069	0.237
Back	0.710	0.693	0.216	***0.016***
Foot	***0.018***	0.121	0.256	0.977

5. Discussion and conclusion

5.1 Examination of physical activity

In the current sample differences due to occupation strongly influence physical activity at the workplace, and thus also influences the total weekly physical activity. We analysed participants with sedentary (152 people) and walking (157) occupations, yet the sample has a low level of physical inactivity (total sample: 3,6%, women: 4.6%, men: 1.8%). Hungarian researches claim a much higher level of physical inactivity among Hungarian participants. Hungarostudy 2002 claim that 75% of the adult Hungarian population does not commit to regular physical activity, and Eurobarometer 2010 claims that 77% of the Hungarian population leads a physically inactive life (*Ács et al., 2011; Kopp and Kovács, 2006*).

Most researches claim an indirect strong correlation between obesity and physical activity (*Tudor-Locke et al, 2009*). Some studies report participants with high level of BMI complete appropriate level of physical activity (*Chen and Mao, 2006*). The results of the current research prove the abovementioned data. I found statistical correlation between high physical activity and high level of BMI ($p<0.002$). It is well-known that evaluation of BMI does not highlight body fat distribution. High level of BMI may also be due to high amount of muscles, which might explain high level of BMI among participants with high level of physical activity.

High level of physical activity among men is a lot more frequent (91.2%) compared to women (49.2%). This result may be influenced by the fact that the analysed men complete high level of physical activity at their work place, especially compared to women, who usually do sedentary work.

Regarding age, physical inactivity is most common in the age group 29 and under (7.4%), and the age group 50 and above (4.3%). Certain researchers similarly claim low levels of physical activity among young age groups (*Drygas et al, 2009*).

5.2 Pedobarographic examination of the foot

My results prove previous research claiming that with ***aging*** peak pressure and force lowers at the back and front area of the foot, and contact time increases at the mid-area of the foot (*Hessert et al., 2005; Scott et al., 2007*). My results are also in line with previous research that claim that both maximum force and peak pressure lowers with aging (*Scoot et al., 2007).* In this research I detected similar changes at the medial area of the foot. Scott and colleagues (2007) connected the increased amount of pressure at the heel area with shortening steps due to aging, when the legs probably need smaller force to move forward.

At the *frontal area of the foot*, under the lateral metatarsus, I detected smaller peak pressure and maximum force. Scott and colleagues (2007) detected similar results documenting decreased lateral pressure and force, which was connected to the shortening steps. I find it is possible that this change occurs at the older individuals of this sample. Furthermore, similar to other researches' findings, my results claim that peak pressure decreasingly changes at particular areas of the foot throughout the aging process. However, regarding time unit based load, we detected highly increased pressure compared among elderly compared to younger participants at the medial midfood area (25%) and the lateral toes (20%), which may be due to the starting structural and functional changes of the locomotive system and the foot at the 50-65 age group, that influences the foot pressure pattern.

In terms of ***gender***, most examined parameters in case of the medial midfoot area of women was significantly higher, thus I claim it a more loaded plantar area – similarly to contact are (10%), contact time, pressure-time integral value (10%), maximum force (15%), and the force-time integral value. My results indicate that the increased valgus axis standpoint of the lower limb and the looser soft tissue apparatus may cause the increased load on the plantar area in case of women. I detected no significant difference at the *heel* among the two genders. Significantly higher peak pressure at the lateral area of the heel was detected at men.

My results also show that individuals with high level of ***physical activity*** has higher peak pressure and pressure-time integral values at the midfoot and the area of the lateral metatarsus, and lower maximum pressure value at the toes, compared to individuals with lower physical activity. It seems apparent that the midfoot and the lateral metatarsus areas bare more pressure at individuals with higher level of physical activity, compared to medium level of physical activity, while the pressure is decreasing at the area of the toes. I found significantly bigger contact area at the total plantar area, and increased contact time at the midfood and the metatarsus area among individuals with higher physical activity. This research did not aim to analyse the direct connection between muscle tiredness and plantar pressure patterns, although I believe that change in plantar pressure patterns may be due to the individual physical activity as it is part of a tiring process, given that the examined, high physical activity group's weekly physical activity was extremely high (8991.6±4654.3 MET minutes/ week). Certain literature claim that the probably the whole rolling process changes due to the distal muscle tiredness (which can not be compensated by the proximal muscles), thus the load on the midfoot and the metatarsus is increasing (*O'Connor and Hamill, 2004*).

In line with international research, my results allow us to conclude that ***obesity***'s influence on plantar pressure patterns is significant, the load on the foot increases significantly, outside the toes but all around the total area of the foot, especially at the middle and frontal areas of the foot. My results show that the *midfoot area* can be considered as pathologically loaded planater area, especially the medial area, where the peak pressure (34%) is significantly increased compared to the non-obese individuals. My result are in line with the results of Birtane and Tuna, and Menz, Butterworth et al. (*Birtane and Tuna, 2004; Menz and Morris 2006; Butterworth et al., 2015*). Monterio and colleagues (2010) interestingly claim that peak pressure increases at midfoot area increases without the change in foot structure and next to steady dynamic posture index. My research did not examine this, thus I can only agree with the assumption of Monterio et al. (2010) and The et al. (2006), that when the conforming ability of the arches no longer works against body weight load, the midfoot load increases. However, Hills et al. (2002) and Butterwort et al (2014) claim that the midfoot load increase at obese individuals points at the dysfunction of the foot structure and the sinking of the longitudinal arch.

5.3 Examination of joint pain

My results show that in case of most joints, ***age*** shows the most connection with joint pain frequency. In all three examined groups waist- and back area has the highest incidence of rare and chronic pain. In the total sample the area with the least occurrence of pain is the hip joint – frequency of pain in this area is significantly correlated with increase of age. Chronic knee pain is three times more frequent in the 50+ age group compared to the chronic pain of the hip joint. Age showed significant correlation in case of the shoulder-, neck, ankle, hip- and knee joints; similarly to the results of Picavet et al (2003) who reported that with aging the incidence of ankle-, foot-, hip- and knee pain significantly increased.

No statistical correlation was found in this research between ***gender*** and frequency of joint pain. Nevertheless our results underline the findings of other researchers who claim that frequency of chronic pain among women is higher (women: 42.6%, men: 30.7%). Similar frequency of chronic pain examined at both genders was reported by Rollman and Lautenbacher (2001). Statistical correlation was detected among women and chronic pain in the Netherlands (909 men and 1178 female) at the areas of the neck, shoulder, back and foot by Wijnhoven et al (2006), but none was found at the waist area. In this research I found similar connection between women and back pain, but this was not the case in other joints.

Above all this, my results show that chronic pain in the shoulder ($p<0.001$) and ankle ($p=0.029$) is significantly correlated with high level of ***physical activity.*** Significant correlation with physical activity was not found in case of any other joint. Ericsen et al (2004) examined a Danish population (N=2694) and their results are in line with my results that physical work does not influence the occurrence of pain.

I found connection between ***BMI*** and ankle- and foot pain. Several relevant research prove this connection (*Mølgaard et al., 2010*). Butterworth et al's (2014) summary work claim that chronic heel pain and non-specific foot pain was significantly more frequent in case of obese individuals. Rare pain in the *ankle* showed significant correlation with BMI in my sample, similarly to the work of Linton et al (1998) – ankle pain was more severe in case of obese individuals and women.

6. Conclusions

The most important conclusions of this research:

High level of physical activity is strongly correlated with the male gender. No correlation can be found in work-age group between physical activity and age. This sample showed statistical correlation between physical inactivity and high level of BMI. Correlation was found between high level of physical activity and high level of BMI.

The individual's high level of physical activity correlates with the increased level of peak pressure and pressure-time integral value at the midfoot area and the lateral metatarsus. This increased load may influence the health of the foot on the long run.

Among the examined parameters, excess weight meant the highest load for the foot. Load on the foot on almost all plantar areas increases with obesity. The area at the highest threat id the medial area.

Using objective examination method I found in this research that several factors (such as BMI, aging and individual physical activity) has the highest influence on the longitudinal arch of the foot. Furthermore I found that the most sensitive area of the foot in regarding several factors is the longitudinal arch.

No significant correlation was found between physical inactivity and joint pain. Statistical correlation was found between high level of physical activity and pain in the shoulder- and joint pain.

Among the examined variables (age, gender, physical activity, BMI), aging showed significant correlation with the occurrence of joint pain in most cases.

Regarding the localization and the frequency of pain in the work age population, waist pain occurs the most often, and ankle pain occurs the least often.

7. Novel findings

According to my knowledge, these results show for the first time in Hungary the possible correlation between individual physical activity and joint pain.

This is the first research to report on the effects of individual physical activity on plantar pressure patterns. These results show that high level of individual physical activity significantly influences plantar pressure patterns.

Objective methods were applied to claim that several examined factors, such as BMI, aging, and individual physical activity influences the longitudinal arch of the foot the most. Furthermore, this study showed that the longitudinal arch is the most sensitive area of the foot in regards to several examined factors.

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