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Theoretical Approaches in Non-Linear Dynamical Systems

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Editors

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Influence of the shoe type on the ground reaction forces

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Abstract: The aim of this work was to estimate a relationship between the type of the footwear and ground reactions. Differences in medio-lateral, anterior-posterior and vertical reactions are compared for different shoe-types for male and female volunteers. Each of the participants gait was recorded in case of different shoes and without them, also stabilograms were analyzed. Results revealed differences in ground reaction forces for different shoe-types and its influence on static stability.

1. Introduction

The concept of gait measurement can have various approaches, depending on the used method. One of the way is to record ground reaction forces/pressure distribution during locomotion [1], [2]. For this purpose, a dynamometric platform or pedobarographic forceplates are used [1–4].

Over the years, different types of footwear were created depending on activity and in order to facilitate foot. A differences between shoes are i.e.: sole thickness and its shape, height of the heel, presence of additional elements, geometry and used materials etc. According to research project, conducted by [5], which aim was to present the relation between well-fitted sports shoes and pain/discomfort reduction. Good assistance at store level in shoe selection has a great influence on orthopedic condition, heel's stability and grip, which give shock absorption and prevent sliding, vertical or horizontal movement. This leads to reduced risk of pain, fractures and overloads and also extends the life span of shoe.

Coordination between postural and locomotive mechanisms is essential to provide effective locomotion. Maintaining constant speed requires continuous renewing of energy – dissipated during center of pressure (COP) movements, limbs swing, friction and drag [6]. The energy is recovered by production of driving and support forces by alternating lower limb work. Under the movement, stability conditions are disturbed. It refers to initial swing phase, when a lower limb pushes off and area of support is reduced. Decreasing periods of double support phase, along with increased speed of gait, can influences balance. With regard to biomechanics, improper transmission of acceleration from limbs to trunk can also affect stability control [6], [7].

As soon as the heel strikes the ground, elastic structures of ankle joint absorbs the energy. Exchange of energy is low and only a small part of it can be reused in loading response (LR) phase.

Rest is dissipated as a sound and heat. Some kinds of soles may influence energy absorption and its further transformation [1]. Knee joint is subjected to inner, bending moment, which results in release of power, while the energy comes from concentric work of knee flexors and elastic strain energy of ligaments. Contrary to knee joint, a hip joint is affected by inner, erectile moment, produced by concentric work of hip extensors, which generates power [1], [8].

An objective of this work is to determine the relationship between different types of footwear and ground reaction and its characteristics – varying between sexes and shoe types. The scope of the research contained measurement of three components of ground reaction forces, center of pressure (COP) deviations due to changing shod type, basic body measurements and preparation of questionnaire, which investigated physical activity habits.

2. Materials and methods

2.1. Participants

The study group contained 12 people of both sexes, aged 22-27: 7 women and 5 men. They were asked to fill in the questionnaire, provided by the researcher, which scope of questions concerned: the age and sex of the subject, the trauma of the musculoskeletal system and its area, the time of undertaking physical activity, the type of physical activity most frequently undertaken and the type of footwear most frequently worn. Anthropometric measurements consisted of several steps, in which the mobility of the motor system was tested globally by the physiotherapist. Only participants, whose results were in range of norm (range of motion, faulty posture) were taken a part in measurements. Their anthropometric data are presented in Table 1a and b. The study was conducted in the Laboratory of Biomechanics, in the Department of Automation, Biomechanics and Mechatronics at the Lodz University of Technology. The respondents, whose health status foreclosed proper testing or did not agree with terms of participation, were excluded from the study, as well as those, whose measurement results indicated faulty postures. Research was organized according to Helsinki Regulations, all volunteers were informed in detail about aim and scope of the experiment, all of them sign a form of conscious agreement.

Table 1a. Female volunteers basic anthropometric data.

Volunteer	Body mass [kg]	Height [cm]	Age [years]
1	56.5	168	22
2	82	165	22
3	58	170	22
4	57.5	164,5	22
5	92	172	24

6	53	165	24
7	53	168	25
EX	64.57	167.50	23.00
SD	15.72	2.84	1.29

Table 1b. Male volunteers basic anthropometric data.

Volunteer	Body mass [kg]	Height [cm]	Age [years]
1	76	183	26
2	75.5	171	22
3	85	180	25
4	94	187	24
5	82	182	25
EX	82.5	180.6	24.4
SD	7.58	5.94	1.52

2.2. Materials

For reaction forces recording, the Steinbichler force platform (SFP Active 3D, Steinbichler GmbH force platform) with dedicated software were used. Gait measurements and center of pressure (COP) movement were recorded in following variants: for women: barefoot, shoes with flat, profiled sole, high-heels and for men: barefoot, suit shoes and sports shoes. Each subject was asked to bring his/her own shoes, which were then classified as suitable for the experiment according to the proper range of stiffness and heel height. The subject was asked to walk through the dynamometric platform with preferred, comfortable speed. Reaction forces of the right limb were recorded. In order to avoid their intentional adjustment of footsteps, the force plate was masked on the gait-path. From all trials only three correct (with whole foot placed close to the center of the force platform) were chosen for further analysis. After the correct series of passes in the given footwear, the subject was asked to stand freely with both feet on the platform, so that they did not go beyond its edge and not to move for 30 sec. At that time, the COP transitions were recorded for each shoe-type.

3. Results

3.1. Ground reaction forces

Obtained results are presented in form of graphs with average values with standard deviations in case of each graph: medio-lateral, anterior-posterior and vertical direction, separately for male and female participants and shoe-types.

3.1.1. Anterio-posterior reaction

In the case of female anterior-posterior reaction for barefoot gait (Fig. 1a.a) the first peak is low, rounded and corresponding to the moment of the heel striking the ground. After that, a sudden decrease of forces to the average value of about -75 N appeared. Then the phase of loading response (LR) is visible, with the mid stance (MST) point around 1.35 sec. The force rises to the average value of about 120 N, then drops down to toe off point around 1.75 sec. The largest deviations from the mean value were recorded near the first peak - in some of the studied women it took the shape of a sharp peak. Before the start of the LR phase, in some of the examined women, a temporary decrease and increase in the value of the acting force was noted, which may result, for example, from imbalance and attempt to stabilize the heel during loading. Also, a large difference in value was observed in the area of the second peak and just before the toe-off phase — some of the women had values up to 150 N.

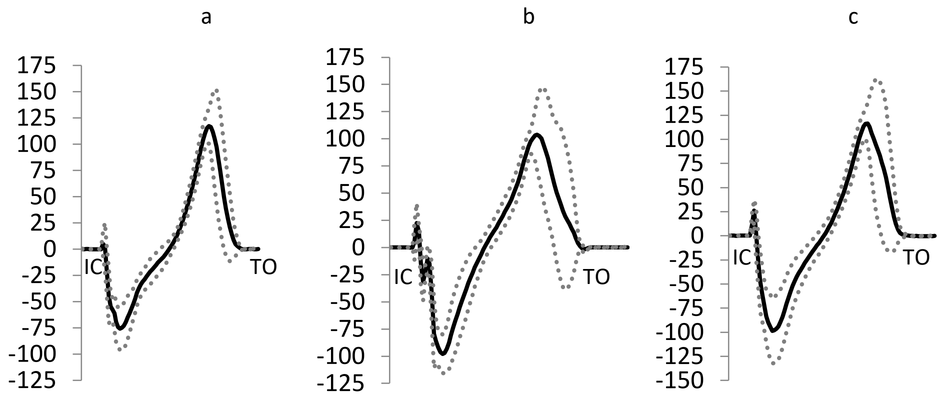

Figure 1a. Ground reaction force, female, anterio-posterior direction, a) barefoot b) highheels c) sport – shoes; description in text; horizontal axis – support phase, vertical – force [N].

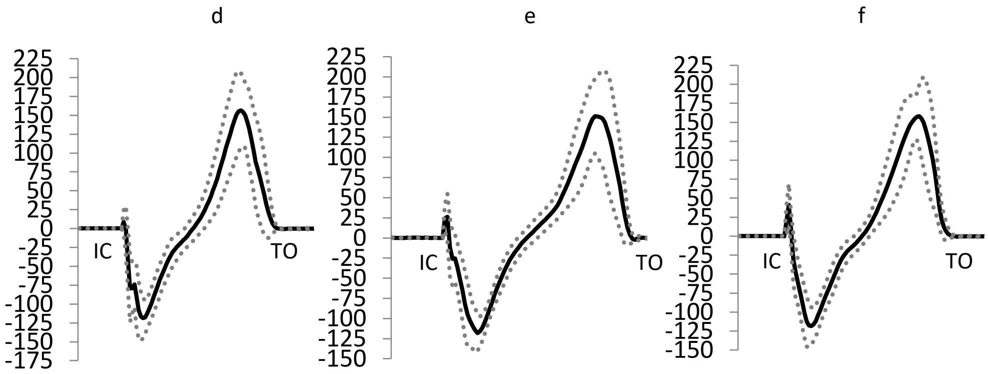

Figure 1b. Ground reaction force, male, anterio-posterior direction, d) barefoot e) suit f) sport – shoes; description in text; horizontal axis – support phase, vertical – force [N].

Similarly to the previous characteristics, for the high-heels (Fig. 1a.b), there is a sharp peak associated with the heel strike on the ground, then the curve drops sharply and rises until the beginning of the LR phase, which reaches an average value of -100 N. The MST point was reached a little earlier, in comparison to remaining shoes - before 1.35 sec. The next visible peak reaches the value of approximately 100 N. The values of extreme peaks are lower than for shoes with a flat, profiled sole (Fig. 1a.c). The variation in values among the examined group is particularly evident in the LR, heel-off (up to 150 N) and toe-off (about -40 N) phases. The total support phase is slightly extended to approx. 0.8 sec.

In case of sport-shoes (Fig. 1a.c female), the measurement begins with a sharp force peak during heel contact to the ground. The decrease in the force direction is smooth up to the value of -100 N. The increase in the force value is almost linear, up to the value of approx. 115 N. In the case of sports footwear, the greatest deviations from the average value, are located in the LR phase and between heel-off and toe-off phases. The highest values exceed -125 N and 150 N. Moreover, the curve appears smoothed without additional sways.

Fig, 1b.d (male, barefoot) shows small, but evident peak at the beginning of stance phase. Then a rapid drop in values occurs, until it reaches the approx. -125 N. What is more, a noticeable increase and drop in values at the beginning of LR phase is visible. Then values increase rapidly with marked MST phase around 1,30 sec - as well as in female group. At heel-off phase, the highest, obtained value of force was 150 N. Just like among the examined group of females, beginning of LR and heel-off phase showed the highest difference in values.

Suit type of footwear (Fig. 1b.e), presents some additional fluctuations of force and higher deviations from mean values – significant between IC and LR phase as well as heel-off phase. As well as in case of other types of footwear, measurement begins with rounded peak (25 N) directed upwards. Some of the male subjects present the value above 50 N. At the beginning of the LR phase, force reaches the value -125 N and at the end of the phase 150 N.

The characteristics of gait in sports footwear (Fig. 1b.f) is smooth and begins with sharp, positive peak with a value up to 50 N. Additional fluctuations, like in case of suit shoes, are not visible. The lowest value (approx. -125 N) is followed by the beginning of LR phase. The highest value stands for the end of LR phase - above 150 N. Differences among the group in sports shoes are significant, as in the other footwear - especially in the IC, LR and heel-off phases. In some of the examined males, the first positive peak reached a value up to 75 N.

3.1.2. Medio-lateral direction

For female barefoot (Fig. 2a.a) right after the initial contact (IC) phase (0.9 sec.), a sudden drop in vales of acting force is noticeable - reaching the value around -10 N - the lateral side of the heel is loaded. A rapid increase in values indicates the COP movement towards metatarsals and beginning of MST phase. However, force hardly exceeds the value of 0 N, which suggests load positioning on the lateral edge of the foot – COP approximates to middle foot, but the load is finally directed more laterally. A further decrease in the force value to -25 N means the displacement of COP over the head of the 5th metatarsal bone. In the case of a barefoot support phase, this is the most weighted point on the foot. The value of the force increases again to positive values, showing the beginning of the heel-off and toe-off phases. For COP medial movement (and MST phase), some of the female subjects achieved positive values - over 5N. The lowest achieved values, under the load of head of the 5th metatarsal bone were approximately -33 N.

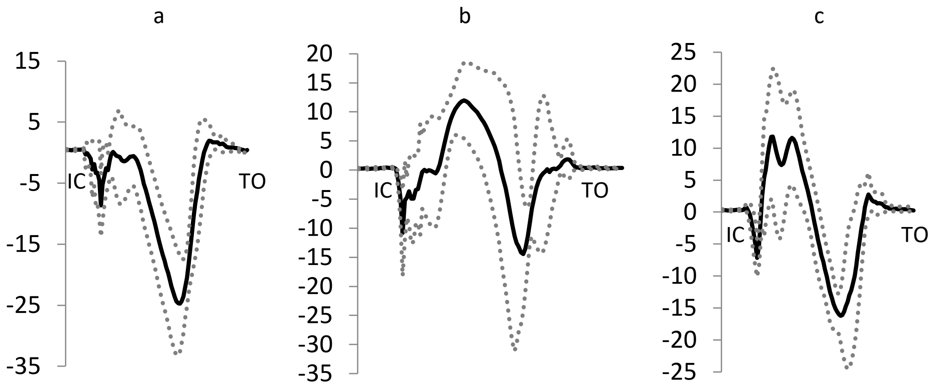

Figure 2a. Ground reaction force, female, medio-lateral direction, Fy: a) barefoot b) high-heels c) sport - shoes; description in text; horizontal axis – support phase, vertical – force [N].

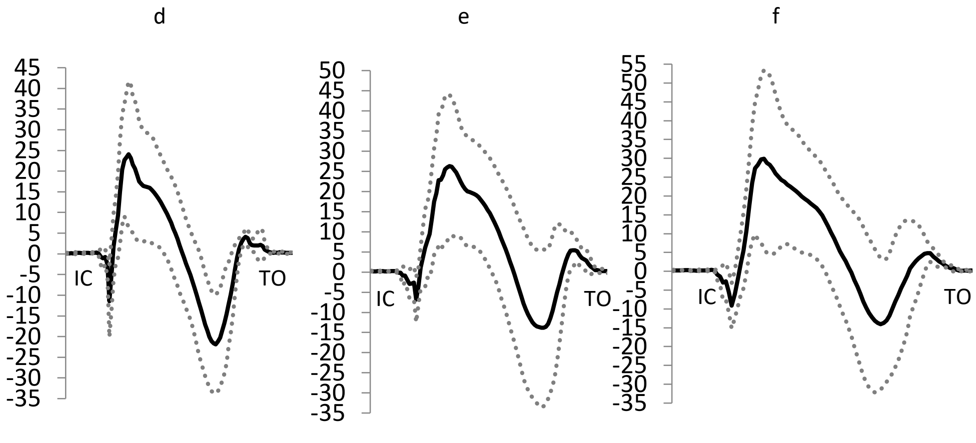

Figure 2b. Ground reaction force, male, medio-lateral direction, d) barefoot e) suit f) sport – shoes; description in text; horizontal axis – support phase, vertical – force [N].

The medio-lateral component for gait in high-heels (Fig. 2a.b) is the most diversified from all presented characteristics. The point of maximum lateral heel load is over -10 N and is the lowest of measured gaits. The increase in force values during the LP phase was non-uniform and many irregularities were registered. The maximum medial load was over 10 N - the graph in this area is arranged in the shape of a smooth hump. Loading attached to head of 5th metatarsal bone has reached the lowest value from the examined footwear - approx. -15 N. The values representing the heel-off and toe-off phases are similar for all examined types of footwear. The greatest variation in the values occurred during LP phase and before the start of the heel-off phase. The average values of the obtained curve for high-heels suggests more medial foot loading.

In the case of gait in sports footwear (Fig. 2a.c), the value of the maximum lateral heel load was lower than -5 N. While moving the COP towards the metatarsal bones, the highest values were registered above 10 N, with characteristic two humps before the COP was moved over the head of 5th metatarsal bone (below -15N). The values before the heel-off and toe-off phase were similar to those for other footwear. For the sports footwear examination, it can be said that the deflection of COP in the medio-lateral direction was evenly distributed. The largest differences in values for individual subjects were found in the LR phase. It is important to note, that characteristics of medio-lateral component of gait was strongly diversified, as is demonstrated by standard deviation curves.

For male volunteers, in case of barefoot gait (Fig. 2b.d) right after the IC phase, a sudden drop to less than -10 N is visible – the lateral side of the heel is fully loaded. While the LR phase begins, the values of force rise to positive value approx. 25 N – it suggest, that COP is moved above the medial side of metatarsal. Then a hump-like drop in values is noticed, below -20 N – the head of 5th metatarsal is loaded. A renewed increase in values, above 0 N indicates movement of COP towards head of 1st metatarsal and beginning of heel-off phase.

Figure 2b.e, which shows the measurement of the same medio-lateral component for suit shoes presents irregularities. The maximal load of the lateral side of heel stand at -5 N, which is the highest value of all presented types of footwear. An acting force during COP movement towards metatarsals reaches its maximal value around 25 N. Then an extended decrease in force values occurs, to approx. -15N – higher than for barefoot or flat shoes. For suit shoes, toe-off phase has the highest recorded value, up to 5 N. For the suit type footwear, the largest irregularities were recorded over the entire time of the support phase.

A characteristic feature of the medio-lateral component for sports footwear (Fig. 2b.f) is a rapid, partially linear decrease in values of acting force, during COP movement towards head of 5th metatarsal bone. For remaining types of footwear, the decrease is hump-shape. For the lateral side of the heel, load values are approx. -10 N, and for the head of 5th metatarsal bone is -15 N. Before the toe-off phase, the force reaches 5 N. The largest deviations of the measured force values concern the COP movement over the metatarsus - the extreme value is about 55 N and 5 N – and before the toe-off phase.

3.1.3. Vertical reaction force

Figure 3a.a presents the average values for women barefoot measurement. On the graph a characteristic peak at the beginning of single support phase - initial slope (UP) is presented. However, it should be mentioned, that not each subject presented such a wave. Two peaks related to LR phase are evident and located approx. 600 N and above 650 N. Second peak reached higher value. This suggests, that push-off phase was launched stronger in comparison with beginning of LR phase. The drop in acting force estimated almost 500 N.

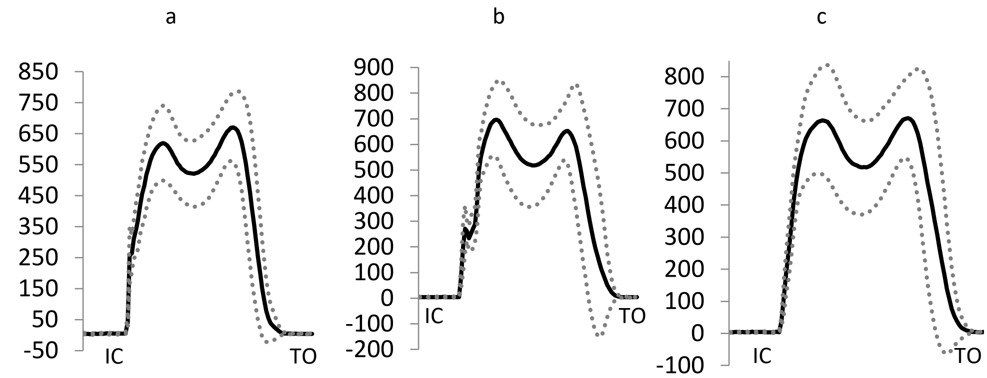

Figure 3a. Ground reaction force, female, vertical direction, a) barefoot b) high-heels c) sport - shoes; description in text; horizontal axis – support phase, vertical – force [N].

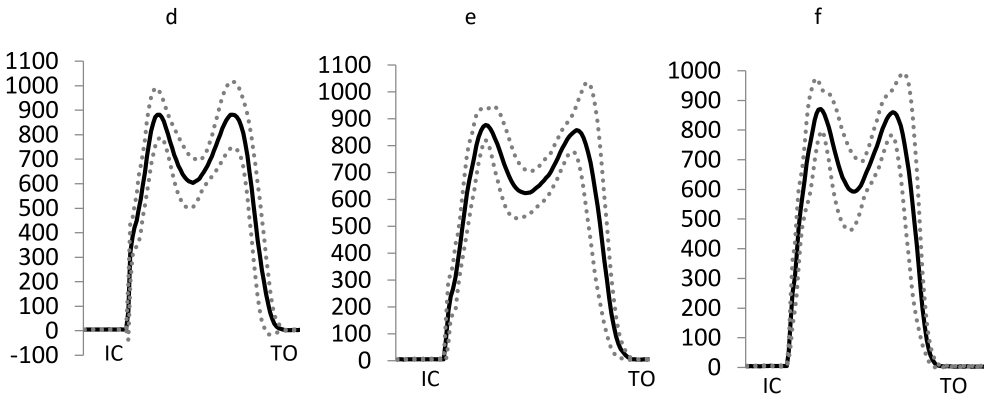

Figure 3b. Ground reaction force, male, vertical direction, d) barefoot e) suit f) sport - shoes; description in text; horizontal axis – support phase, vertical – force [N].

High-heels measurement (Fig. 3a.b) was the most non-uniform. On the front edge of graph, a sharp and clear-cut UP peak was visible - present in all examined females. This may indicate, that heel centering on the ground was difficult for all women. The curve showed also higher values of the first peak – 700 N, while the second one reaches the value of approx. 650 N. It suggests strong heel load before the LR phase and lighter push-off. A drop in acting force was approx. 500 N as well.

The graph showing the measurement in sports footwear for women (Fig. 3a.c) showed the smoothest line without any irregularities on the first slope. The UP waves and curve was not present. The curve seems quite symmetrical - peak values are similar and amount to over 650 N. The second peak seemed to be more narrow due to the first one, same as in case of flat shoes, with profiled sole. The drop in acting force was close to 500 N as well. However, characteristics of vertical component for sports shoes, for both sexes were smooth, the graph for females was more rounded and smoother.

In comparison to female characteristics, each male measurement (apart from suit shoes) demonstrated equal level of registered peaks – average at the level below 900 N. Curves obtained on the basis of the average values of the measurements did not show the specific UP waves – by analyzing the standard deviation on the graph, it can be seen that these waves appeared among male subjects, especially when measuring barefoot and suit type footwear (Fig. 3b.d and Fig. 3b.e). An elevating slope (Fig. 3b.d) of barefoot measurement, showed temporary irregularities. Two, peak values, in opposition to female group were equal and reached the force value up to 900 N. The drop in values, standing to MST phase went to 600 N.

In case of suit shoes (Fig. 3b.e), second peak has slightly lower value than the first one and some irregularities were found on the elevating slope. During MST phase, values approximated 600 N. The highest deviations in values were located around second peak (above 1000 N). What is more, representation for the suit shoes seemed to be more widen, indicating on extended stance phase.

As in the women's group, the graph for sports footwear was the smoothest (Fig. 3b.f). For sports footwear, the lowest, registered values are in the main part of MST phase – below 600 N. The both peaks are equal and reaches the value up to 900 N as well. Also the largest deviations from the mean value were recorded when the foot was placed flat on the platform (MST phase).

3.2. Stabilogram

The Table 2 shows the average values of amplitude of COP displacements, measured for each subject in static state. The values are delivered with standard deviation for both sexes. Minimal and maximal values for each footwear and both sexes are also presented. The amplitude was calculated in two directions on the basis of stabilogram: medio-lateral (M-L) and anterior-posterior (A-P).

Table 2. Average values of COP displacement for different sexes and shoe-types.

FOOTWEAR	Barefoot				Flat				High-heels		Suit		Sport			
COG DIRECTION	M-L		A-P		M-L		A-P		M-L	A-P	M-L	A-P	M-L		A-P	
SEX	F	M	F	M	F	M	F	M	F		M		F	M	F	M
MEAN ± SD [mm]	12,94 ± 4,10	13,92 ± 3,54	11,67 ± 4,45	9,47 ± 2,94	12,27 ± 4,18	14,68 ± 3,46	11,19 ± 4,29	10,02* ± 2,47	16,77* ± 4,33	13,17* ± 3,58	11,44 ± 2,56	9,51 ± 0,86	13,59 ± 4,46	15,50* ± 3,56	9,94 ± 2,31	9,30 ± 1,99
MIN. VALUE [mm]	8,99	9,40	7,03	5,76	6,99	11,53	7,37	7,00	12,18	9,27	9,00	8,09	8,25	11,09	7,08	7,19
MAX. VALUE [mm]	20,81	18,56	17,12	12,32	19,15	20,44	19,44	13,62	23,88	19,46	14,98	10,33	19,69	20,61	13,82	12,33

For medio-lateral movement of COP, among female subjects, the lowest, average value was obtained in case of flat shoes with profiled sole – 12.27 ± 4.18 mm. The highest, average value of COP displacement in medio-lateral direction concerned high-heels – 16.77 ± 4.33 mm. Average displacement in sport footwear were second highest – 13.59 ± 4,46 mm. The minimal, registered value of COP deflections in M-L direction, among examined females was 6.99 mm (flat shoes), while the maximal – 23.88 mm (high heels). For anterior-posterior movement of COP, among female subjects, the lowest average value was obtained for sports shoes – 9.94 ± 2.31 mm. The highest average value of COP displacement in anterior-posterior direction concerned also high-heels – 13.17 ± 3.58 mm. Average displacement in flat shoes with profiled sole and barefoot were similar. The minimal, registered value of COP displacement in A-P direction, among examined females was 7.03 mm for barefoot measurement, while the maximal – 19,46 mm – for high-heels. For medio-lateral movement of COP, among male subjects, the lowest, average value was obtained in case of suit shoes – 11.44 ± 2.56 mm. The highest values of COP deflections in medio-lateral direction concerned sports footwear – 15.50 ± 3.56 mm. Average displacement in flat shoes were the second highest – 14.68 ± 3.46 mm. The minimal, registered value of COP displacement in M-L direction, among examined males was 11.09 mm – for barefoot measurement, while the maximal – 20,61 mm – for sports footwear. For anterior-posterior movement of COP, among male subjects, the lowest average value was obtained for sports footwear – 9.30 ± 1.99 mm. The highest average value of COP displacement in anterior-posterior direction concerned flat shoes with profiled sole, however, the difference was not significant – 10.02 ± 2.47 mm. The minimal, registered value of COP deflections in A-P direction, among examined males was 5.76 mm for barefoot measurement, while the maximal was 13.62 mm for flat shoes.

4. Discussion and conclusions

The graphs presenting A-P component, for both, women and men started with positive peak, which is the smallest for barefoot measurements. This may be explained as a way of contact the heel on the ground. However, this phenomenon is common in case of loose or bad fitted shoe [9]. The foot moves backwards in relation to shoe. The lowest values were recorded for barefoot measurement.

The highest values of first peak were recorded for sports and flat shoes, for both sexes. Those types of footwear were usually laced-up, so the respondent might not put them on tight enough. What is more, most of the responders pointed out those kind of footwear as mainly worn. The footwear used for the study, belonged to the subjects. It is likely that it could be deformed as a result of normal, everyday use. What's more, all-day use of a given pair of shoes imposes it’s change of shape to maintain comfort. Considerations about flat, profiled shoes, focus on irregularities and amplitude values among females and males. However, the values of A-P component are not the highest obtained. The proceed of suppression and loading response is strongly marked, in comparison with barefoot. What is more, the values of recorded force are close to barefoot, which indicates on lack of amortization. Feminine gait is seem characterized by smaller, light steps. The construction of flat, profiled shoes resemble man-like style, so it may affect gait pattern. Simultaneously, this type of foot wear was chosen as mostly worn, so the gait could be more confident. What is more, this type of footwear obtained the lowest values of COP swings in medio-lateral direction among females. It is clearly shown on graphs for M-L force component, where outstanding movement of COP are not visible. In case of males, registered anterior-posterior COP swings were the highest. Majority of male participants brought shoes with springs at both sides, which are responsible for sudden bounce of the foot [10]. Gait in flat, profiled shoes seems to be more smooth, in comparison to barefoot, however it does not show any significant amortization abilities – the values of suppression and push-off are even higher, than those for barefoot – unlike than expected. In their study, Isabel Sacco et al. [3] presented a strong differences between shod and barefoot gait among diabetic neuropathic and healthy patients. Focusing on healthy subjects, Sacco noticed that gait in any footwear shows higher values of vertical component of ground reaction force at IC phase and higher propulsive force. She suggests, that smaller values in case of barefoot measurement were related to precautious gait. Sacco also admits, that the results are in opposition to the common opinion, that any shoes reduces ground shocks. What is more, in the previous study, they observed lower values of peaks in case of hard-sole shoes. It was also found the lowest values for barefoot measurement in his study of mechanical comparison of barefoot and shod running. They have suggested, that this phenomenon is related to neural-mechanical adaptation of body in order to reduce external stress under repetitive movements [11]. It can lead to opinion, that gait kinematics, changed in response to different footwear conditions can be caused by neurosensory mechanism, which founds wearing shoes as interaction between foot and material. In other study researchers examine the effect of footwear motion on foot relative motion during walking and running. For the measurement two types of sandals (with hard and soft sole) were used. A control, barefoot measurement was registered as well [12]. The differences between sole types were not significant. The push-off phase, abduction and adduction of the foot, in case of shoes were restricted. Authors considerate if footwear limits natural foot motion. They conclude, that too restricted footwear can lead to pain and discomfort.

In presented study, the most characteristic are the high-heels results. At the beginning of measurement in M-L component, a visible irregularity stands for problems with centering lifted heel on the ground. Extended second part of the apparent LP phase, toe-off phase and relatively low value of heel-off phase are visible on the graph. It might correspond to pronation and plantar flexion, where the body weight hinges on forefoot and COG is moved to the front. Registered COP swings for high-heel shoes showed maximal values in both directions. The M-L force component confirms this statement by registered irregularities. Those may originate from single support phase, where - in case of high-heel - area of support is reduced.

A characteristic, delayed hump (in M-L component), which occurs in MST phase may stand for sudden ground positioning the front part of the shoe – medial part of the forefoot is loaded, while the swing phase of the opposite lower limb had started. Conversely to other types of shoes, values of push-off are smaller than for suppression phase in vertical component. In case of high-heels the proper LP phase does not occur – the foot is not in a proper position to carry on the load, so the virtual COP movement is set between lifted heel and forefoot – no energy from lifting the heel can be recovered (vertical component). It should be mentioned, that all females, apart from one, claimed that they are not used to high-heels and presented difficulties in walking at the beginning of the measurement. In study [13] of long-term and short-term high-heels users found out, that walking in high-heels enlarges vertical component of ground reaction force. Author refer to other study, which explains that phenomenon by increased muscle work on tendon-aponeurosis complex [4], analyzed the influence of lifted heel on gait as well. They took into consideration several heel heights. The results are similar to presented in this work. The values of vertical component of ground reaction force presents the smaller second peak – the push-off phase was diminished, due to bare foot.

The anterior-posterior component presented problem of stabilization of heel on the ground and increased pressure at the beginning of LR phase. The characteristic of medio-lateral component differed from presented in this work, however both showed that loading on the head of 5th metatarsal bone was higher in case of barefoot [4]. Melvin in his doctoral thesis analyzed the effect of heel height on several variables [9]. The overview of papers, presented in his thesis, shows findings, similar to this work. Other authors, mentioned by Melvin, indicate, that lifted heel enlarged values for vertical and anterior-posterior ground reaction force. What is more, medio-lateral component increased in values due to heel height. Also it was mentioned, that greater load was located on medial side of the foot and reduced on lateral side. It is important to indicate an interesting fact - UP-peak appeared only in barefoot and high-heel measurement. It might suggest, that this element is present in case of gait with firm and point heel strike.

Gait in suit shoes seems to be similar, but smoother than in case of barefoot. The values do not differ from rest of shoe types. The COP swings among men received the smallest, recorded values in medio-lateral direction. However, swings in anterior-posterior direction are low as well. The M-L force component show lowest lateral movement and extension of loading response phase. The push-off values are lower than suppression. It can result from foot design, which is stiffer and imposes slower movement. It should be mentioned, that suit shoes were not pointed as often worn.

The general outcome from measuring the sports footwear for males and females is that the gait was smooth and uniform. Ground reaction was reduced only partially. Female subjects were the most stable in anterior-posterior direction in sports shoes. Male subjects had the lowest values of COP swings for anterior-posterior direction, but the highest in medio-lateral direction. Gait in sports shoes among men was smooth as well and all the disturbances are faded out. The M-L component for both sexes, present highest medial COG movements, leading rapidly to head of 5th metatarsal bone. However, the push-off phase is not that strong, which also indicates equal peaks from vertical component. In next work, authors took into consideration changes in stiffness in heel lifts of sport shoes [14]. The study consists of measuring plantar pressure distribution, COG position and ground reaction force for three types of heel lifts, characterized by different stiffness – it does not influence anterior-posterior COP movements – due to barefoot. However, the heel height of 2.5 cm affects COP visibly. What is more, peak pressure for sport, lifted shoes in metatarsal area was 1/3 higher than in case of barefoot and the highest values were obtained for wedge of medium stiffness. This one decreased values of A-P component, kept unchanged first peak and pit of M-L component, but decreased the second peak and kept the vertical component unchanged – due to barefoot measurement.

A review of several papers of walk differences between barefoot and shod gait in general, was made by [15]. Some interesting results are distinguished, which are in accordance with those, obtained in this work. Analysis of vertical component of force for barefoot measurement showed, that the first peak was smaller (due to the second one) in case of subject, who habitually wear shoes. What is more, there was a reduced drop force values (MST phase) for bare foot measurement in opposition for shod gait. This can lead to the assumption, that for barefoot, forces were more evenly distributed in time. Authors also compared results of habitually barefoot subject – their plantar pressure at heel and metatarsals were reduced. The same results appeared in case, where the foot was placed flatter on the ground in order to increase its friction. From the investigation of stability, it came out, that less space for forefoot width (narrow ball of shoe) indicates less support and simultaneously - worse stability, which can lead to injury, and worsened stability again. It showed, that shoes can limit the movement and functions of the foot.

It can be stated, that footwear influences gait pattern and ground reaction, despite of sexes. The differences were strongly visible in anterior-posterior and medio-lateral component of ground reaction force. High-heeled shoes had the greatest influence on gait, which proved to be the most unstable and loading for medial and fore part of the foot. The variations were visible in ground reaction as well as stability measurements. Any significant deviations were not obtained in case of suit and flat shoes with profiled soles, however the values for flat shoes indicate on robust achievement of critical phase points (suppression, push-off). The differences could come from shoe design. Sports shoes evened the gait by reducing its regularities, caused by external shock. In case of vertical component – sports shoes unify suppression and push-of phase, which can come from its design. Sports shoes evened the gait by reducing its regularities, caused by external shock. In case of vertical component – sports shoes unify suppression and push-of phase, which can come from its design. According to COP swing amplitude, barefoot was not the most stable environment. In the majority of data, any footwear (apart from high-heels) obtained better stability results. The difference was in case of sports shoes, where medio-lateral swings were higher, but anterior-posterior swings were smaller. Other important factors, which influence gait pattern are degree of wear and habituation to given type of footwear.

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