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"IDO MOVEMENT FOR CULTURE. Journal of Martial Arts Anthropology",
Vol. 17, no. 3 (2017), pp. 38–47
DOI: 10.14589/ido.17.3.5

KINESIOLOGY

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Autocorrelation in the analysis of a stochastic process of athletes and students

Submission: 29.10.2016; acceptance: 22.03.2017

Key words: force, balance, motion control, autocorrelation, foot

Abstract

Background. It was assumed that an indirect evaluation of motor control processes could be conducted on the basis of autocorrelation function computed from time series. The time series were computed from the values of changes of the ground reaction force during maintaining balance in the upright standing position. The researchers deliberately selected a process of standing in the upright position since it is a permanent act of movement.

Aim. This research aimed to determine correlations occurring between the right and left limb in balancing ground reaction forces while maintaining an upright body position. The correlations were computed on the basis of the autocorrelation function (zero of a function). The study was conducted on track and field athletes, football players and students.

Methods. The study comprised of taking measurements and recording ground reaction forces while maintaining balance in the upright standing position. The measurement process lasted 15 seconds and was repeated three times. Changes of ground reaction forces attained from two independent Kistler plates were recorded as time series. The recordings were synchronized in time. Values of force components recorded during the testing were used to draw autocorrelation function. The function was adopted to determine time needed by the autocorrelation function to reach 0.

Results. Differences observed in the examined groups showed statistical significant differences in the lateral force direction. There were also statistically significant differences in the values of horizontal force components of pressure exerted by the left and right foot. Analysis of mean values of time needed by the function to reach 0 for the lateral force component indicated that time needed by the track and field athletes was the longest for both feet. Statistically significant differences in values of the football players were observed between the right and left foot but only in the lateral force.

Conclusions. The study revealed that the students displayed the least control over balancing ground reaction force in a vertical position. All groups attained statistically significant differences in balancing force pressure on a surface exerted by the right and left foot for vertical force components. Values computed for the group of students were random. There were no statistically significant differences observed between the right and left foot in the athletes. While, statistically significant differences in the football players' values were observed between the right and left foot, this applied only for the lateral force.

Introduction

One of many ways to examine the surrounding reality and human behaviours is to record, process and analyze different signals [Zielinski 2012; Moczko, Kramer 2001]. A signal is considered to be a measurable value changing within a time function. Many signals which act on man are random. Information embedded in a signal and hidden in its features are not visible to the naked eye. Such processes are often described by many characteristics, which are frequently connected to one another. Therefore, it is necessary to do research on all the properties of a selected process in time which aims to determine their correlation [Stone *et al*. 2004; Szymaniec 2006]. That is why autocorrelation function suits this purpose, since it shows the correlation of a process with itself at different points in time [Descherevsky *et al.* 2003]. This function enables researchers to discuss certain flow of information and its future course. For instance, analysis of geological signals based on autocorrelation may predict earthquakes in seismically endangered zones [Telesca *et al.* 2004; Drapik, Kobielski, Prusak 2011]. Correct interpretation of loads on railways of a traction substation enables to plan efficient use of devices securing these places [Zoltowski 2005: 375–382]. Information generated in vibration processes facilitates building, maintenance and restoration in order to minimize risk and avoid future damage [Roj *et al.* 2008]. Medicine uses these signals to check basic vital life functions (pulse, heartbeat rhythm, breathing and nervous system activity). Their analysis helps prevent many threats not only those related to health but also to life itself [Sokolov *et al.* 2007; Byeon *et al.* 2007]. Researchers specializing in physical education conduct research mainly on short motor activities, with a beginning and end, performed by man such as: take off, push, kick or hit etc. There are very few studies on motor processes in man based on mathematics methods. Hence, this research aims to contribute to still yet to be developed literature.

Maintaining balance in the upright standing position may be considered to be a process in time series. A time series of autocorrelation function can be used to determine correlations between the current and future events. Analysis of maintaining balance in the upright position aims to prevent: balance loss and falls in old age, results of excessive lateralization due to performing asymmetrical sports by athletes and aims to evaluate healing processes after injuries needed in diagnostics. The areas mentioned above are beyond any question related to processes controlling human behaviours. Much research, however, examines episodes of movement performance.

The authors have decided that the process of motion control may be indirectly evaluated by computing autocorrelation function from the time series. The time series would be determined on the basis of ground reaction force values balanced by body pressure exerted on a surface in maintaining balance in the upright position [Broersen 2006]. Selection of this movement process resulted from the fact that it is performed permanently. It means that a man can stand on a surface for an unlimited amount of time. Such activity does have neither a beginning nor end. Moreover, maintaining balance in the standing position requires particular coordination abilities [Raczek, Mynarski, Ljach 2002]. It is one of the few motor activities aiming at static but at the same time being a dynamic process of "subtle" features [Blaszczyk, Klonowski 2001; Ladislao, Fioretti 2007].

Recording of force in time function obtained during measurements and presented as time series is a stochastic process [Lawler 2006]. Time series are computed on the basis of probability theory [Jaynes 2003]. They are used to calculate the autocorrelation function, a tool used to compare a signal to another signal, in particular to itself at different points in time. It can be determined for any data and any stationary or non-stationary time series.

Aim

This research aimed to determine correlations occurring between the right and left limb in balancing ground reaction forces during maintaining an upright body position. The correlations were computed on the basis of the autocorrelation function (zero of a function). The study was conducted on track and field athletes, football players and students.

The following research questions were posed:

1. Does autocorrelation function take more time to reach 0 in athletes or students?
2. Does a sport discipline influence the autocorrelation function time lags?
3. Are there, if any, differences between the values of force pressure of the right and left foot put on a surface when the function reaches 0 observed in the groups of athletes and students?
4. Are there, if any, differences between the values of force pressure of the right and left foot put on a surface when the function reaches 0 depending on a sports discipline?

Research group and methods

The research was carried out on three groups of men. The first group comprised of 11 track and field athletes aged between 19-26. The subjects were top class athletes engaged in hurdles, jumps and throws (shot put). The second group comprised of 13 football players in the 3rd and 4th league aged between 21-26. The third group consisted of 13 Wroclaw University (AWF) students aged between 20-26.

All the participants had given their written consent prior to participation in the research. The research was approved by the local research ethic committee.

The study comprised of taking measurements and recording ground reaction forces balanced by the body pressure put on a surface during maintaining balance in the upright standing position. A subject stood on two parallel Kistler plates with each foot positioned on one plate (fig. 1). Synchronic recordings of ground reaction forces in time were taken in three directions: lateral, vertical and anterior-posterior.

The measurement process lasted 15 seconds and was repeated three times. Figure 2 presents exemplary recordings of changes of force values in time as two time series for the left and right foot.

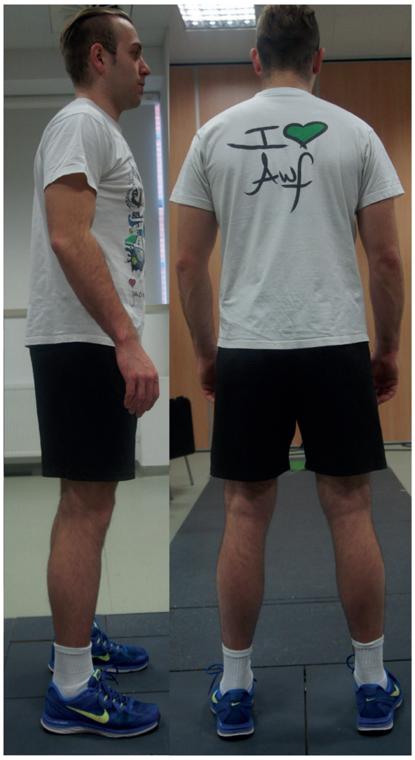

Figure 1. Tested subjects

Measurements of ground reaction forces were conducted by the use of two independently calibrated piezoelectric plates (600 x 400, Kistler Type 9286B; Kistler Instruments AG, Winterthur, Switzerland). The plates enabled the researchers to conduct measurements of three components of ground reaction forces (Fx, Fy and Fz) in the range from -10 kN to 20 kN. Four piezoelectric sensors attached to the corners of a platform were used to measure ground reaction forces. The sampling frequency of the measurements was 480 Hz. The piezoelectric plates had been calibrated prior to the research. Accurate and reliable measurements of the ground reaction force were taken by using a BTS Smart system. Values of ground reaction forces were divided by the body mass values and expressed in body mass percentage, separately for the left and right foot. Referring to a foot the authors of this study mean a spot where the measurement was conducted, in this case being a place where the body touched the plate. In general it was about an equal distribution of values of ground reaction forces, balanced body pressure exerted on a surface while maintaining balance in the upright position and its distribution on the left and right foot.

The analysis was recorded on a line graph of ground reaction force in time created on the basis of every 10th sample. Such prepared values of force components recorded during the testing were used to draw an autocorrelation function.

To work out this function the researchers accepted a formula connecting x(t) values in t and after t+τ time in the absolute range of T:

$$Rx(\tau)=\lim_{T\to\infty} \tau\ 1/T \int_0^T x(t)x(t+\tau)dt$$ [Greene 2012]

where:

Rx (τ) – autocorrelation function of x(t) signal,

τ – signal time lag,

T – period of time [Szymaniec 2006].

F(t) signal was correlated with itself with a time lag of 1/48 seconds. Figure 3 presents an exemplary autocorrelation function for the left and right foot for one of the tested subjects.

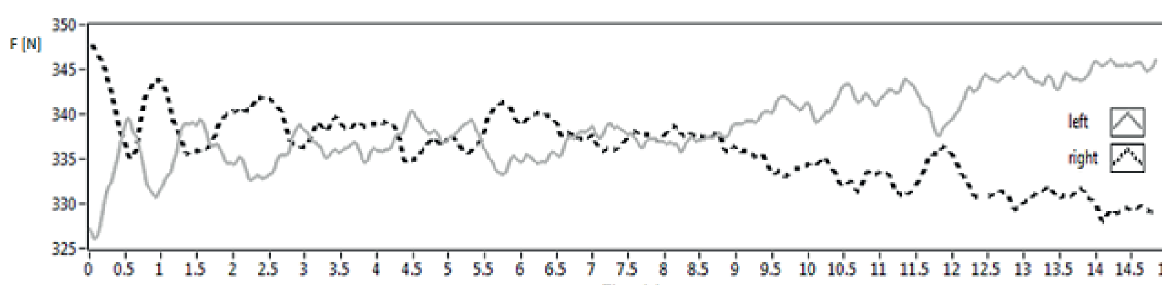

Figure 2. Exemplary changes of the ground reaction forces in time balanced by body pressure exerted on a surface by the left and right extremity

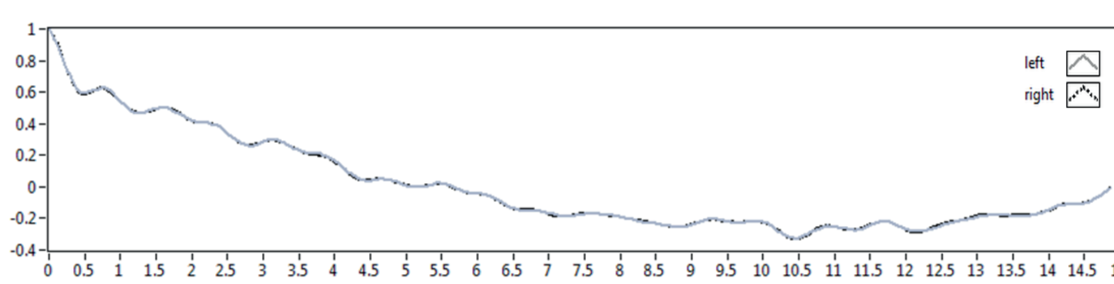

Figure 3. Chart of the autocorrelation function in time

Table 1. Statistical characteristic and assessment of significance of the changes in the somatic parameters

Features	Group						ANOVA		probability values for the post-hoc, NIR test, p value		
	Athletes N=11		Football players N=13		Students N=13						
	Means	SD	Means	SD	Means	SD	F	p	athletes – football	athletes – students	football – students
Age [years]	22,82	1,72	23,00	1,47	21,85	2,23	1,45	0,2479	0,8110	0,2063	0,1195
Body height [cm]	187,00	5,76	180,23	5,64	177,85	7,78	6,22	**0,0050**	**0,0159**	**0,0016**	0,3568
Body mass [kg]	80,18	14,70	76,23	4,80	79,77	12,60	0,46	0,6334	0,3993	0,9295	0,4301
BMI	22,86	3,46	23,48	1,42	25,23	3,68	2,05	0,1439	0,6168	0,0628	0,1477

Probability values for p < 0,05 are in bold

Table 2. Statistical characteristic of mean values of time needed by the function to reach 0 for the 15 second measurements in the three consecutive trials while maintaining balance

Group	Force vector	Foot	Repetitions					
			1		2		3	
			Means	SD	Means	SD	Means	SD
Athletes N=11	left-right	right	3,48	1,66	3,78	1,62	3,08	1,67
		left	3,47	1,77	4,06	1,39	3,13	1,87
	anterior-posterior	right	2,89	1,90	2,50	1,80	2,66	1,81
		left	2,88	1,91	2,52	1,81	2,67	1,83
	up-down	right	3,71	1,93	2,90	2,11	2,70	1,77
		left	3,59	2,08	2,18	1,76	2,75	1,95
Football players N=13	left-right	right	3,05	1,64	3,52	1,87	1,67	1,09
		left	2,35	1,64	3,16	1,90	2,33	1,63
	anterior-posterior	right	3,23	1,99	3,26	1,78	3,11	1,94
		left	3,24	2,01	3,27	1,63	3,04	1,90
	up-down	right	3,46	1,82	2,96	1,66	2,81	1,73
		left	3,14	2,05	1,96	1,33	2,59	1,48
Students N=13	left-right	right	2,57	1,33	2,45	1,72	1,83	1,32
		left	3,04	1,31	2,52	1,67	2,39	1,42
	anterior-posterior	right	2,81	1,53	2,69	1,78	3,33	2,01
		left	2,81	1,54	2,68	1,79	3,29	1,96
	up-down	right	2,77	1,81	3,08	1,43	2,91	2,05
		left	2,58	1,79	2,34	1,70	3,10	1,86

The function was used to determine the time needed by the autocorrelation function to reach 0.

All tests were performed in a certified Laboratory of Biomechanical Analyses, University of Physical Education in Wroclaw (certificate no PN-EN ISO 9001:2001).

Statistical methods

The attained data was analyzed by commonly used methods of descriptive statistics. Standard deviation and arithmetic means were computed. The calculated variables were subject to the Shapiro-Wilk test for normality. ANOVA providing multiple variance analysis with repeated measures was applied to compute significance of differences between the mean values of the variables. While, post-hoc NIR test was employed to evaluate least significant differences. Significance of difference was computed for $p<0.05$.

All the calculations were conducted by the use of *STATISTICA 9.*

Results

The test of the distribution of variables supported a hypothesis of normal distribution.

The examined groups did not differ statistically in regard to somatic parameters, except those athletes whose values were statistically significant and differed from these of football players and students. The differentiating parameter was body height, which from the research point of view was insignificant, since discussed variables referred to the ground reaction forces. So, it can be stated that the examined groups were homogeneous in regard to the body build (Table 1).

Analysis of mean values of time needed by the function to reach 0 for the lateral force component indicated that time needed by the athletes was the longest for both

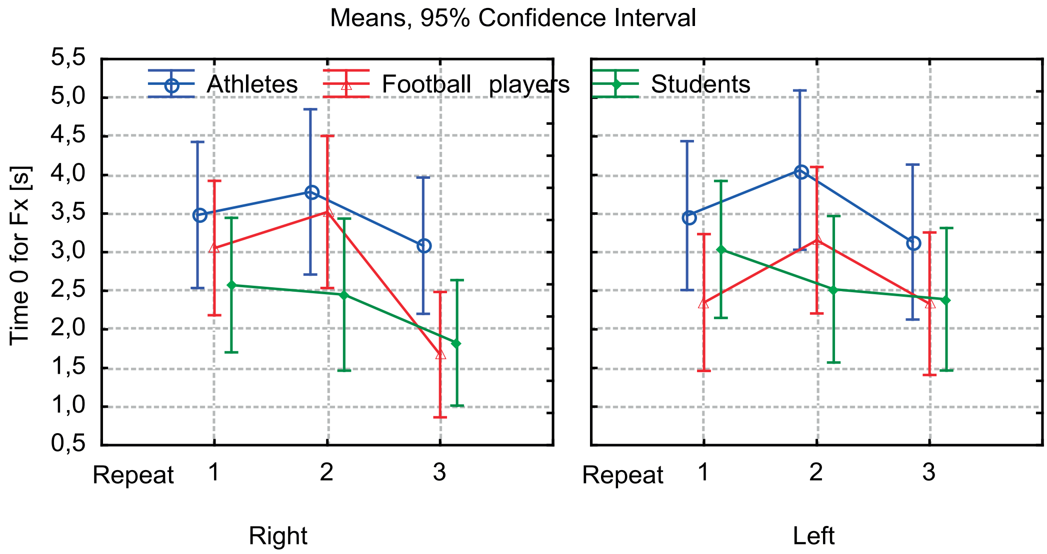

Figure 4. Distribution of mean time lag values of the autocorrelation function for 0 in the consecutive trials for the lateral force component (Fx)

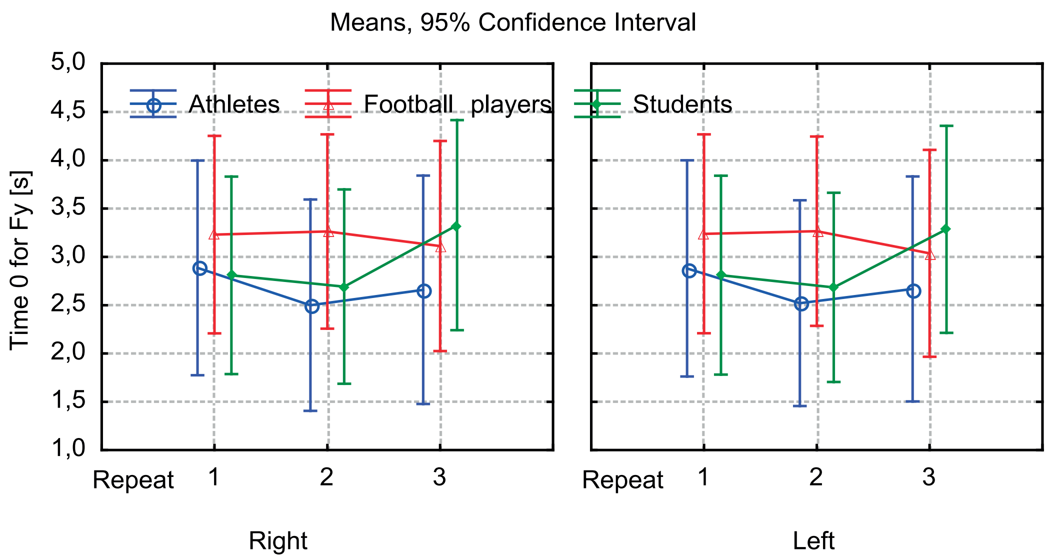

Figure 5. Distribution of mean time lag values of the autocorrelation function for 0 in the consecutive trials for the anterior – posterior force component (Fy)

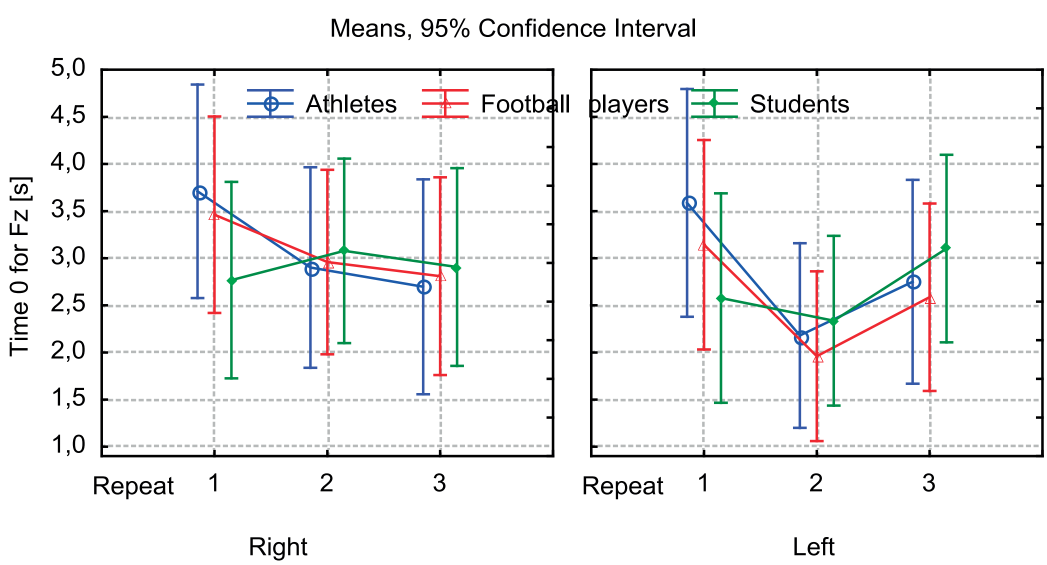

Figure 6. Distribution of mean time lag values of the autocorrelation function for 0 in the consecutive trials for the vertical force component (Fz)

feet. In the first and third trial both football players and students attained similar time values, but still shorter that the athletes. In the second trial the discussed values decreased for both feet. The highest drop was observed in the group of students, followed by the soccer players and finally athletes (Table 2, figure 4).

The analysis of the selected parameter of the anterior-posterior autocorrelation function were similar to time lag values of the autocorrelation function for 0. The similarities were observed between the right and left foot in each trial and for each group (Table 2, figure 5).

The analysis of time lag values for the autocorrelation function for 0 of the tested groups enabled the researchers to spot certain regularity. The authors observed that among the athletes the vertical ground reaction force of the right foot decreased along with each repetition. The time lag of the autocorrelation function for 0 observed for the left foot first shortened and next lengthened. There were no correlations in the group of students so the adapted values were random (Table 2, figure 6).

Table 3 presents the result of the repeated measurements analysis of variance between the tested groups, repetitions and feet.

Upon analyzing directions of force components, the authors observed statistically significant differences in the lateral direction (p = 0.0226) in all the groups. Differences between the left and right foot (0.0426) were statistically significant for vertical force components.

Correlations between the feet (right, left) in the consecutive trials were statistically significant in reference to the following force components and their directions: lateral (0.0497) and vertical (0.0209). Statistically significant differences for all the parameters (repetitions, groups and feet) were reported in the lateral force components (0.0413). 3).

Evaluation of variability of mean values revealed statistical differences between the athletes and students and their significance in the second and third trial for the lateral force component. A similar difference was also observed between the athletes and football players, but only in the third trial and for the right foot (tab. 4).

Analyzing correlations occurring between the trials, the researchers discovered that all the examined groups indicated statistically significant differences between the anterior-posterior force components for the left and right foot. And in general, the largest number of statistically significant differences of the discussed data was detected in the athletes, especially between the first and second trial (tab. 5).

Correlation analysis of the trials showed that the greatest number of statistically significant differences was observed for the lateral force components in the groups of football players (first and third trial) and students (third trial). There were no statistically significant differences observed in the athletes (Table 6).

Table 3. Evaluation of the main effects of the analysis of variance

Force vector	Main effect													
	group		repeat		repeat × group		foot right–left		foot × group		repeat ×foot		repeat × foot × group	
	F	p	F	p	F	p	F	p	F	p	F	p	F	p
left-right	4,24	**0,0226**	3,09	0,0521	0,50	0,7343	0,86	0,3593	1,54	0,2280	3,14	**0,0497**	2,64	**0,0413**
anterior-posterior	0,44	0,6451	0,16	0,8541	0,31	0,8680	0,37	0,5497	0,30	0,7455	0,67	0,5156	0,27	0,8945
up-down	0,07	0,9350	2,20	0,1187	0,93	0,4509	4,44	**0,0426**	0,30	0,7456	4,10	**0,0209**	0,05	0,9960

Table 4. Evaluation of variability of mean values of the examined parameters between the groups

Group	Force vector	Probability for post-hoc, NIR test, p values					
		repeat 1		repeat 2		repeat 3	
		right	left	right	left	right	left
Athletes – football players	left-right	0,4560	0,0541	0,6509	0,1181	**0,0170**	0,1674
	anterior-posterior	0,6535	0,6408	0,3229	0,3341	0,5553	0,6313
	up-down	0,7532	0,5745	0,9411	0,7808	0,8870	0,8362
Athletes – students	left-right	0,1180	0,4456	**0,0239**	**0,0094**	**0,0322**	0,1996
	anterior-posterior	0,9199	0,9274	0,8019	0,8311	0,3849	0,4231
	up-down	0,2366	0,2052	0,8228	0,8430	0,7905	0,6559
Football players – students	left-right	0,3842	0,2138	0,0557	0,2494	0,7814	0,9162
	anterior-posterior	0,5665	0,5607	0,4388	0,4299	0,7682	0,7351
	up-down	0,3613	0,4561	0,8755	0,6192	0,8972	0,4964

Table 5. Evaluation of variability of mean values of the examined parameters between the repetitions

Foot	Force vector	Probability for post-hoc, NIR test, p values								
		Athletes			Football players			Students		
		repeat 1 – 2	repeat 1–3	repeat 2–3	repeat 1 – 2	repeat 1–3	repeat 2–3	repeat 1 – 2	repeat 1–3	repeat 2–3
Right	left-right	0,2917	0,1624	**0,0158**	0,0753	**0,0000**	**0,0000**	0,6354	**0,0052**	**0,0185**
	anterior-posterior	**0,0000**	**0,0000**	**0,0029**	0,5004	**0,0146**	**0,0022**	**0,0159**	**0,0000**	**0,0000**
	up-down	**0,0411**	**0,0112**	0,6001	0,1648	0,0723	0,6746	0,3872	0,6976	0,6328
Left	left-right	**0,0402**	0,2277	**0,0015**	**0,0027**	0,9509	**0,0022**	0,0504	**0,0151**	0,6179
	anterior-posterior	**0,0000**	**0,0001**	**0,0054**	0,5666	**0,0001**	**0,0000**	**0,0093**	**0,0000**	**0,0000**
	up-down	**0,0006**	**0,0347**	0,1467	**0,0015**	0,1242	0,0839	0,5033	0,1458	**0,0356**

Table 6. Evaluation of variability of mean values of the examined parameters between the right and left foot

Force vector	Probability for post-hoc, NIR test, p values for the right - left foot								
	Athletes			Football players			Students		
	repeat 1	repeat 2	repeat 3	repeat 1	repeat 2	repeat 3	repeat 1	repeat 2	repeat 3
left-right	0,9786	0,3199	0,8670	**0,0082**	0,1630	**0,0133**	0,0793	0,7910	**0,0329**
anterior-posterior	0,9124	0,6867	0,8545	0,8660	0,9462	0,1160	0,9731	0,8660	0,3637
up-down	0,7522	0,0675	0,8918	0,3752	**0,0067**	0,5350	0,5952	**0,0416**	0,5860

Discussion

There are many situations in sports when a person needs to shift their balance due to jumping or running [Hrysomallis, McLaughlin, Goodman 2006]. The results attained in this study showed that the athletes, best maintained their upright body position for the lateral force components, while football players for the anterior-posterior force. The results obtained by the students, regarding balance control in the discussed directions were the poorest albeit values attained in some trials were similar to these of the athletes. It may result from training which also strengthens postural muscles and gives more ease. An athlete does not have to concentrate on subconsciously and automatically performed activities, such as maintaining balance, and can focus on a specific motor task which requires complex balance coordination. Bosek *et al*. [2004] showed in their research that prolonged, interfering with balance control training may cause permanent alterations in balance coordination, which has been confirmed by the research conducted by the authors of this study. For the athletes autocorrelation function reaches 0 in the longest time. It suggests that changes in the balance maintaining process are less random. It can be assumed that the athletes, unlike the students, tried to perform their trials in a calm, moderate way limiting the number of unpredictable stimuli to minimum.

The process of maintaining balance depends on a subject. Hence, in order to achieve the best sports results one needs to consider individual predispositions of an athlete in planning a training process. Track and field training aims to develop the human body in a comprehensive way. Many exercises included therein develop human body symmetrically. Athletes performing track and field sport (hurdling, jumps and throws) require certain technique, which need to be developed through training. Taking all this into consideration, the researchers deliberately selected subjects who created a group of athletes. This way, evaluating the process of balance control, they were able to consider factors determining the quality of the discussed motor activity. In the track and field athletes the quality is determined by lower extremities which, in their case, mainly carry the body. A football players training differs from the one of an athlete since it comprises of many elements involving participation of a single lower extremity such as kicks, receives, direction changes. Such training may cause disproportions in generating ground reaction forces by the left and right extremity (foot). The results obtained in this study confirmed this theory. There were no statistically significant differences observed between the right and left foot in the athletes in comparison to the football players. However, the football players showed the greatest number of statistically significant differences between the values of feet pressure.

An ability to maintain balance is a key skill in many sports activities. It often determines a successful performance during i.e. sports competition [Adlerton, Moritz, Moe-Nilssen 2003]. Many researchers believe that training of balance control is significant in reaching high sports level and it should be included in an everyday sports training [Bahr, Lian, Bahr 1997; Mallio *et al.* 2004; Gioftsidou *et al*. 2006; Soderman *et al.* 2000].

Many researchers emphasis significance of balance in obtaining excellent sports results as well as preventing injuries [Abbasi *et al.* 2012; Gokdemir *et al.* 2012; Hrysomallis 2008; Kayapinar 2011]. Balance control exercises decrease risk of musculoskeletal injuries [Caraffa *et al.* 1996; Wedderkopp *et al.* 1999]. Strengthened postural muscles maintain an upright position better and protect the skeletal system. An athlete performs better even on an unstable surface and is not prone to injuries. Being a champion, long training experience, specific sport discipline and other factors requiring sports training point to a right direction and determine the correlation level in maintaining balance. So in order to fit a training process to particular needs a trainer first needs to establish the subject's ability to maintain balance [Kruczkowski, Fostiak 2012].

This study aimed to evaluate balance maintaining process in the upright position by the young subjects performing different motor activities. The analysis was conducted on the basis of time lag of a zero autocorrelation function. This evaluation was designed to facilitate future diagnostics of conditions disrupting balance maintenance, determine results of injury rehabilitation and point out to irregularities in training programs. The tackled issue was mainly related to the idea and performance of movement while the proposed method was to support its understanding.

Conclusions

1. In the track and field athletes the autocorrelation function reached 0 in a shorter time than in the students. It was distinct in the vertical ground reaction force (mainly in lateral direction). Balance maintained by the students in the tested directions was the poorest.
2. Performance of different sports did not have any influence on balance maintenance in the upright position. The time lag of the autocorrelation function for lateral balance control observed in the athletes was longer in comparison to the football players. While the soccer players in comparison to the athletes displayed longer time in the anterior-posterior direction. It can be concluded that there are very little disturbances in sending information from the nervous system to suitable motor units both in the athletes and football players.
3. There were statistically significant differences observed for all groups in balancing force pressure on a surface exerted by the right and left foot for vertical force components. The analysis of a selected parameter of the anterior-posterior autocorrelation function was similar to time lag values of the autocorrelation function for 0. The similarities were observed between the right and left foot in each trial and for each group. Values in the group of students were random.
4. In the athletes correlation between the right and left foot in balancing ground reaction force displayed a decrease of time lag (for vertical force component) in the consecutive trials when the autocorrelation function reached 0. The time lag for the left foot shortened and then lengthened. There were no statistically significant differences observed between the right and left foot in the athletes. Statistically significant differences in the football players' values were observed between the right and left foot but only for the lateral force.

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Autokorelacja w analizie przebiegu procesu stochastycznego realizowanego przez człowieka na przykładzie sportowców i studentów

Słowa kluczowe: siła, równowaga, kontrola ruchu, autokorelacja, stopa

Abstrakt

Tło. Założono, że proces sterowania ruchem można pośrednio ocenić poprzez obliczenie funkcji autokorelacji z szeregu czasowego. Szereg czasowy otrzymano z zapisu zmian wartości siły reakcji podłoża podczas utrzymywania równowagi w pionowej pozycji ciała. Proces utrzymywania równowagi w pionowej pozycji ciała wybrano, dlatego że jest on aktem ruchowym wykonywanym permanentnie.

Cel. Celem pracy jest określenie, na podstawie funkcji autokorelacji (miejsca zerowego funkcji) związków, jakie zachodzą dla lewej i prawej stopy w równoważeniu sił reakcji podłoża podczas procesu utrzymywania równowagi ciała w pozycji pionowej przez zawodników uprawiających lekkoatletykę, piłkę nożną i studentów.

Metody. Badania polegały na pomiarze i rejestracji siły reakcji podłoża podczas utrzymywania równowagi w pionowej pozycji ciała. Pomiar trwał 15 sekund i powtórzono go trzykrotnie. Zapisano zmiany siły w funkcji czasu z dwóch niezależnych platform Kistlera jako dwa szeregi czasowe. Zapis ten był zsynchronizowany w czasie. Z każdego zarejestrowanego przebiegu składowej siły obliczono wartości i wykonano wykres funkcji autokorelacji. Z wykresu funkcji autokorelacji wyznaczono czas, jaki upływa do osiągnięcia przez funkcję autokorelacji wartości 0.

Wyniki. W badanych grupach, z uwagi na kierunek działania sił składowych, istotne statystycznie różnice wystąpiły w bocznym działaniu sił. Odnotowano również różnice istotne

statystycznie między wielkościami sił składowych nacisku lewą i prawą stopą działających w kierunku pionowym. Analiza średnich wartości odstępów czasowych osiągnięcia przez funkcję autokorelacji wartości 0 dla siły składowej działającej w kierunku bocznym wykazała, iż najdłuższy czas w każdym powtórzeniu osiągnęli lekkoatleci zarówno dla lewej jak i prawej stopy. W grupie piłkarzy nożnych różnice istotne statystycznie między obiema stopami wystąpiły w sterowaniu wielkościami sił działających w kierunku bocznym.

Wnioski. Studenci wykazali się najmniejszą kontrolą utrzymywania równowagi w działaniu składowych sił reakcji podłoża w płaszczyźnie poziomej. W badanych grupach różnice istotne statystycznie w równoważeniu sił nacisku na podłoże przez lewą i prawą stopę odnotowano dla sił składowych działających w kierunku pionowym. W grupie studentów przyjmowane wartości mają charakter losowy. Różnice pomiędzy lewą a prawą stopą u lekkoatletów, na podstawie zapisanych wielkości sił reakcji podłoża, nie były istotne statystycznie. W grupie zaś piłkarzy nożnych różnice istotne statystycznie między obiema stopami wystąpiły w sterowaniu wielkościami sił działających w kierunku bocznym.