COMPARATIVE ANALYSIS OF THE SUPPORT PHASE DURING FIRST TWO STEPS AFTER LEAVING THE STARTING BLOCKS

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BACKGROUND: Biomechanical analysis of accelerated running dynamics provide valuable information about movement execution. The key phase of the movement is the ground contact phase, in which force impulses applied on the human body are generated.

OBJECTIVE: The main goal of the study was to analyze differences in the support phase during first and second ground contact off the blocks.

METHODS: 10 male athletes (22.9 ± 4.6 years) took part in laboratory experiment. Force-plate Kistler 9281 EA (Winterthur, Switzerland) was used to determine the contact forces in both steps independently. Matlab Software (The MathWorks, Inc., Natick, USA) was used for calculations of the force impulse, produced velocities and average acceleration during the support phase. Matlab also provided the tool for statistical processing of the results (paired T-test and correlation analysis).

RESULTS: Significant differences ($\alpha = 0.01$) were identified between the first and second step's support phase in contact duration, produced horizontal velocity and average horizontal acceleration. Produced horizontal velocity achieved value 1.117 ± 0.081 ms^{-1} during first and 0.835 ± 0074 ms^{-1} during second ground contact after blocks. Average acceleration showed negative correlation with the height of the athlete during the first ground contact off the blocks ($r = -0.42$). If braking force was present during first 20–40 ms of ground contact, it led to longer duration of support phase and was coupled with a smaller value of average acceleration.

CONCLUSIONS: Braking phase during first steps after the blocks should be considered always as an imperfection of movement execution. Taller athletes seem to be disadvantaged during first ground contact after leaving the blocks. The first and second step's ground phases are significantly different.

Keywords: Biomechanics, dynamics, start, acceleration, running.

INTRODUCTION

The typical example of human locomotion, in which alternate support and flight phase, is running. The movement unit of running is one stride of the lower limb which consists of two steps (Hay & Reid, 1988; Bosch & Klomp, 2004; Sedláček et al., 2004).

Speed of locomotion remains unchanged during stabilized running. In this case the total impulse of ground reaction force must compensate the work against the resistance of surrounding environment (Vanderka & Kampmiller, 2011). Even more, athlete should during support phase exert sufficient vertical impulse to obtain the time for execution all aerial movements in wide range but in shortest possible time (Auvinet et al., 2002).

The support phase is usually divided into braking and propulsion subphases. Some authors (Bosch & Klomp, 2004; Ciacci, Di Michele, & Merni, 2010) consider the dividing instant, when center of mass (COM) is located above the support foot or center of pressure. According to the dynamic analysis, also change from negative to positive values in anterior-posterior component of horizontal force might be more accurate (Novacheck, 1998; Herzog & Leonard, 2005; Kyrölainen et al., 2005).

The difference of accelerated running is arising from the specific movement task – achieve maximum horizontal velocity increase in shortest possible time. Therefore many differences are observed in the inter-segment dynamic and the time-space specific location of those segments (Kugler & Janshen, 2010). Propulsion force impulse should achieve much greater value than braking force impulse (Hunter, Marshall, & McNair, 2005). Čoh, Peharec, Bačič, and Kampmiller (2006) published average values of first two support phase's duration 177 ms in the first and 159 ms in the second step performed by top sprinter. Another study of Čoh, Tomažin, and Štuhec (2009) of an international class female athlete present values of support duration 168 ± 17 ms in the first and 139 ± 22 ms in the second ground contact after leaving the blocks.

Vertical force impulse provides the fluent rise of COM, which enables execution of aerial movements in higher range of motion. On the other hand, too high value of vertical impulse may decrease the firing rate of support phases and therefore to decrease of number of horizontal propulsions. Finally, it may lead to a decrease of the efficiency of performance. Lower limb extensors exhibit greater muscle excitation during acceleration running than during steady pace running, which is followed by greater force production, energy consumption and greater mechanical power (Roberts, 2006).

The movement task of acceleration running is repetitive production of high propulsion force impulse. The goal of each support phase should be braking-force minimization and propulsion impulse maximization alongside with shortening the contact time. The general solution of this problem is touch-down execution dorsal from COM vertical projection. Coupled with muscle pre-activation both strategies combined should ensure qualitatively superior performance. Modern trends in sprinting (Kobayashi et al., 2009; Slawinski et al., 2010) identify the strategy of longer steps in acceleration phase with active ground preparation phase and activation of muscle elasticity.

The aim of our study was to compare parameters that describe the dynamics of the support phase during first two steps after blocks. From these parameters individual strategy should be identified, which athlete used for the movement task solution. Differences in dynamics of first and second step are expected.

METHODS

10 athletes (decathletes with personal best over 6000 points in competition; 100 m personal best 10.73–11.99 in competition achieved in 2006–2011; height 181.6 ± 5.8 cm; weight 73.7 ± 6.6 kg; age 22.9 ± 4.6 years) took part in laboratory experiment. All participants signed the informed consent. The research was agreed by the Ethics committee of the Faculty of Physical Education and Sport of Charles University in Prague.

Athletes should perform a crouch start from the blocks with first step (resp. second step) foot placement on the force-plate. One force-plate (Kistler 9281 EA; Winterthur, Switzerland) operating on sample rate 1000 Hz was used to determine the ground reaction force in three components (anterior-posterior, lateral and vertical). Measured ground reaction force (GRF) data were exported to Matlab R14 (The MathWorks, Inc; Natick, Massachusetts, USA). The instant, when vertical component of ground reaction force overcame the three standard deviations bandwidth of unloaded force plate, it was defined as the instant of touch-down (beginning of the support phase). The end of the support phase was defined as the instant, when vertical component of ground reaction force fell down to earlier defined bandwidth.

The movement criterion was maximization of anterior-posterior velocity production Δv_h during support phase calculated as a ratio of force impulse and athlete's mass –

$$\Delta v_h = \frac{\int_{t_d}^{t_o} F_{ap}\,dt}{m}$$

where F_{ap} denotes anterior-posterior component of ground reaction force from the instant of touch-down (t_d) to the instant of the take-off (t_o) and m denotes the mass of the subject.

Athletes performed 3 trials with first step on the plate and 3 trials with second step on the plate. All participants completed a warm-up and unmeasured free trials to maximize probability of whole foot placement on the plate. The best attempt of each subject in first (respectively second) support phase in terms of defined optimization criterions were analyzed. Following characteristics of the support phase were analyzed:

- ground reaction force impulse in three components,
- support phase duration,
- anterior-posterior velocity production during the support phase,
- average acceleration during support phase calculated as a ratio of Δv_h and t_{sup}.

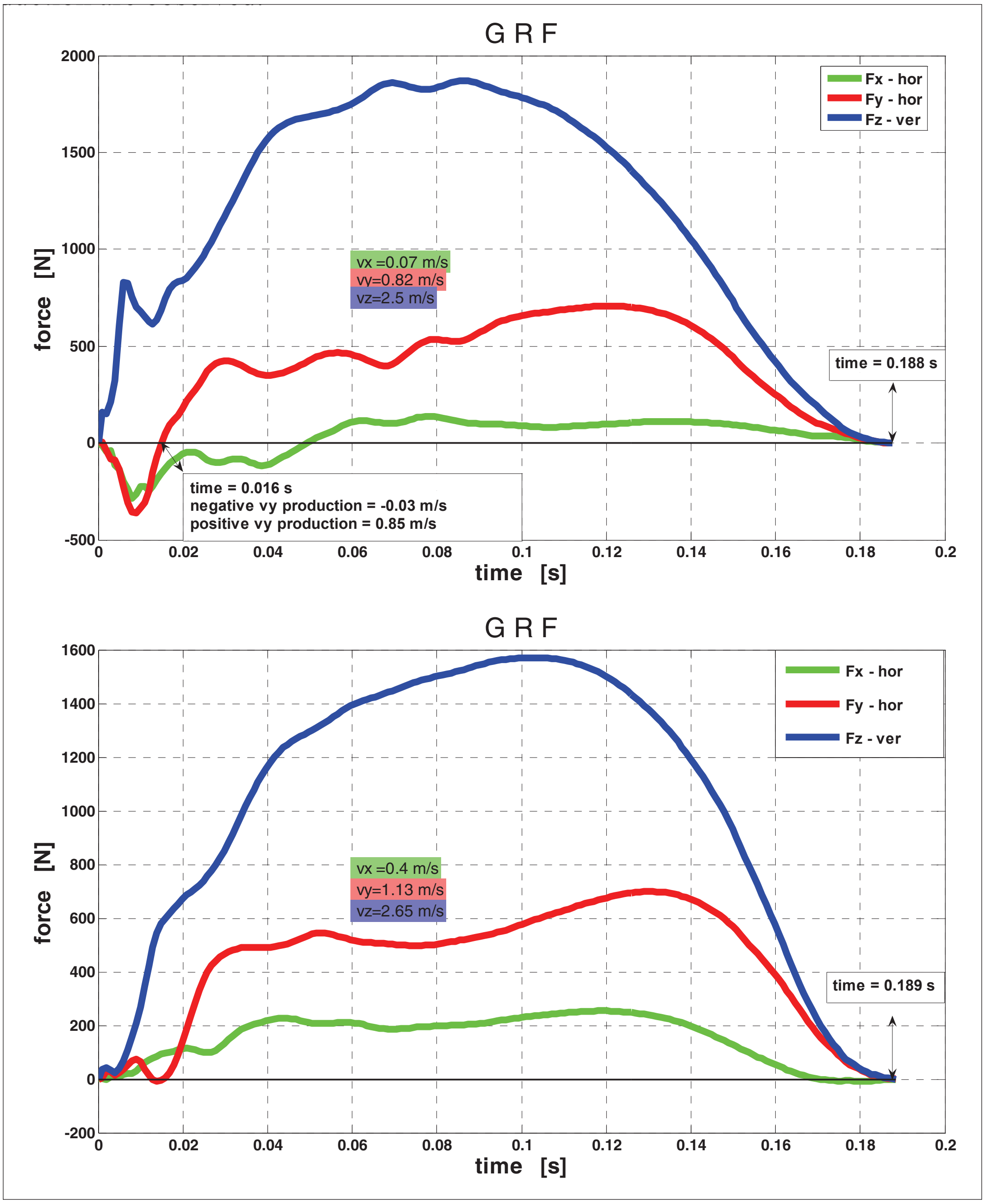
T-test function in Matlab was used to compare characteristics of the first and second step. Significance level α was set to 0.01. T-test function returned value 1, if the null hypothesis can be rejected on pre-defined significance level 0.01. Correlation analysis was used to identify relationship between pair of characteristics. Pearson's correlation coefficient was used for description of dependence of height of the body and produced average acceleration during first two steps and also to identify the relationship between produced velocity and the duration of the support phase.

RESULTS

Differences in components of ground reaction forces were identified in each individual. Four participants performed with braking force during first ground contact after leaving the blocks. The same number of participants exhibited the same imperfection during second support phase, but these individuals were not identical (only two). The examples of well-performed step and the step with braking phase are displayed in Fig. 1.

Parameters of the first two steps of each participant are presented in TABLE 1. Athletes are ordered according to two-steps average acceleration.

Fig. 1
Resulting GRF in three components. The support phase with the braking force is displayed on the upper graph. Braking force, which was presented for 16 ms, caused velocity loss of 0.03 m/s. This braking phase is also associated with impact force peak of vertical component. Well executed steps's characteristics are shown on the second figure. Although duration of both strides is similar, huge differences in horizontal velocity production are observed



Typical trends in the changes of parameters between first and second steps are evident from the table. Produced velocity during first ground contact achieved value 1.117 ±0.081 ms^{-1} and 0.835 ±0.074 ms^{-1} during the second ground contact. Therefore average acceleration achieved smaller values by approximately 0.8 ms^{-2} during the second support phase than in first one. Also duration of the second step was by 26 ms shorter in the average. Produced horizontal velocity, ground contact duration and average acceleration exhibit all statistically significant differences between the first and second support phase on significance level 0.01, because T-test values of comparisons were 1 in all three cases.

Dependence of the increase of horizontal velocity and duration of support phase showed greater correlation in second step (r = 0.67) than in the first step (r = 0.25).

TABLE 1
Parameters of support phase during the first and second step in accelerated running

Athlete	height	1st step			2nd step			cumulative		
	[cm]	v_h	t_{sup}	acc	v_h	t_{sup}	acc	v_h	t_{sup}	acc
1	**178**	1.127	0.189	5.946	0.817	0.172	4.763	1.944	0.361	5.384
2	**191**	1.203	0.218	5.512	0.960	0.188	5.118	2.163	0.406	5.330
3	**173**	1.211	0.199	6.095	0.859	0.190	4.508	2.070	0.389	5.318
4	**179**	1.127	0.205	5.487	0.925	0.192	4.808	2.052	0.398	5.159
5	**179**	1.087	0.200	5.423	0.758	0.168	4.524	1.845	0.368	5.014
6	**177**	1.120	0.209	5.349	0.757	0.180	4.216	1.877	0.389	4.826
7	**185**	1.170	0.228	5.130	0.921	0.224	4.110	2.092	0.452	4.624
8	**188**	1.104	0.229	4.815	0.820	0.188	4.373	1.924	0.417	4.616
9	**177**	0.903	0.199	4.529	0.785	0.169	4.654	1.688	0.368	4.586
10	**189**	1.122	0.229	4.895	0.744	0.180	4.141	1.866	0.409	4.564
mean	**181.6**	**1.117**	**0.211**	**5.318**	**0.835**	**0.185**	**4.522**	**1.952**	**0.396**	**4.942**
sd	**5.8**	**0.081**	**0.014**	**0.465**	**0.074**	**0.016**	**0.307**	**0.135**	**0.026**	**0.321**

Legend: Green marked athletes use the strategy of shortening ground contact, while yellow marked athletes mostly rely on strength. Athletes are displayed in the order according to average acceleration in both steps. Last two rows displays mean and standard deviation of each parameter

The influence of body height showed negative correlation with average two-steps acceleration (r = –0.31) and with the first step average acceleration (r = –0.42), but no correlation with average second step acceleration (r = –0.01). These findings lead to idea, that higher body height may be disadvantageous especially during first ground contact.

Two strategies were identified in comparison of athletes – green marked athletes used the strategy of shorter contact time, while the yellow marked tend to longer contact time and thus relied more on their strength. The dividing range was 370–390 ms in the duration of two support phases, in which no strategy was identified.

DISCUSSION

In comparison with values reported by Čoh et al. (2006) and Čoh et al. (2009) our subjects perform with longer duration of the support phase in both steps. The explanation is better sport performance of their subjects than ours. An interesting finding was that the athlete with best personal record on 100 m (10.73 s), was the worst in the acceleration performance criterion.

Braking force impulse in the beginning stage of the support phase (usually in duration of 20–40 ms), always negatively influenced the gain of total horizontal momentum. The solution of this problem should be to avoid passive foot placement on the ground during first strides.

Two common strategies were identified in acceleration stage of running. The first strategy is primarily based on shortening of the support phase (green marked in TABLE 1). In the second strategy (yellow marked athletes in TABLE 1), a major role is played by the lengthening of the support phase in order to maximize the horizontal velocity production. The purpose of our study was not to decide which strategy leads to better results. Although the idea that minimizing ground contact and maximizing the efficiency of force application lead to better results, is evident. The best athlete was typical member of the first group, while from second and fourth belonged to the second group.

Another interesting finding was that the length of support is associated with the height of the athletes. Taller athletes such as {2, 7, 8, 10} tend to spend more time on the ground, while smaller athletes were usually in short contact with the ground {1, 9}. Previously mentioned taller athletes exhibit the braking force in anterior-posterior direction.

In advance of the further steps shorter contact times and smaller acceleration achievement are expected. Another important parameter that strongly influenced the performance was the level of explosive strength of the lower limbs. Its level depends on athlete's typology, especially on muscle design, and also on the level of sport preparation. Its level may be calculated as the norm of the vector of GRF impulse divided by individual mass and contact time, but it was not purpose of the study.

The low value of correlation between force production and support duration during first step may be explained by wide technical variance of movement execution. While during second support phase athletes tend to perform more predictable – higher force impulse is usually compensated by time loss. Thanks to higher initial horizontal velocity value, it is easier to overcome the braking phase due to inertia and quickly begin the propulsion.

The limitations of our research are the absence of information about flight phase parameters, such as length of the stride and duration of flight. Stride firing rate and the range of motion during the flight would determine the increase of velocity alongside with the support phase execution.

CONCLUSION

Duration of the support phase and produced horizontal velocity are significantly different during the first and the second ground contact off the blocks. Taller athletes tend to spend more time on the ground especially during first step. If braking force occurred during both steps, it negatively influenced the duration of ground contact and average acceleration, so athletes should execute the steps to avoid it.

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KOMPARATIVNÍ ANALÝZA OPOROVÉ FÁZE PRVNÍCH DVOU KROKŮ PŘI NÍZKÉM STARTU

(Souhrn anglického textu)

VÝCHODISKA: Biomechanická analýza dynamiky akcelerovaného běhu poskytuje cennou informaci o provedení pohybu. Klíčovou fází pohybu je fáze kontaktu s podložkou, při které dochází k aplikaci silových impulsů na lidské tělo.

CÍLE: Cílem práce bylo analyzovat odchylky v dynamice oporové fáze při prvním a druhém kroku akcelerovaného běhu po výběhu z bloků.

METODIKA: 10 mužů (22.9 ± 4.6 roku) se zúčastnilo laboratorního šetření. K detekci kontaktních sil

během oporových fází v obou krocích byla použita dynamometrická deska (Kistler 9281 EA – Winterthur, Švýcarsko). Výpočty silových impulsů, produkce rychlosti a průměrného zrychlení byly provedeny v programu Matlab (The MathWorks, Inc., Natick, USA). V Matlabu jsme provedli i následný párový T-test a korelační analýzu.

VÝSLEDKY: Statisticky významné diference ($\alpha = 0.01$) mezi první a druhou oporou byly nalezeny v délce kontaktu, produkci horizontální rychlosti a průměrném zrychlení. Produkce horizontální rychlosti činila v prvním kroku 1.117 ± 0.081 ms^{-1} a 0.835 ± 0.074 ms^{-1} během druhého kroku. Průměrné zrychlení ukázalo negativní korelaci s tělesnou výškou atleta ($r = -0.42$). Pokud se během prvních 20–40 ms oporové fáze objevil brzdný impuls, docházelo k prodloužení trvání oporové fáze a celkovému nižšímu průměrnému zrychlení.

ZÁVĚRY: Výskyt brzdné fáze v prvních krocích po výběhu z bloků je považován za technický nedostatek. Atleti vyššího vzrůstu jsou pro akcelerovaný běh lehce znevýhodněni. Oporové fáze prvního a druhého kroku vykazují významné odlišnosti v dynamických parametrech.

Klíčová slova: biomechanika, dynamika, nízký start, akcelerovaný běh.

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