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PLANTAR PRESSURE REDISTRIBUTION DURING RUNNING AS A RESPONSE TO CHANGE OF LOCOMOTION IN TRIATHLON

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SUMMARY

Background

A triathlon is a multi-sport endurance event where a change of locomotion, especially a change from biking to running, affects coordination and running efficiency. However, information about how the change of locomotion influences foot load is missing. Thus the aim of this study was to determine if the plantar pressure distribution during running changes as a consequence of change of locomotion after biking part of a triathlon race.

Methods

10 competitive triathletes (8 male and 2 female) at age 22–46 years underwent competition simulated laboratory test which included 10 min of running, 50 min of cycling and 10 min of running at intensities corresponding to their racing speeds. Plantar pressure at 5 segments of the foot (hindfoot, midfoot, medial forefoot, lateral forefoot, and toes) were detected during running before and after the cycling using Pedar-X Novel tensometric system.

Results

Maximal pressure values within entire plantar area after cycling were not significantly different. However, maximal pressure values in medial and lateral forefoot were significantly higher ($p < 0.05$) on both feet. The maximal pressure measured on hindfoot after cycling was also higher, although, the increase was significant only on left foot ($p < 0.05$ left, $p < 0.15$ right). Contrary, the maximal pressure measured after cycling on toes was significantly lower on both feet ($p < 0.05$).

Conclusion

The results indicate a shift of footload from toes dorsally to forefoot and hindfoot during running as a consequence of fatigue resulting from previous intensive cycling. Although the results of this study revealed a significant change in plantar pressure distribution in triathletes after the bike-run transition, further research is needed to determine the effect of cycling on foot loading during running.

Key words: plantar pressure, stance phase of running, triathlon, tensometrics, Pedar-X system

INTRODUCTION

A triathlon is a multi-sport endurance event involving swimming, biking and running in immediate succession. In triathlon, a change of locomotion, especially a change from biking to running, plays an important role in overall performance. After cycling, it usually takes at least several minutes before triathlete's running technique can reach its optimal level. Thus, in triathlon, the optimal managing of cycling to running change is a prerequisite for a good performance. Different time-spatial, neuromuscular and energy demands of cycling performed by similar muscle groups of lower limbs as in running, represent higher demands on running movements coordination following the cycling which in combination with global, as well as local muscle fatigue leads to decrease of running performance. Research has shown that a triathlete is therefore more susceptible to injury, in particular of lower back or knee, during first kilometers of running, just after the transition (Miglioroni, 2011).

Most triathletes, including highly trained ones, report a perception of impaired coordination when running after cycling (Chapman, 2009). Although, this phenomenon is largely caused by a fatigue, a significant part in the altered coordination also takes the neuromotor control. Interference in learning is a phenomenon that occurs when newly learned information interferes with and impedes the recall of previously learned information. Similar effect may occur in short-term adaptation when performing a learned activity, and may temporarily affect the performance in another learned activity that follows (Karniel, 2002). In triathlon, the bike-run transition is primarily related to physiological adaptation, however, it may also be associated with ongoing neuromotoric adaptation (Millet, 2000; Bonacci, 2009). Cyclic motions in humans, as well as, in animals are provided by a neural structure called CPG (central pattern generator) located in spinal column (Calancie, 1994). One possible explanation of gradual adaptation to change of motion has been described by Gottschall (2000): "The CPG possibly dictates the frequencies involved for the activities, in this study cycling and running. This structure in the central nervous system determines the order of muscular contractions, thereby coordinating various rhythmic movements. Thus, the firing rate of the CPG gradually transforms from the optimal cycling frequency to the optimal running frequency".

Bernard, Vercruyssen, Grego, Hausswirth, Lepers, Vallier, & Brisswalter (2003) investigated the effect of cycling cadence on a subsequent 3000 m running performance in triathletes. They found no significant effect of cycling cadence on middle distance running performance. However, they indicated that during the first 500 m of the run, stride rate and running velocity were significantly higher after cycling at higher cadence. Also, they demonstrated a significant alteration in running performance completed after the cycling event.

Lower cadence of cycling during the last 10 minutes of cycling is associated with the lower metabolic load (reduced VO_2, ventilation, heart rate, and blood lactate concentrations) and leads to the longer time to fatigue in the following run (Vercruyssen, Suriano, Bishop, Hausswirth & Brisswalter, 2005). They suggested that the mechanisms, such as changes in muscular activity, contribute to the effects of cadence variation on time to fatigue.

Previous research has shown that some characteristics of running locomotion and neuromuscular activity are altered by neuromuscular and metabolic fatigue resulting from an intensive cycling. Hottenrott, Hoos and Sommer (2001) indicated that fatiguing cycling leads to decrease of stride frequency, increase of stride length and stance time in subsequent running. They have suggested that these changes in locomotion structure result from an altered stability of initial ground contact manifested by dysbalance between tension ratio of flexor and extensor muscles in order to stabilize the joints during the initial ground contact. They concluded that neuromuscular fatigue alters motor control, leads to the development of muscular disbalance and increases the risk of musculoskeletal overload.

Neumann, Pfützner and Hottenrott (2004) investigated the effect of previous cycling on plantar pressure magnitude during the stance phase of subsequent running. They demonstrated a difference between maximal values of plantar pressure in an experienced triathlete with a good running technique and other individual with lack of running experience and poor running technique (Figure 1). Moreover, Neumann and Hottenrott (2002) emphasized the importance of running technique for foot load during running performed 0:30 min, 1:30 min and 2:30 min after intensive cycling when compared the plantar pressure values in an experienced triathlete and inexperienced jogger (Figure 2).

In endurance events that involve running, significant change in running style and technique may occur due to muscle fatigue. Affected running technique results in decreasing movement efficiency and running economy and consequently impairs performance. Previous research has shown that running technique is associated with running economy (Saunders, Pyne, Telford & Hawley, 2004). Recent research has comprehensively investigated the relation between running mechanics and economy. It has been well demonstrated that various biomechanical factors are positively associated with running economy. Many of these factors are closely related to lower leg and foot. These include: Angular velocity

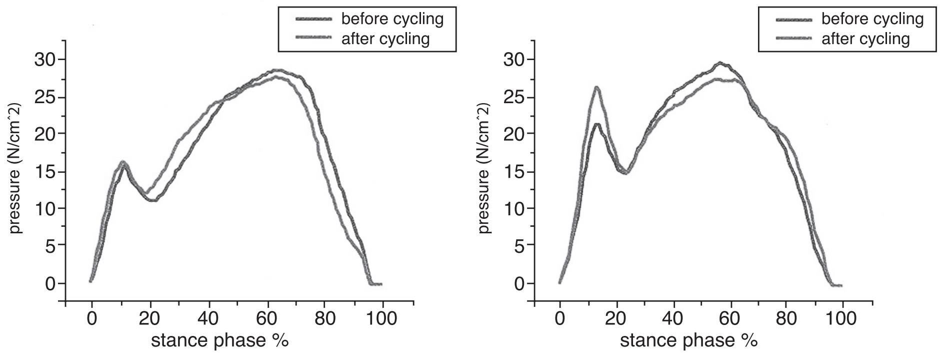

Figure 1. Pressure-time curve based on mean pressure values from four steps made at the same speed (3.3 m/s) before and immediately after an intensive cycling in a triathlete with a good running technique (left) and in-line skater (right). (Neumann, Pfützner & Hottenrott, 2004).

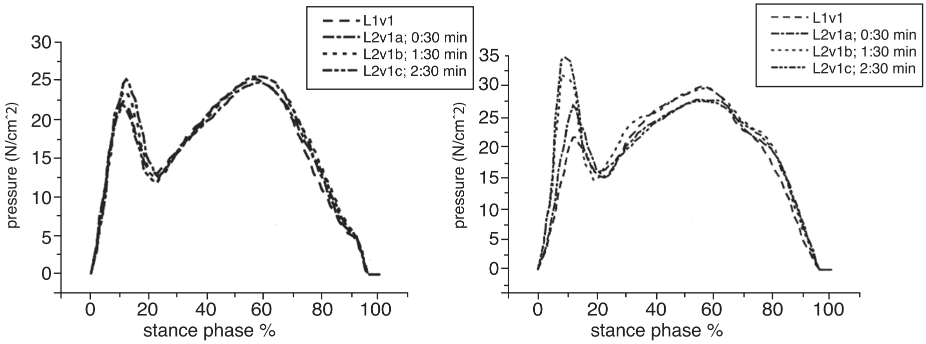

Figure 2. Pressure-time curve based on mean pressure values from four steps made at the same speed (v1 = 3.3 m/s) before (L1) and immediately after (L2) an intensive cycling in a distance runner with a good running technique (left) and a recreational runner (right). (Neumann & Hottenrott, 2002).

of plantar flexion during toe-off, low peak ground reaction forces, effective exploitation of stored elastic energy, foot contact time, shank angles at heels strike, foot strike position, horizontal heel velocity at foot (Kyrolainen, Belli & Komi, 2001; McCann & Higginson, 2008; Saunders, Pyne, Telford & Hawley, 2004).

In recent studies various techniques have been used to examine foot strike pattern during running in an effort to evaluate efficiency of running technique and to prevent injuries resulting from abnormal action of lower leg. Lower leg overuse injury has been reported to be very common in distance runners and triathletes, especially those who are former swimmers and cyclist (Miglioroni, 2011). One of the most frequent injuries in distance runners and triathletes is metatarsal stress fracture. It has been previously shown that this injury is related to excessive foot loading that can be characterized by ground reaction forces and peak pressure in specific areas of the foot. Nagel, Fernholz, Kibele, & Rosenbaum (2008) investigated the effect of long distance running on plantar pressure patterns using a capacitive platform. Two hundred recreational runners were involved in this study. Their plantar pressure during walking was measured before and after a marathon race. They found a significantly higher peak pressure and impulse values in the forefoot regions compared to those under the toes after the race. These results suggest that there is a load shift from the toes to metatarsal heads during the marathon race. An increased loading of the metatarsal bones after the long distance race may become a cause of metatarsal stress fracture (Nagel, Fernholz, Kibele & Rosenbaum, 2008). Rearfoot pronation following foot strike is a part of the running motion that has been shown to be associated to frequent knee and foot injury (Williams, 2007). It has been previously reported that more than 90% of running related injuries are localized in the lower extremity, equally affecting the knee, shank or foot (Nagel, Fernholz, Kibele & Rosenbaum, 2008).

There is a lack of information in the literature how the change of locomotion during bike-run transition influences a foot load and changes running technique. Therefore, the aim of this investigation was to determine whether any changes in plantar pressure distribution occur in triathletes during the stance phase of running as a consequence of fatigue and altered coordination resulting from previous cycling.

MATERIALS AND METHODS

Subjects

12 well-trained competitive triathletes (10 male and 2 female) at age 22 to 46 years participated in this study. All the subjects had been regularly training and competing at the national to international level (mean age: 30.7 ± 6.53 yr; mean weight: 71.5 ± 7.84 kg; mean height: 177.4 ± 5.54 cm). 2 of them were specialized on off road triathlon, 2 on sprint triathlon, 2 on Olympic triathlon, 2 on long distance triathlon and 2 on ironman triathlon. 2 subjects were excluded from the experimental group due to insufficient objectivity of obtained data. All participants performed, in a laboratory setting, competition simulated test which included 10 minutes of running, 50 minutes of cycling and again 10 minutes of running at intensities similar to their racing speeds. Plantar pressure at 5 segments of the foot (hindfoot, midfoot, medial forefoot, lateral forefoot, and toes) was measured during running before and after the cycling using Pedar-X Novel tensometric system. Subjects' basic characteristics are in table 1.

Table 1. Basic characteristics of subjects

Subject	**D. G.**	**D. S.**	**J. F.**	**J. S.**	**M. K.**	**M. M.**	**M. P.**	**P. K.**	**P. S.**	**R. Š.**
Sex	male	female	male	male	male	female	male	male	male	male
Age (years)	33	31	34	46	34	28	22	30	23	26
Height (cm)	173	179	176	185	178	165	184	177	175	182
Weight (kg)	63	74	82	77	81	58	78	70	69	63
Racing distance	Olympic	Off-road	Off-road	Sprint	Ironman	Olympic	Sprint	Long distance	Long distance	Ironman
Number of transition workouts per month	0	1	4–5	0	5	0	6–7	10	4	0
Duration of specialized training (years)	5	5	3	6	1	4	3	10	8	5
Maximal heart rate	180	186	199	175	198	191	203	190	196	194

Ergometers

All experimental cycling bouts were conducted on cycle ergometer equipped with an electromagnetic brake (Kettler Ergorace, Germany). Handlebars and racing seat on this ergometer were vertically and horizontally adjustable to reproduce conditions known to subjects from their own bicycles. Ergometer was also equipped with pedals with toe clips allowing subjects to wear any kind of shoes that would be comfortable for cycling. The ergometer allowed athletes to maintain constant or arbitrarily change the power output, independent of cycling cadence. Power output, heart rate, speed, and cadence data were continuously available on a screen control.

All experimental running bouts were performed on a motorized treadmill (h/p/cosmos pulsar 4.0, Germany). Running speed could be set and alternatively regulated manually according to subject's indications.

Heart rate was detected by Polar heart rate monitor fully compatible with cycle ergometer, as well as, treadmill.

Plantar pressure determination

An analysis of plantar pressure distribution was accomplished in each of the triathletes during the stance phase of the initial (before cycling) and final (after cycling) running bout by using Pedar-X system produced by Novel co. Pedar-X system is a device that is able to detect and analyze pressure distribution between the foot and the ground during the foot loading with frequency 50 Hz. By means of this system, plantar pressure distribution and some other spatio-temporal characteristics can be recorded and depicted, during the stance phase of walking or running.

The system consists of two elastic tensometric insoles, recording device with a built-in Bluetooth system and a flash memory storage, and software for processing data. The insoles that are inserted in the shoes cover the entire sole area. The area of each insole is divided into 99 fields equipped with pressure sensors for actual pressure measurements. Both insoles are connected via a cable with recording device which is fixed to a subject's waist by an elastic band. Pedar-X system can be connected with a PC via an optical USB cable. The device is also able to communicate with a desktop or laptop PC through Bluetooth signal. Internal memory storage for collecting data has capacity 32 MB. This capacity, at scanning frequency 50 Hz, allows collecting data of about 1 hour of continuous activity.

In order to process collected data, version 19.3.30 of Pedar-X Standard software was used in this experiment. It has various features for quick collecting, evaluating, and presenting data recorded by the tensometric system. Among others, it allows running and viewing of an obtained record in real time or tracing a detailed course of every step from the moment of the first contact to the moment of the last contact of foot with ground. For more detailed analysis, the area of the insole can be divided into number of segments. The software then enables to analyze all measured variables for each of the segments separately, as well as, generally. Also, it enables to watch the detected data directly on PC screen or globally process and analyze it by using the database program unit – Novel database essential.

Procedure

Changes in plantar pressure distribution were evaluated during running on treadmill before and after cycling on cycle ergometer. After inserting in the shoes, tensometric insoles were calibrated. All subjects were instructed to wear neutral type of running shoes for testing. In all the triathletes, the testing was scheduled for the beginning of racing period. In order to prevent distorting of results due to accumulated fatigue, the testing was conveniently scheduled in their training plan, so that they had a day off or just an easy workout at least a day before the testing.

Before the measuring had been started, each subject ran 10 minutes warm-up which also enables to control a functioning and proper fastening of all parts of the device. Based on their actual fitness and reported maximal heart rate values, the individual loading

Table 2. Loading characteristics

Subject	Running speed (km/h)	Power output during cycling (W)	Heart rate (beats/min)	Lactic acid (mmol/l)
D. G.	18–18 18–18	190–195–195	154–162 145–148–151 161–168	3.4–3.0
D. S.	13–13.5 13–13	180–180–180	153–161 160–169–165 169–171	2.0–2.1
J. F.	15–15 15–15	195–200–200	188–193 182–189–190 196–197	3.2–3.1
J. S.	13–13 11–11	250–220–220	161–166 166–169–168 165–167	3.2–3.6
M. K.	15–15 15–15	220–210–210	167–170 158–153–157 170–176	1.6–1.3
M. M.	15–15 14–14	140–140–140	177–180 168–163–158 175–179	3.0–2.9
M. P.	17–17 16–16	190–200–200	161–167 140–150–144 170–177	1.7–1.6
P. K.	17.5–17.5 17.5–17.5	145–175–150	165–179 134–144–133 176–183	1.9–2.2
P. S.	18.5–19 18.5–18.5	235–230–210	165–170 160–158–154 169–171	6.5–3.8
R. Š.	14–14 14–14	160–160–160	174–171 171–175–173 179–184	3.0–2.7

Running speed measured at 5th and 10th minute of the initial and the final running bout.
Power output during cycling measured at 25th, 45th and 50th minute of cycling.
Heart rate measured at 5th and 10th minute of the initial running, 25th, 45th and 50th minute of cycling, and 5th and 10th minute of the final running.
Lactic acid measured at 25th and 45th minute of cycling.

intensity was determined in each subject. The metabolic intensity during these cycling and running bouts corresponded approximately to the cycling and running competition intensity of our subjects during the Olympic triathlon (80 to 95 HRmax). All subjects were therefore instructed to keep the intensity of locomotion on treadmill, as well as on cycle ergometer, as close as possible to their racing intensity and their heart rate within 80 to 95% of their maximal heart rate. During running on treadmill, the intensity was controlled by adjusting running speed (km/h) while during cycling on cycle ergometer by adjusting the power output (watts). Each subject started the test with 10 minute running bout at his or her racing intensity corresponding to individual race pace of the Olympic triathlon. After the completion of running, tensometric device was taken off while the subject changed his or her running shoes for shoes individually chosen for cycling and then started cycling. Each subject completed a 50 minute cycling bout at the freely chosen cadence still at the racing intensity corresponding to individual race pace in the Olympic triathlon. After the completion of cycling, subject put on running shoes with tensometric insoles inside, tensometric apparatus was fastened and calibrated and the subject immediately started running at the racing intensity. Final running was started within 2 minutes after cycling. HR was controlled by using the Polar heart rate monitor. HR were monitored and recorded every 5 minutes during the running sessions and at 25th and 45th minute of cycling bout.

Two blood samples were collected at 25th, and 45th minute during cycling in order to control the load during cycling and before the final running. Subjects' loading characteristics are in table 2.

During the test, the detected pressure data was directly collected and saved in the internal memory storage of the portable device for data collecting and saving that was connected with tensometric insoles via a cable. Consequently, collected data was transferred by means of Bluetooth signal to the hard drive of a PC and by using software Pedar-X Standard processed and interpreted. Finally, 200 steps (100 left and 100 right) period was selected in each subject from last 5 minutes of the initial, as well as, final run and statistically processed by using the database program unit Novel database essential. Consequently, maximal and mean values of observed variables were obtained from the number of steps.

Observed variables

Following variables were observed in each subject:

1. **Plantar pressure distribution**
   Changes were evaluated visually on a graphic spatial representation created by software using 8-degree color scale corresponding with the individual pressure levels, and on the graphic picture of trajectory of the center of mass during the stance phase.
2. **Average maximal pressure within entire plantar area**
   Changes were evaluated by means of numeric values and the graphical representation.
3. **Average maximal pressure in five plantar segments** (hindfoot, midfoot, medial forefoot, lateral forefoot, and toes).
   Changes were evaluated by means of numeric values and the graphical representation.

Data analysis

Average pressure values for 5 foot areas (hindfoot, midfoot, medial forefoot, lateral forefoot, toes) of all subjects were calculated. Peak pressure values from 100 right foot and 100 left foot steps were extracted, using "peakdet" Matlab function in GNU Octave, version 3.2.4 software. Welch two-sample statistical test was performed to analyze collected data. The 0.1 level of significance was used for all repeated measures of plantar pressure at all the foot segments in left and right foot respectively.

RESULTS

Mean values of measured maximum pressures (in kPa) during initial and final running period and corresponding Liliefors' t-test p-values are shown in Table 3.

Table 3. Mean values of measured pressures in kPa before and after cycling bout and corresponding t-test p-values

Foot segment	Side	Pressure (kPa)		p-value
		before	after	
Hindfoot	R	136	139	0.15
	L	125	133	< 0.05
Midfoot	R	89	88	0.15
	L	86	92	< 0.05
Medial forefoot	R	154	167	< 0.05
	L	146	160	< 0.05
Lateral forefoot	R	167	173	< 0.05
	L	161	174	< 0.05
Toes	R	136	106	< 0.05
	L	131	121	< 0.05
Total object	R	337	344	0.60
	L	344	342	0.80

Statistical test (Welch two-sample test) suggests significant differences ($p < 0.05$) of mean values of step maximal pressures before and after cycling period. In three areas – hindfoot, medial and lateral forefoot – maximal pressure increased; in midfoot, there were different results between right (decrease) and left (increase) foot; pressure in toes area decreased. Differences between average maximal pressure values of the total plantar area were not statistically significant (Figure 3a, 3b; Figure 4a, 4b, Colour Appendix)

DISCUSSION

The results have shown that foot load during running following cycling in triathlon competition may be shifted from toes to the forefoot. This dorsal shift of the foot load may result in overloading metatarsals during triathlon race and may be associated with certain injuries including metatarsal stress fractures.

In the experimental group of this pilot study, male and female triathletes of different ages and racing experience were included. One of the biggest problems in terms of the objectivity of testing was the tensometric device itself. It had to be carried during the entire testing. First, it was tensometric insoles that were inserted into shoes, then cables for connecting the insoles with recording device that were fixed by elastic bends to lower extremities of a subject, and finally the device for collecting and storing data, which was fixed to a subject's waist. Although, this device, as stated by manufacturer, weighs only 400 g, it could affect running technique and distort observed variables.

Concerning the measurement, one of the most limiting factors was the size of the tensometric insoles. Each size of the insole covered two real sizes of foot. Also, the shape of the insole not always corresponded to the anatomical shape of the subject's foot which could significantly affect the results. Moreover, the foot load assessment by using this tensometric device is based on detection of vertical components of exerted forces. However, the foot load is more complex, as reported by Jelen et al. (2007), who suggested that a load of foot segments should be considered in 3D involving other components of applied forces. A method of detecting changes of foot morphological characteristics by means of computational 3D modeling has been previously described by Jelen et al. (2006).

Another limiting factor may be a repeatability of the pressure measuring system. Earlier studies have indicated that measurement performed by using the Pedar-X in-shoe pressure measuring system is repeatable, however, some investigations have uncovered a lower repeatability at the toe 2, 3, 4 and 5 region of the foot, and the middle degree repeatability at the big toe region of the foot. These values is therefore necessary consider carefully (Putti, Arnold, Cochrane & Abboud, 2007; Ramanathan, Kiran, Arnold, Wang & Abboud, 2010).

In all the subjects the aim was to make them complete the initial and the final running, as well as the cycling part of the test at high intensity corresponding to their racing speeds at the Olympic distance triathlon. However, some of the subjects had difficulties to keep their heart rate within the determined range. Moreover, the lactic acid concentration in some of the subject did not indicate the required degree of fatigue.

Testing procedure in laboratory settings could be another substantial problem. Cycling and running technique, as well as, pressure and temporal characteristics of stance phase can differ on ergometer from those obtained while exercising outdoors. In order to get more objective information, this experiment should be carried out in outdoor conditions including different kinds of surfaces and various course profiles.

The type of shoe is concededly another important factor with regard to the objectivity of results. Some mechanical properties of a shoe, such as hardness and elasticity of midsole or insole, may influence kinetics and kinematics of the foot during the stance phase of running (MacLean, Davis & Hamill, 2009; Dixon, 2008). The results of testing may even be affected by a way of lacing and its tightness (Hagen & Hennig, 2009). During the experiment all the subjects underwent loading in neutral training shoes, which means without any motion control components. Nevertheless, during testing, each subject wore shoes from different producer, thus the effect of different shoe characteristics could not be excluded. To maximize the objectivity of detected data, all subjects would have to be tested in the same shoes made in the same year and with the same degree of wear-out.

With regard to a low number of subjects participating in this pilot study, the results cannot be generalized for competitive triathletes or general population.

CONCLUSION

Based on the observations made during this experiment we came to a conclusion that in competitive triathletes the footload during running after cycle to run transition tends to shift from toes to forefoot, possibly due to altered coordination associated with a change of locomotion and fatigue resulting from previous cycling. Since Novel Pedar-X tensometric system allows to perform such an experiment in outdoor conditions, we recommend for the future research to perform this experiment in outdoor conditions that would better simulate racing conditions. The suggested investigation using Novel Pedar-X tensometric system could be beneficial for an assumption and maintenance of the efficient running technique, prevention of structural and functional changes of foot developed in consequence of prolonged and inadequate load, and primarily for improving running performance after cycle to run transition in triathlon race.

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REDISTRIBUCE PLANTÁRNÍHO TLAKU PŘI BĚHU JAKO ODEZVA NA ZMĚNU LOKOMOCE V TRIATLONU

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SOUHRN

PROBLÉM

Triatlon je vytrvalostním vícebojem, kde změna lokomoce, obzvláště přechod z cyklistiky na běh ovlivňuje koordinaci a běžeckou účinnost. Chybí však informace o tom, jakým způsobem ovlivňuje změna lokomoce zatížení nohy. Cílem této studie je proto zjistit, zda se v důsledku změny lokomoce po cyklistické části triatlonového závodu mění distribuce plantárního tlaku při běhu.

Metody

10 výkonnostních triatlonistů (8 mužů a 2 ženy) ve věku 22–46 let absolvovali laboratorní test simulující závod, který zahrnoval 10 min běhu, 50 min jízdy na kole a 10 min běhu intenzitou odpovídající jejich závodní rychlosti. Plantární tlak v 5 segmentech nohy (zánoží, středonoží, mediální přednoží, laterální přednoží a prsty) byl detekován při běhu před a po jízdě na kole pomocí tenzometrického systému Novel Pedar-X.

Výsledky

Hodnoty maximálního tlaku celé nášlapné plochy po jízdě na kole nebyly významně rozdílné. Hodnoty maximálního tlaku na mediálním a laterálním přednoží však byly významně vyšší ($p < 0.05$) na obou nohách.

Maximální tlak naměřený po jízdě na kole na zánoží byl také vyšší, ačkoli zvýšení bylo statisticky významné pouze na levé noze ($p<0.05$ levá, $p < 0.15$ pravá). Naproti tomu maximální tlak naměřený po jízdě na kole na prstech byl na obou nohách významně nižší ($p < 0.05$).

Závěr

Výsledky ukazují na posun zatížení nohy při běhu z prstů dorzálně na přednoží a zánoží v důsledku únavy vycházející z předchozí intenzivní jízdy na kole. Ačkoli výsledky této studie odhalují významnou změnu v distribuci plantárního tlaku u triatlonistů po přechodu z kola na běh, je zapotřebí dalšího výzkumu ke stanovení účinku jízdy na kole na zatížení nohy při běhu.

Klíčová slova: plantární tlak, oporová fáze běhu, triatlon, tenzometrie, Pedar-X systém

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