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Can parallel use of different running shoes decrease running-related injury risk?

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The aim of this study was to determine if runners who use concomitantly different pairs of running shoes are at a lower risk of running-related injury (RRI). Recreational runners (*n* = 264) participated in this 22-week prospective follow-up and reported all information about their running session characteristics, other sport participation and injuries on a dedicated Internet platform. A RRI was defined as a physical pain or complaint located at the lower limbs or lower back region, sustained during or as a result of running practice and impeding planned running activity for at least 1 day. One-third of the participants (*n* = 87) experienced at least one RRI during the observation period. The adjusted Cox regression analysis revealed that the parallel use of more than one pair of running shoes was a protective factor [hazard ratio (HR) = 0.614; 95% confidence interval (CI) = 0.389–0.969], while previous injury was a risk factor (HR = 1.722; 95%CI = 1.114–2.661). Additionally, increased mean session distance (km; HR = 0.795; 95%CI = 0.725–0.872) and increased weekly volume of other sports (h/week; HR = 0.848; 95% CI = 0.732–0.982) were associated with lower RRI risk. Multiple shoe use and participation in other sports are strategies potentially leading to a variation of the load applied to the musculoskeletal system. They could be advised to recreational runners to prevent RRI.

Running is characterized by the repetition of a large number of almost identical movements with very few variations. Consequently, most of the running-related injuries (RRIs) are cumulative micro-trauma injuries (progressive in nature), and thus, could be classified as overuse injuries (Hreljac, 2004). The latter occur when repetitive stress is applied to a muscle, tendon, or bone resulting in micro-traumatic damage followed by insufficient time to heal or repair (Hreljac, 2004). Various studies have estimated that 27–70% of recreational and competitive runners sustain overuse injuries during 1 year of practice (Ferber et al., 2009). Different strategies could be used to prevent overloading and to vary the stress applied to the body. For example, it has been reported that non-injured runners participated significantly more often in other sports in comparison with injured runners (Jacobs & Berson, 1986). However, contradictory results have also been found (Satterthwaite et al., 1999), and this point needs further study (van Mechelen, 1992; van Gent et al., 2007).

A number of reports have shown that shoe characteristics influence the magnitude and the type of stresses applied to the musculoskeletal system (Wakeling et al., 2002; Kong et al., 2009; Lieberman et al., 2010; Rethnam & Makwana, 2011; Bonacci et al., 2013). For example, it has been recently demonstrated that running with flat-midsole footwear for 3 months result in a ~30% lower shock magnitude at the heel (Giandolini et al., 2013). Other authors have shown that the characteristics of cushioned running shoes induce an adaptation of running style (Wiegerinck et al., 2009; Perl et al., 2012). It has also previously been demonstrated that slight modifications in shoe mechanics as a result of shoe usage leads to kinematic changes. As a consequence of shoe degradation, stance time was increased and the ankle displayed lower maximum dorsiflexion and greater plantar flexion at toe-off (Kong et al., 2009). Midsole hardness was also shown to induce changes in lower-extremity muscle activity (Wakeling et al., 2002). Because these studies demonstrated that shoe characteristics impact on running pattern, a regular change of running shoes might cause variation of repetitive external loads which, according to the overuse injury mechanism, could decrease its incidence.

Few studies have investigated the relationship between shoe use and RRI risk (van Gent et al., 2007), yielding inconsistent results. To date, no information regarding the effect of alternation between several pairs of running shoes on RRI risk is available. Therefore, the purpose of the current study was to establish the relationship between parallel use of different running shoes and RRI incidence. It was hypothesized that runners using concomitantly more than one pair of shoes would be at a lower risk of sustaining a RRI. A secondary hypothesis was that the practice of other sports would be a protective factor as this also allows a variation of the type of stress applied to the body.

Material and methods

Participants and study design

This prospective 22-week follow-up study targeted all types of amateur runners. The advertisement for recruitment of runners was done through the local media and the website of the ING Marathon Luxembourg. Healthy participants above 18 years old with any level of fitness were eligible to take part in the study, without any obligation to participate in the race. All participants received a full description of the study objectives and protocol, and provided signed informed consent for participation at the moment of their registration for the study on an online sports diary (TIPPS – Training and Injury Prevention Platform for Sport). A total of 455 participants created their account on the website during the recruitment phase. They were asked to familiarize themselves with this online tool in December 2011 while the data collection period lasted throughout the following 5 months. This sample size was estimated sufficient to answer our main hypothesis considering the following assumptions: given a desired power of 0.8 and an α-level of 0.05, to detect a significant difference for injury incidence between participants using more than one pair of shoes and those using only one, based on expected injury rate of 37% over the 5-month follow-up period (van Gent et al., 2007) and a hazard ratio of 0.62, the total number required is 360 runners. The background information of the participants was collected at the time of registration, while running experience (years of regular practice) and regular running practice over the last 12 months (number of months with at least one session a week) were recorded via electronic questionnaires during the follow-up. Additionally, participants were asked to upload information regarding previous injury to the lower back or lower limbs preventing them from normal running activity and sustained during the 12 months preceding the follow-up in the TIPPS. Participants also received explanations about the main study requirements: (1) to train on average at least once a week; (2) to upload training data pertaining to running and all other sports practice at least once a week; and (3) to systematically report any injury sustained during the follow-up period. The study protocol and online procedures had previously been approved by the National Ethics Committee for Research (ref. 201111/10).

Recording of sport participation and injury information

The TIPPS is a specially designed Internet-based electronic database, which allows for uploading, reviewing, and managing of information related to training and sports injuries (Malisoux et al., 2013; Theisen et al., 2013). All participants had access to the TIPPS on the Internet via a personal username and password. The researchers had access to each participant's contact details and could follow information on sport participation and injuries in real time. Data were rendered anonymous during the extraction process before the statistical analyses. Throughout the follow-up, participants were instructed to upload all running or other sporting activities undertaken onto their TIPPS account. Required information included the type of activity, context, duration, subjectively perceived intensity, distance, shoe pair used, running surface (hard or soft), and whether the participant had experienced any pain during the session forcing him/her to reduce practice volume or intensity, or to interrupt the practice. Session intensity was determined using the Borg's rating of perceived exertion scale, a purely subjective 10-point scale (Foster, 1998). Multiple shoe users were identified as those who reported a minimum of two different pairs of running shoes (different brand, model or version) in the system and who alternated a minimum of two times between them over the observation period. Indeed, some participants had to replace their old pair of shoes and were characterized by a unique change of shoe pair.

All adverse events preventing participants from normal running activity were reported by the participants via a dedicated questionnaire on their TIPPS account. A new injury could be declared either via the sport session interface (see earlier) or a dedicated injury declaration page. A RRI was defined as a physical pain or complaint located at the lower limbs or lower back region, sustained during or as a result of running practice and impeding planned running activity for at least 1 day (time–loss definition) (Bovens et al., 1989; Buist et al., 2010). These RRIs were classified according to the latest consensus on sports injury surveillance studies (Fuller et al., 2006, 2007, 2008). Once an injury was registered, the system considered the injury ongoing, and generated an automatic e-mail to ask participants to close their injury file by specifying the exact day of return to sport.

Data quality control

Individual e-mail reminders were sent to the participants who had not provided the system with any data for the previous week. Personal phone calls were made if the participants did not react to the e-mail reminders and if the reported information in either the training log or on the injury form was found to be inconsistent. Injury data was systematically checked by one of the investigators for completeness and coherence. Participants who did not complete their entire running calendar with weekly information were contacted by one of the investigator to ensure that a RRI was not the reason for non-compliance or dropping out.

Statistics

The study group characteristics were compared using Student *t*-tests for independent samples and chi-square tests after checking the data for normal distribution. RRI incidence was calculated as the number of RRIs per 1000 h of exposure to running activity. The period of interest was defined as the period from the beginning of the follow-up until the first RRI (event), the end of the observation period or the moment of drop out. A participant was considered as dropping out of the study when no data was uploaded in the system for more than 2 weeks despite the automatic reminder sent by the system and a phone call from the research team. A Cox proportional hazard regression analysis was used to identify injury risk factors among participants' characteristics and sport participation characteristics over the period of interest. Exposure volume to running activities (hours) during the period of interest was used as the outcome variable. First, unadjusted analyses were performed, entering each variable separately into the Cox regression model. For the final adjusted model [forward likelihood ratio (LR) method], all variables with a *P*-value below 0.250 were introduced in the model (Buist et al., 2010). Additionally, previous regular running practice and previous injury were introduced in a first block (enter method) to control for these factors. Forward LR method was chosen because of the low number of events (87 RRIs) observed during the period of interest and the high number of potential predictors ($n = 10$) identified with the unadjusted model. Results are presented as mean ± standard deviation. Significance was accepted for $P < 0.05$.

Results

Of the 455 participants who created an account in the TIPPS and registered to the study, 154 did not take part in the study as they did not upload any sporting activities during the observation period. Additionally, 37 participants recorded less than two running sessions in total and were excluded. Therefore, a total of 264 amateur runners

Table 1. Participants' characteristics and sport participation pattern ($n = 264$)

Characteristics	Unit/qualifier	Single shoe users (N = 116)	Multiple shoe users (N = 148)	P-value
Participants' characteristics				
Age	Years	40.5 ± 9.8	44.2 ± 8.8	0.002
Sex	Male	80 (69.0%)	115 (77.7%)	0.122
	Female	36 (31.0%)	33 (22.3%)	
BMI	kg/m^2	23.0 ± 2.6	22.9 ± 2.4	0.717
Previous Injury*	Yes	53 (45.7%)	67 (45.3%)	0.608
	No	52 (44.8%)	77 (52.0%)	
Running experience†	Years	6.6 ± 8.9	7.3 ± 9.8	0.561
Regularity (last 12 months)‡	Months (1–12)	9.4 ± 3.8	10.8 ± 3.0	0.001
Half-marathon (last 12 months)§	Yes	61 (52.6%)	120 (81.1%)	<0.001
	No	38 (32.8%)	22 (14.9%)	
Sport participation pattern				
Mean number of shoe pairs	Unit	1.3 ± 0.5	3.6 ± 1.6	<0.001
Use of main shoe pair	%	91 ± 17%	58 ± 19%	<0.001
Volume of other sports	h/week	1.20 ± 1.51	1.69 ± 2.43	0.045
Mean session frequency	sessions per week	1.94 ± 1.06	2.82 ± 1.18	<0.001
Mean session distance	km	9.8 ± 3.2	11.7 ± 3.0	<0.001
Mean session duration	min	58.6 ± 15.9	69.7 ± 17.5	<0.001
Mean session intensity	Borg CR10 scale – a.u.	3.82 ± 1.02	4.04 ± 0.93	0.072
Mean running speed	km/h	10.1 ± 1.5	10.2 ± 1.4	0.477
Running on hard surface	% of total sessions	56.8 ± 34.6	61.1 ± 28.8	0.282
Competitions	% of total volume	4.9 ± 8.5	9.8 ± 11.4	<0.001

*15 missing data; †17 missing data; ‡16 missing data; §23 missing data; a.u., arbitrary unit.

were finally included in the analyses. The characteristics of the single shoe users ($n = 116$) and the multiple shoe users ($n = 148$), as well as their sport participation pattern are presented in Table 1. As expected, multiple shoe users wore a higher number of different pairs of shoes during the observation period when compared with single shoe users (3.6 ± 1.6 vs 1.3 ± 0.5 pairs of shoes, $P < 0.001$). The proportion of usage of the predominant pair of shoes was lower in the multiple shoe users group (58 ± 19% vs 91 ± 17%, $P < 0.001$). Multiple shoe users were more regular in their running training over the 12 months prior to the study ($P = 0.001$), more experienced in half-marathon ($P < 0.001$) and competitions ($P < 0.001$). Furthermore, they had a higher volume of other sports practice ($P = 0.045$), and a greater running training load regarding frequency ($P < 0.001$), distance ($P < 0.001$) and duration ($P < 0.001$) during the observation period (see Table 1).

Of the 264 participants included in the analyses, 87 (33%) experienced at least one RRI during the 5-month follow-up period. The overall incidence was 7.64 RRI/1000 h of running during the period of interest. The latter ranged from 1 week (for a few participants who sustained a RRI during the first week of follow-up) to 22 weeks for those who were not injured and remained compliant over the whole observation period (mean: 15.5 ± 7.4 weeks). Table 2 presents the characteristics of the first RRI reported by the participants. More than 2/3 of these RRIs affected muscles and tendons (67.8%) and 2/3 of all RRIs were progressive in nature, while about 36.8% of all RRIs required more than 1 week before a full recovery and return to a normal training program.

Among the participants' baseline characteristics, previous injury, regularity of running practice over the past 12 months and participation in a half-marathon over the last 12 months were independently associated with RRI (Table 3). Additionally, some aspects related to sport participation measured during the follow-up were or tended to be associated with RRI occurrence: mean session distance, mean session duration, mean session intensity, mean session frequency, proportion of competition, average volume of other sports practiced, and in

Table 2. Characteristics of reported running-related injuries ($n = 87$)

	RRI n (%)	Incidence RRI/1000h
Injury location		
Lower back region/pelvis	9 (10.3)	0.79
Hip/groin	6 (6.9)	0.53
Thigh	16 (18.4)	1.41
Knee	17 (19.5)	1.49
Lower leg	17 (19.5)	1.49
Ankle	14 (16.1)	1.23
Foot	7 (8.0)	0.61
Toe	1 (1.1)	0.09
Injury type		
Muscle and tendon	59 (67.8)	5.18
Capsules and ligaments	20 (23.0)	1.76
Contusion	3 (3.4)	0.26
Other injury/unknown	5 (5.7)	0.44
Injury severity		
Slight (0–3 days)	38 (43.7)	3.34
Minor (4–7 days)	17 (19.5)	1.49
Moderate (8–28 days)	18 (20.7)	1.58
Major (>28 days)	14 (16.1)	1.23
Recurrence		
Yes	31 (35.6)	2.72
Injury category		
Contact acute	2 (2.3)	0.35
Non-contact acute	29 (33.3)	2.46
Progressive	56 (64.4)	4.83

Table 3. Unadjusted and adjusted Cox regression models for variables tested (n = 241/264)

Indicator	Unit/qualifier	Unadjusted model		Adjusted model	
		HR	*P*-value	HR	95%CI
Participants' characteristics					
Age	Years	0.991	0.428		
Sex	Male is ref.	0.842	0.510		
BMI	1 kg/m^2 increase	1.034	0.441		
* Previous injury	No (prev. inj.) is ref.	1.528	0.050¶**	1.722	1.114–2.661
† Running Experience	Years	0.998	0.860		
‡ Regularity (last 12 months)	Months (1–12)	0.945	0.049¶**	–	–
§ Half-marathon (last 12 months)	No is ref.	0.436	0.001¶	–	–
Sport participation pattern					
Multiple shoe use	No is ref.	0.446	<0.001¶	0.614	0.389–0.969
Volume of other sports	h/week	0.869	0.046¶	0.848	0.732–0.982
Mean session frequency	Sessions per week	0.707	0.002¶	–	–
Mean session distance	Km	0.805	<0.001¶	0.795	0.725–0.872
Mean session duration	minutes	0.963	<0.001¶	–	–
Mean session intensity	Borg CR10 scale – a.u.	0.873	0.248¶	–	–
Mean running speed	km/h	0.947	0.481		
Running on hard surface	% of total sessions	0.997	0.482		
Competitions	% of total volume	0.973	0.038¶	–	–

*15 missing data; †17 missing data; ‡16 missing data; §23 missing data; ¶Variables with P-value <0.25 included in the multivariate model (Forward LR); **Variable included in the first block (Enter); HR, hazard ratio; 95%CI, 95% of confident intervals; a.u., arbitrary unit.

line with our expectation, multiple shoe use. The adjusted Cox proportional hazard regression analysis revealed that parallel use of more than one pair of shoes is a protective factor ($P = 0.036$). Among personal characteristics, previous injury ($P = 0.014$) was a significant risk factor, but none of the variables related to running experience and short-term regularity of practice were significantly identified as protective factors. Nevertheless, sport participation pattern had an impact on RRI occurrence, as mean session distance was a significant protective factor ($P < 0.001$), as well as weekly volume of other sports ($P = 0.028$).

Discussion

To the authors' knowledge, this prospective follow-up is the first investigation on the relationship between concomitant use of different running shoes and RRI risk. As hypothesized, runners reporting the use of different pairs of running shoes during the observation period had a 39% lower risk of RRI compared with runners using only one pair of shoes. Because multiple shoe users wore their predominant pair of shoes for no more than 58% of their running sessions on average, it could be argued that the relationship between a multiple shoe use strategy and the lower injury risk arises from the alternation in the forces applied to the body. Running is a repetitive movement that subjects the musculoskeletal system to two different types of forces: external impact forces and active forces. External impact forces are influenced by a number of variables including the material properties of the damping elements such as soft tissue, shoes, and the surface of contact (Hreljac, 2004). On the other hand, active forces are mainly determined by the movement of the runner during foot contact. Although RRIs are generally thought to be connected to impact forces, there is evidence suggesting that active forces also play a significant role in some overuse injuries (Messier et al., 1991). A number of studies have shown that the characteristics of running shoes influence external impact forces and kinematics of runners. First, plantar pressure measures in runners using new and old running shoes showed that newer shoes have higher peak pressures than older shoes, suggesting a higher risk of injury to the foot and ankle when running shoes are used for shorter periods (Rethnam & Makwana, 2011). Thus, the authors recommended breaking into new running shoes slowly, using them for mild physical activity. Conversely, a biomechanical study comparing the effect of shoe cushioning on kinetics and kinematics of new and worn shoes concluded that worn shoes resulted in an increased stance time and kinematic adaptations by the runner as shoe cushioning decreased (Kong et al., 2009). Thus, runners adapt their patterns to maintain constant external loads when shoe cushioning capacity declines. Another study showed that shoe midsole hardness influences lower extremity kinematics during running (Nigg et al., 2012). Results from a study measuring lower extremity muscle activity while running with two different pairs of shoes characterized by different material hardness of the insole showed that the intensity of EMG and muscle fiber type recruitment significantly differed between the two pairs (Wakeling et al., 2002). This suggests that muscle activity, fiber type recruitment and active forces can be altered with different shoe materials. Taken together, the aforementioned studies suggest that the concomitant use of different pairs of running shoes will provide alternation in the running pattern and vary external and active forces on the lower legs during running activity. Whether the reduced RRI risk can be ascribed to alternation of different shoe characteristics, such as midsole densities, structures or geometries cannot be determined from these results and warrants future research.

The concomitant participation in other sporting activities next to running training was also found to be protective against RRI (HR = 0.85). It has been previously speculated that runners who spend more time in others sports decrease their risk of overuse injuries, because they use different muscle groups (Jacobs & Berson, 1986). In youth sport, it has been shown that athletes who engage in a variety of sports have fewer injuries and play sports longer than those who specialize before puberty (Brenner, 2007). Our results suggest that similar principles may also apply to recreational adult runners. Multiple shoe use and participation in other sporting activities are strategies leading to a variation of external and internal loads applied to the musculoskeletal system that could have a beneficial effect on RRIs. Although speculative, it could be that any training paradigm that limits excess repetitions will decrease the risk of RRI, especially overuse injuries which typically result from highly repetitive activities.

Previous injury was a significant predictor for RRI (HR = 1.72), as already reported by others (Marti et al., 1988; Macera et al., 1989; van Mechelen, 1992; Bredeweg et al., 2010). Previous injury is one of the most frequently identified risk factor. This means that people who expect to start or to resume a running training program after having been injured are at a higher risk and should be a target for preventive measures. Additionally, a greater mean session distance was found here to be a protective factor (HR = 0.80). This observation is in line with a previous study showing that long-distance/marathon runners were characterized by a lower injury incidence than middle-distance runners (Lysholm & Wiklander, 1987). It could be argued that individuals running longer distances exercise at a lower mean intensity. As training speed was significantly associated with an increased risk of running injuries (Jacobs & Berson, 1986), recreational runners aiming to practice longer distances could be exposed to a lower injury risk because of a lower intensity and/or running speed. Many studies focused on weekly running distance and found it to be a significant risk factor, even when controlling for volume of exposure (van Mechelen, 1992; van Gent et al., 2007). On the other hand, a significant relationship between running frequency and running injury was put forward in some studies (Jacobs & Berson, 1986; Macera et al., 1989; Walter et al., 1989). As weekly running distance and running frequency are closely related, it could be speculated that the increased RRI risk associated with weekly running distance is a consequence of an increase of running frequency rather than mean session distance. This needs to be confirmed by future studies. Other participants' characteristics and sport participation characteristics were not associated with the risk of sustaining a RRI in the adjusted Cox regression model (see Table 3).

Previous studies have reported incidences between 2.5 and 38 RRIs/1000h of running (Nielsen et al., 2012). The overall RRI incidence found in the present study (7.64/1000h) is in line with those reported in the literature, and lies in the lower third of the range. This could be explained by the characteristics of our study participants. Indeed, most of the runners followed here were experienced (mean: 7.0 ± 9.4 years) and had practiced running regularly over the preceding 12 months (mean: 10.2 ± 3.4 months of regular running), such characteristics being usually associated with lower injury incidence (Marti et al., 1988; Macera et al., 1989; Macera, 1992; van Mechelen, 1992).

The main limitation of this study is the duration of the observation period (22 weeks). The end of the study was announced at the date of a regional Marathon race, with the event being used as a vector of communication for the recruitment, and that we anticipated having a lot of drop outs and rest period in the week following the race. This rather short observation period limited the number of expected injuries for a given number of participants. Additionally, some of the participants ($n = 56$) dropped out of the study for other reasons than sustaining a RRI before the end of the observation period. One of the investigators systematically contacted these participants to ensure that no RRI was overlooked (see methods). Even if they were maintained in the survival analysis, the total volume of exposure was affected by their shortened period of interest. As a consequence, considering the injury incidence, the number of events ($n = 87$) and the injury rate (33%) recorded during the study were lower than the values expected and considered for the sample size calculation (133 events, 37%). Therefore, the present results should be confirmed by a study of a larger scale, a longer duration or by a randomized control trial.

Perspective

Running is one of the most popular leisure sports activities. However, annual RRI incidence has recently been reported between 19% and 79% (van Gent et al., 2007). The identification of specific risk factors has received growing interest since running continues to increase in popularity. Few epidemiological studies have focused on the impact of running shoes on injury incidence (Theisen et al., 2013). While some studies have shown the influence of shoe characteristics on running pattern (Wakeling et al., 2002; Kong et al., 2009; Lieberman et al., 2010; Rethnam & Makwana, 2011; Bonacci et al., 2013), the causal relationship between running pattern and RRI has not been established. This prospective cohort study showed that runners using concomitantly more than one pair of shoes had a lower risk of RRI. A possible explanation would be that the alternation of running shoes induces a variation in the type of physical load applied to the musculoskeletal system. Furthermore, a decreased risk was observed in runners who practice concomitantly other sports. These results open the door to a large field of research on training scheduling and variation of contents with the aim to decrease the occurrence of preventable RRIs. Furthermore, a large number of questions still remain unanswered concerning running shoe use and injury prevention.

Key words: recreational runners, risk factors, injury incidence, survival analysis, cohort study.

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