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CLINICAL COMMENTARY

CLASSIFYING RUNNING-RELATED INJURIES BASED UPON ETIOLOGY, WITH EMPHASIS ON VOLUME AND PACE

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ABSTRACT

Background and Purpose: Many researchers acknowledge the importance of "training errors" as the main cause of running-related injuries. The purpose of this clinical commentary is to present a theoretical framework for the assumption that some running-related injuries among rear-foot strikers develop due to rapidly changing running volume, while others develop due to rapidly changing running pace.

Description of Topic with Related Evidence: Evidence from clinical and experimental studies is presented to support the assertion that rapid change in running volume may lead to the development of patellofemoral pain syndrome, iliotibial band syndrome, and patellar tendinopathy, while change in running pace may be associated with the development of achilles tendinopathy, gastrocnemius injuries, and plantar fasciitis.

Discussion/Relation to Clinical Practice: If this assertion is correct, bias may be prevented in future studies by categorizing injuries into volume or pacing injuries. However, more work is needed to provide further evidence in support of this approach. Future investigations of the link between training patterns and injury development should be designed as large-scale prospective studies using objective methods to quantify training patterns.

Level of evidence: 5

Keywords: Etiology, running pace, running-related injury, training volume

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BACKGROUND AND PURPOSE

The incidence of running-related injuries (RRIs) ranges from 20% to 70%[1-13] or from 2.5 to 59 RRIs per 1000 hours of running.[11,14,15] This high incidence makes RRI prevention a priority area in sports medicine. However, effective intervention requires thorough understanding and description regarding the etiology of RRIs.[16]

From a causal perspective, it has been suggested that exposure to injury is a combination of possessing risk factors and to a greater or lesser degree participating in activities (in this case running) where these risk factors are present.[17] Adopting this view, running volume and running pace may be factors that give rise to RRIs, which must be considered when identifying other complementary causes and potential causal pathways.[18] Many researchers acknowledge the importance of running as the main exposure variable of interest. Thus, "training errors" have been suggested as the main cause of RRIs.[5,11,19-21] A weekly running volume that is being changed (in this case increasing) or an absolute training volume above 40 miles per week has been suggested to have a particularly deleterious effect in most studies,[11,13,19,20,22,23] but not in all.[3,24,25] This conflicting evidence suggests that RRIs are caused not only by running volume; running short distances at a pace rapidly changing (in this case increasing) over a short period of time has also been associated with injury development.[26] According to a recent review, no firm conclusions on the etiology of RRIs may yet be drawn,[26] and both volume and pace may be associated with development of different kinds of RRIs. If this assumption is true, many studies may be confounded because they combine these injuries into a single group. This bias problem may be solved by dividing RRIs into injuries caused by a rapid change in running volume and injuries caused by a rapid change in running pace. However, the rationale for such a categorization remains to be developed. The purpose of this clinical commentary is to provide support for the assumption that some RRIs develop due to rapidly changing running volume, while other RRIs develop due to a rapid change in running pace. The authors review the present evidence and present a design to further study these assumptions in a population-based setting.

DESCRIPTION OF TOPIC WITH RELATED EVIDENCE

Literature search

Two literature searches were conducted in Pubmed, Scopus, and PEDro; firstly, articles investigating the torque and muscle contributions while running at different paces were identified. The searches were conducted using the following terms: Runners, biomechanics, torque, kinetics, and kinematics. In relevant articles located in the search, additional articles were identified from reference lists. Secondly, articles included in a recent systematic review on training errors and RRIs were used, and the search was reproduced using the same key words in order to identify new articles investigating the associations between running volume or running pace on selected RRIs.[26]

Definition of running volume and running pace

The most commonly used approaches to define running volume have been to measure the average weekly miles or kilometers of running over a period of time,[26,27] while running pace has been defined as the average pace of the workout measured as minutes per mile (min/mile) or minutes per kilometer (min/km).[26] Running volume is a partially independent variable, while running pace is dependent on volume and duration, since pace is volume divided by duration.[26] In the present paper, definitions of running volume and running pace were used as presented elsewhere.[26] The definition of running volume and pace may, therefore, vary across the papers included in this article.

Presentation of common running-related injuries

Taunton et al[28] provided data on the diagnosis of RRIs based on 2002 cases, which were divided into the 26 most common diagnoses (n = 1579) and others (n = 423). The most common injuries were patellofemoral pain syndrome (PFPS), "runners knee", plantar fasciitis, meniscal injuries, tibial stress syndrome, patellar tendinitis, and achilles tendinitis. These injuries each accounted for 4.8-16.5% of all injuries. The list presented by Taunton et al[28] was used as a starting point for dividing RRIs into either volume injuries or pacing injuries. Six diagnoses on the list were excluded because the etiologies of these diagnoses are traumatic injuries,[28] neurologic, or rheumatologic, which are diagnoses that are generally not held to play any etiologic role in a traditional sports overuse injury. These diagnoses were: spinal injuries, metatarsalgia, osteoarthitis, sacroiliac injuries, ankle inversion injuries, and Morton´s neuroma. In total, these injuries accounted for 7.6% of all injuries. Another 15 diagnoses were excluded because the biomechanical focus of this paper was to relate simple 2D movement patterns in the sagittal plane of the knee and ankle to injury development. Injuries possibly linked to complex 3D movement patterns were excluded even though the etiological mechanisms leading to such injuries are important to identify. Injuries excluded based on complex or varied movement patterns that could contribute to their development were: meniscal injuries, medial tibial stress syndrome, gluteus medius injuries, stress fracture of the tibia, anterior compartment syndrome, greater trochanteric bursitis, hip adductor injuries, stress fracture femur, iliopsoas injuries, chondromalacia patellae, peroneal tendinopathy, hip abductor injuries, hamstring injuries, tibialis posterior injuries, and calcaneal apophysitis. Table 1 lists the remaining six diagnoses, which comprise slightly less than 50% of injuries reported, according to either a volume or a pacing injury group.

According to Taunton et al,[28] the total frequency of the six diagnoses is 43.8%. Of these, 29.7% were categorized in the volume injury group and 14.1% in the pacing injury group. This categorization was made based on clinical observations among rearfoot strikers which were supported by evidence found in biomechanical and clinical literature. The overall number of RRIs could potentially be higher if excluded injuries and injuries occurring less frequently had been included; but it is beyond the scope of this article to include more diagnoses than those presented. In the following, the evidence for linking volume and pacing exposure to the included injury groups is reviewed. In addition, it is beyond the scope to present assumptions for injury development among mid-foot strikers and fore-foot strikers.

Running volume as exposure to injury

Volume injuries are assumed to be located primarily at the anterior/lateral part of the knee (PFPS, iliotibial band syndrome, patellar tendinopathy (PT)). Diffuse lateral knee pain just above the lateral joint line and, in some cases, pain and tenderness at the insertion on Gerdy´s tubercle are symptomatic of iliotibial band syndrome (ITBS).[29] This injury is the second leading cause of knee pain in runners and the most common cause of lateral knee pain.[30] ITBS accounts for 8.4% of the total number of injuries; there is a significant difference ($p < 0.05$) between its distribution between the genders as 38% of the cases occur in males.[28] In a case-control study from 1988, Messier and Pittala[31] found no significant difference in training pace or distance between 13 runners with ITBS and 19 controls. In a later study, Messier et al[32] reported a higher mean weekly running volume (mean 31.3 miles $\pm$ 1.66 standard error (SE)) in 56 runners with ITBS than in 70 healthy controls (mean 26.4 miles $\pm$ 1.82 SE). In the study, no significant differences in running pace during training or competition were found. It was concluded that the weekly volume and the maximum normalized braking force (posteriorly oriented ground reaction force, measured by a force plate, divided by body weight)

Table 1. *The frequency (percentage) of specific diagnoses based on 2002 injury cases according to Taunton et al. The diagnoses are divided into volume or pace injury groups.*

Diagnosis	Frequency (%)	Volume injury	Pacing injury
Patellofemoral pain syndrome (PFPS)	16.5%	Yes	
Iliotibial band friction syndrome (ITBFS)	8.4%	Yes	
Plantar fasciitis (PF)	7.9%		Yes
Patellar tendinopathy (PT)	4.8%	Yes	
Achilles tendinopathy (AT)	4.8%		Yes
Gastrocnemius injuries (GI)	1.4%		Yes
TOTAL	**43.8%**	**29.7%**	**14.1%**

were the best discriminators between ITBS cases and controls. More specifically, as weekly volume increased and maximum braking force decreased, a runner was more likely to be classified into the ITBS injury group than non-injured runners.[32] Macintyre et al[33] reported a higher rate of ITBS among marathon runners than among persons running shorter distances, which strengthens the assumption that the weekly running volume is linked to the development of ITBS.

Patellofemoral pain syndrome is a term that describes a variety of pathologies leading to anterior knee pain.[34] According to Taunton[28], PFPS is the most common injury seen among runners. Hence, 16.5% of all RRIs are diagnosed as PFPS. There is a significant difference between the genders as 62% of the PFPS cases occur among women. Among marathon runners, Satterthwaite[35] found a positive association between increasing running distance and the development of front thigh injuries (defined as stiffness or pain, or both, in the front thigh), a condition closely related to PFPS. On the contrary, in a case control study,[36] subjects with PFPS ran significantly fewer miles per week before the onset of injury than controls; and Duffey[2] found no differences in the average weekly volume per week between similar groups. While there is conflicting evidence regarding a possible link between weekly running volume and the development of PFPS, two studies[2,36] found no differences in training pace between runners with PFPS and controls. In a 10-week prospective cohort study, Thijs et al[37] found that runners who developed PFPS exerted a significantly higher vertical peak force, as measured by a footscan pressure plate. They concluded that an excessive impact shock during heel strike of running may contribute to PFPS.

Patellar tendinopathy is a diagnosis that is present in 5% of injured runners with 57% occurring in male runners.[28] PT is closely related to PFPS. The development of these two conditions may be linked to the activity of the quadriceps muscles since the quadriceps, the patella, and the patellar tendon are linked in the same muscle-tendon unit. In a simulation study, Hamner et al[38] investigated the muscle contributions to propulsion and support during running and found that the quadriceps muscle was the largest contributor to braking and support (i.e. backward and upward acceleration of the body mass center, respectively) during the early stance phase. Combined with findings of an association between weekly volume and normalized braking force[31] and between PFPS and vertical peak force,[37] the results from Hamner et al[38] establish a possible link between volume and quadriceps activity and, hence, PFPS development. Furthermore, biomechanical evaluations indicate that eccentric overloading of the quadriceps muscle group (knee extensors), which may be more pronounced during downhill running, is a major etiological factor in the development of PT.[39]

Running pace as exposure to injury

Pace injuries are assumed to be located at the posterior part of the lower leg (achilles tendinopathy (AT), gastrocnemius injuries (GI)) and underneath the foot (plantar fasciitis).

Achilles tendinopathy is commonly found in athletic populations. The condition causes pain, disability and compromised sport performance.[40] The pain is typically located 2 to 6 cm proximal to the insertion of the achilles tendon. This is the area where the fibers from the gastrocnemius and the soleus (calf muscles) weave together to form the substance of the tendon.[41] Significantly more males than females develop AT.[28] Furthermore, the injury rate seems to rise with increasing age and increasing running experience.[41] McCrory et al[42] found that runners with AT had trained at a higher average training pace (4.64 ± 0.08 min/km) before injury onset than healthy controls (4.87 ± 0.07). No differences in average weekly running volume were found between groups. Based upon this, McCrory et al[42] hypothesized that the triceps surae undergo quicker muscle tension alternations as the tibia rotates over the foot during stance and then shortens during the forward propulsion phase. The achilles tendon would therefore be prone to develop microtears as pace increased. This is supported by Nelen et al[43] who found that a sudden increase of training intensity or interval training was a risk factor for developing AT. Knobloch[44] found that runners competing in the running disciplines of 1500 to 3000 meters were at increased risk for achilles overuse injury (RR 2.5, CI 1.09 to 5.84) compared to runners running 10 kilometer distances. The risk was slightly more increased as compared to the 5-km distance which increased the injury rate nearly twofold (RR 1.8, CI 1.04 to 3.18, $p = 0.034$), while a half-marathon decreased the injury rate for mid-portion AT twofold (RR 0.5, CI 0.28 to 0.92, $p = 0.025$). This observation may support the proposition that AT develops at faster paces. Also, since elite runners train at faster paces, it may be assumed that they are more likely to develop AT than recreational runners. Knobloch et al[44] found AT to be the most common overuse injury among elite runners with 0.0159 injuries per 1000 kilometers of running.

Gastrocnemius injuries (GI) are closely related to AT and affect runners above 40 years of age more often compared to younger runners.[12] The "classic tennis leg" is caused by a tear at the musculotendinous insertion of the medial head of the gastrocnemius muscle. This area may be particularly stressed at push off since most of the force is directed along the medial aspect of the leg.[41] In a case report,[45] the development of gastrocnemius muscle strain injury occurred while the participant ran at high running speed, had a high external loading rate, had increased muscle-tendon complex length and shortening rate, and had indifferent patterns in ground reaction forces, joint angles, moments, and powers. The muscular-tendon units at the posterior part of the lower leg are primarily active during propulsion and less active during braking.[38] According to Hamner et al,[38] the gastrocnemius and soleus muscles are the largest contributors to propulsion, i.e. the forward acceleration of the body mass center during the last 40% of the stance phase. Nilsson[46] found the vertical ground reaction force at initial contact to increase by 100% during an increase in running speed from 2 m/s to 6 m/s, while the increase in the anterior-posterior force during the propulsive phase at a similar increase in speed was 250%. This is a highly important finding, since the impact on some structures (AT and GI) may be greater than others (anterior knee) if the pace increases. Based on this, the structures exhibiting the greatest impact (AT and GI) may be more vulnerable if the running pace increases. In the simulation study by Hamner et al,[38] the gastrocnemius and soleus muscles were found to be the largest contributors to propulsion during the second half of the stance phase. This finding was supported by others.[47,48] The possible link between pace and gastrocnemius and soleus activity and, hence, AT development is substantiated by a number of findings; an association between running pace and development of AT was reported by McCrory et al[42] and indirectly supported by Nelen et al[43] and Knobloch et al,[44] the relation between AT and GI reported by Kong,[45] and the results of Hamner et al.[38]

Plantar heel pain has been referred to by many names in the literature. The names include heel spur syndrome, plantar fasciosis, and plantar fasciitis. Regardless of which terminology is used, different sources all describe the same pathology: pain along the proximal plantar fascia and its attachment in the area of the calcaneal tuberosity.[49] A slightly higher proportion of males than females sustain PF. The diagnosis is common as it accounts for 7.9% of all RRIs.[28] In a clinical study, Knobloch[44] found marathon runners to have a decreased risk of plantar fasciitis (RR 0.37, CI 0.18 to 0.77, $p = 0.006$) as compared to runners running shorter distances. This suggests that PF may be more easily developed at faster paces. From a biomechanical perspective, the largest strain on the plantar fascia is during the late stance phase where the first ray is dorsiflexed and the gastrocnemius and soleus are transferring forces from the muscles via the achilles tendon into the plantar fascia. This is in accord with the observations by Kibler et al[50] who stated that the plantar fascia may be overloaded at push off. In a simulation study, the maximal stress was concentrated near the medial calcaneal tubercle, which corresponds well with the frequent location of point tenderness and pain in patients with PF.[51] The forces from the gastrocnemius, soleus, and achilles tendon unit influence the stress and strain distribution of the plantar fascia. A 500% increase in achilles tendon force will increase the strain on the plantar fascia by 120%. Furthermore, the strain is increased by 40% from a 15 degree first ray dorsiflexion to a 45 degree dorsiflexsion position, regardless of the force contribution from the achilles tendon.[51,52] This suggests that the greatest strain on the plantar fascia occurs in the late stance phase where the first ray is dorsiflexed and the gastrocnemius and soleus are the main contributors to propulsion.[38] Based on this, it seems plausible to assume that PF is developed more easily if the pace is rapidly changed than if it is not.

DISCUSSION/RELATION TO CLINICAL PRACTICE

The purpose of this clinical commentary was to present the available evidence from clinical and biomechanical studies to investigate the relationship between weekly volume and running pace, and whether either is associated with different types of running injuries. Although causal links between these training characteristics and the presented running injuries have not been identified, the described assumptions may provide a useful foundation for beginning to categorize some injuries as volume injuries and other injuries as pace injuries. This approach could be implemented in future clinical studies investigating the mechanisms causing RRIs. By doing so, the discrepancy in the results reported in many studies on the associations between running volume/pace and running-related injury may be avoided and the effect of running pace on AT, GI, and PF and the effect of running volume on PFPS, ITBS, and PT may become clearer.[26]

It is, however, important, to underline that the feasibility of utilizing these new injury group definitions needs to be carefully evaluated in future studies within this field or by researchers who already have specific knowledge about one or more of the common diagnoses included or excluded in the present framework. Thus, it is possible that there should be more than two categories or that the two proposed categories may include more subtypes of injuries than proposed here. It is notable that over 50% of RRIs was not categorized into one of the two presented injury groups. Still, settling for two categories of pacing and volume seems to be the soundest approach at the present moment, at least in light of the present focus of this commentary.

In the literature, the approaches used to obtain information on injured runners' diagnoses varied widely. Many studies designed to identify factors leading to RRIs relied upon runners' self-report on the localization of the injury and no clinical examination was performed.[26] Such data do not allow the researcher to investigate the association between volume or pace and the development of specific RRIs. In the ideal scenario, injured runners would present for a clinical examination just after having suffered an injury.

Likewise, it is very important to accurately register the volume and pace. Previously, researchers used questionnaires, surveys, or self-report diaries to gather information about training data.[26] Data were typically collected retrospectively over a period of one week to several years. This approach may have caused injured runners to underestimate or to overestimate the amount of training completed before suffering injury compared with healthy runners.[4,25,26] This may lead to a biased estimate. A possible solution to this problem is to follow runners prospectively and to register training data objectively in each training session. The use of a global positioning system (GPS) is a feasible method that has proven to be a valid alternative for measuring pace and volume as compared with questionnaires, surveys, or self-report diaries.[53]

The available evidence presented in this commentary was all based on self-reported data, which may not be a valid method when measuring volume and pace during running. It is suggested that the types of studies cited are replicated in future prospective studies using more accurate and objective measurements methods like the use of a GPS.[54] Also, many of the studies were designed to investigate other exposures and outcomes, whereas the association between training exposure and the development of injuries was included as a sub-analysis.

CONCLUSION

The present commentary presents evidence in support of the assertion that running volume may somehow be associated to the development of PFPS, ITBS, and PT while running pace may be associated with development of AT, GI, and PF. Confusion in terminology may be prevented in future studies by categorizing injuries into volume or pacing injuries, but more work has to be conducted in order to substantiate this assertion. Future studies investigating the link between training patterns and injury development should be designed as large-scale prospective studies using objective methods to quantify training patterns.

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