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Full Length Research

Increased running pace increases net joint moment at the ankle more than at the knee in recreational runners

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The understanding of safe and harmful training programs for runners may be improved by investigating whether running at different paces affects relative joint loads. In an experimental cross-sectional study, the change in peak ankle joint moment (∆A) was compared to the change in peak knee joint moment (∆K) following an increase in running pace. Twelve healthy recreational runners (6 female and 6 male, age 25.7±2.64, BMI 22.4±2.03) utilizing a rear-foot strike were included. Running kinematics was recorded with 8 high-speed motion capture cameras to calculate the net joint moments at the ankle (A) and at the knee (K). An increase in A (2.67 ± 0.44 N·m·kg^{-1} to 3.00 ± 0.50 N·m·kg^{-1}) was found while no increase was found in K (1.60 ± 0.33 N·m·kg^{-1} to 1.58 ± 0.49 N·m·kg^{-1}) following a change in running pace from slow (70% of the 5 km pace) to fast (5 km pace). The ∆A was statistical significantly greater than ∆K (0.35 N·m·kg^{-1} [95% CI: 0.07; 0.63], P = .02). The result suggests that running faster increases the load at the ankle joint more than the load at the knee joint. This knowledge may be used in the design of training programs for recreational runners at risk of developing running-related injuries at the ankle or at the knee.

Keywords: Biomechanics, etiology, running-related injury.

INTRODUCTION

Recreational running is widely regarded as being beneficial for health and fitness (Koplan et al., 1982). Unfortunately, running also exposes practitioners to the risk of developing running-related injuries (RRIs) (Lopes et al., 2012; Van Gent et al., 2007), with incidence reported being as high as between 11-85% or 2.5 to 38 injuries per 1000 hours of running (Nielsen et al., 2012). To ensure adherence to running, an understanding of injury prevention and treatment strategies are needed (Finch, 2006).

Importantly, treatment strategies should be targeted at the risk factors for injury. Risk factors for RRIs are either related to running itself (training errors) or to elements such as running surface,

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equipment, anatomical and biomechanical factors, experience, previous injuries (Hreljac, 2005; Meeuwisse et al., 2007; Taunton et al., 2002; Van Gent et al., 2007). Of these, training errors are assumed to be the cause of the majority of the RRIs (Buist et al., 2008; Hreljac, 2005; Lysholm and Wiklander, 1987).

A recently developed theoretical framework classified six common RRIs as either “Volume injuries” (caused by excessive distance) or “Pacing injuries” (Nielsen et al., 2013); the authors found the most common volume injuries to be patellofemoral pain, iliotibial band syndrome and patellar tendinopathy, while the most common pacing injuries were plantar fasciitis, achillestendinopathy and m. gastrocnemius injuries. Thus, volume injuries seem to be located at the anterior aspects of the knee, while pacing injuries seem to be located at the posterior, distal shank and plantar foot. If it is assumed that injuries to the anterior aspects of the knee are related to activity in the quadriceps muscle, and injuries to the posterior, distal shank and plantar foot to activity in the m. triceps surae and deep plantar flexor muscles, the classification by Nielsen et al., (2013) prompts the hypothesis that increased running pace taxes the plantar flexors more than the knee extensors. This hypothesis can be indirectly supported by experimental data presented from studies using a biomechanical setup.

Although several studies provide descriptive results of the net joint moments at different speeds (Dorn et al., 2012; Hamner et al., 2010; Nilsson and Thorstensson, 1989; Schache et al., 2011), there are a limited number of studies comparing intra-subject change in net joint moments across joints when the speed is increased.

Identifying a possible connection between running patterns (slower-longer vs. faster- shorter) on one hand and specific injury risks (anterior knee vs. posterior, distal shank) on the other could form the basis for advices on changes in running patterns with regard to injury prevention and treatment in recreational runners. As a first step in this direction, the present study tests the hypothesis that increasing recreational running pace (which is typically below 13 $km \cdot h^{-1}$) taxes the plantar flexors more than the knee extensors.

Thus, the purpose of the present study was to compare the increase in peak ankle plantar flexor moment to the increase in peak knee extensor movement when recreational runners change from slow to fast running pace.

MATERIALS AND METHODS

SUBJECTS

Participants were recruited from the Section of Sport Science at Aarhus University, Denmark. Eligible for inclusion was healthy (no pain in the lower extremities three months preceding enrollment) recreational runners utilizing a rear-foot strike and running a 5 km distance slower than 17 minutes. All subjects signed an informed consent prior to inclusion. The study protocol was presented to the local ethics committee and the study was conducted in accordance to the declaration of Helsinki.

MEASUREMENTS

The subjects were required first to run at a pace equal to 70% of their self-reported 5 km pace ("slow") and subsequently at their 5 km pace ("fast") on an 18 meter instrumented runway in the biomechanical laboratory, Section of Sports Science, Aarhus University, Denmark. Running kinematics were recorded in the center of the runway with 8 high speed motion capture cameras (ProReflex MCU1000, Qualisys AB, Gothenburg, Sweden) operating at 240 frames per second. Motion capture was facilitated by 19 mm reflective skin-markers placed bilaterally on trochanter major, epicondylus lateralis, malleolus lateralis, calcaneus and caput ossi metatarsi 5. A force plate (AMTI OR6-7, Advanced Medical Technology Inc., Watertown, MA, USA) imbedded in the laboratory floor was used to measure ground reaction force synchronously with the kinematic data (Gill and O'Connor 1997).

The entire runway was covered with a thin carpet, effectively obscuring the force plate for the subject. Data acquisition and 3D-reconstruction of marker positions were carried out using the Qualisys Track Manager software. The running pace of each trial was measured with photo cells (ALGE-Timing RLS1n, Lustenau, Austria) placed 4 meters apart (2meter form the center of the force plate). A running trial was considered valid when the subject met the target pace ±5% and hit the force plate with

Table 1. Demographic characteristics of the included 12 runners.

	Mean	SD	95% CI
Gender (male / female count)	6 / 6	N/A	N/A
Age (years)	25.7	2.64	24.0 to 27.3
Height (m)	1.77	0.08	1.72 to 1.82
Mass (kg)	70.2	9.23	64.4 to 76.1
BMI (height / mass^2)	22.4	2.03	21.1 to 23.7
5 km time (min.)	23.4	3.89	21.0 to 25.9

Dichotomous data are presented as counts and percentage, and continuous data as mean ± standard deviation (SD) and 95% confidence interval (CI). BMI = Body Mass Index and 5 km time = current personal best time when running a 5 kilometer distance. N/A = Not able to measure this because data was dichotomous.

the entire foot. Each subject continued performing trials until 3-8 valid trials for each pace were acquired.

DATA PROCESSING

The raw motion captures and force plate data were post processed using in-house developed MATLAB software (The MathWorks, Inc., Natick, MA, USA). Firstly, the marker position trajectories were low-pass filtered using a 4th order, zero-lag Butterworth filter with 15 Hz cutoff frequency (Winter, 1990). Secondly, the filtered, sagittal position data and the sagittal force plate data together with Dempster's anthropometric data were used as input to a conventional inverse dynamics analysis (Winter, 1990), resulting in net joint moments for the ankle and knee. For each subject, median trial peak ankle and knee joint moments (normalized for body mass) for both paces were used to calculate the difference in joint moments between paces:

Peak ankle joint moment at slow speed = A_{slow},
Peak knee joint moment at slow speed =K_{slow},
Peak ankle joint moment at fast speed =A_{fast}
Peak knee joint moment at fast speed =K_{fast}
$\Delta A = A_{fast} - A_{slow}$
$\Delta K = K_{fast} - K_{slow}$

STATISTICS

For both paces, A and K as well as ΔA and ΔK were found to follow a normal distribution evaluated by histograms and quartile-quartile plots. Therefore, results were presented as mean ± 1 standard deviation and 95% confidence intervals. Paired t-tests were applied to test for significance (5% alpha level) of the difference of the means between A_{slow} and A_{fast}, between K_{slow} and K_{fast}, as well as between ΔA and ΔK.

RESULTS

Thirteen runners (7 males, 6 females) were tested; of these, one male subject was excluded because of a forefoot strike pattern. The demographic characteristics of the remaining 12 subjects are presented in Table 1.

Ankle and knee joint moments from slow and fast running normalized to individual body mass are presented in Table 2. Changing from slow (9.1 km·h^{-1} on average) to fast (13.0 km·h^{-1} on average) running revealed a significant change in peak ankle plantar flexor moment (ΔA), but not in peak knee extensor moment (ΔK); the change in peak ankle plantar flexor moment was significantly larger than the change in peak knee extensor moment (ΔA-ΔK).

DISCUSSION

The purpose of the present study was to compare the change in ankle net joint moment (ΔA) to the change in knee net joint moment (ΔK) following an increase in running pace in recreational runners

Table 2. Ankle and knee joint moments from slow and fast running.

	A_{slow}	A_{fast}	K_{slow}	K_{fast}	ΔA	ΔK	ΔA-ΔK
Mean	2.67	3.00	1.60	1.58	0.33	-0.02	0.35
SD	0.44	0.50	0.33	0.49	0.15	0.41	0.44
CI					0.23 to 0.43	-0.28 to 0.24	0.07 to 0.63
p					< 0.001	0.854	0.019

SD = Standard deviation, CI = Confidence Interval. Units for Mean, SD and CI values are $N \cdot m \cdot kg^{-1}$. Please refer to text for column title explanations.

utilizing a rear-foot strike. The results verified the hypothesis that the increase in ΔA was significantly higher than the increase in ΔK when the running pace was increased. The absolute values of the ankle and the knee joint moments, as well as the finding that increasing running pace increased the ankle moment, but not the knee moment, were in good agreement with similar descriptive studies in the literature (Belli et al., 2002; Dorn et al., 2012; Hamner et al., 2010; Schache et al., 2011). To our knowledge, the present study is the first study to utilize a paired analysis to verify that the intra-subject increases in joint moments with increasing running pace are significantly different between the two joints. A major strength of the paired analysis is the fact that departures from normality in ΔA and ΔK do not violate the assumptions behind the paired t-test. This is, indeed, an advantage compared to the non-paired t-test where both ΔA and ΔK need to follow a normal distribution in order to for the statistical analyses to be valid.

Owing to the findings in the current study and others (Dorn et al., 2012; Nilsson and Thorstensson, 1989; Schache et al., 2011) that ΔK is not significantly increased as pace is increased, we suggest that injuries located at the anterior aspect of the knee, such as patella-femoral pain, may be less likely to be caused by an excessive increase in running pace. The key factor leading to this injury may instead be associated with excessive progression in running volume. If this is true, the clinicians should be precautious about advising runners with pain at the anterior aspect of the knee to continue running long distances during their period of rehabilitation. Instead, running short distances but at a faster pace may be a more appropriate treatment strategy. Importantly, this assumption needs scientific verification in clinical studies.

In addition to the limited number of subjects included in this study, there are a number of other limitations: Despite running being a 3-dimensional activity, two sagittal dimensions were used in the analysis. By doing so, the movements and ground reaction force components were out of the sagittal plane that would otherwise have contributed to the calculated joint moments. However, it was believed these contributions was minimal, in accordance with Eng and Winter (1995) who argued the sagittal approach to be a valid method especially for the ankle and knee joint. Furthermore, Alkjaer et al., (2001) conducted a direct comparison of sagittal ankle, knee and hip moments calculated by a 2- and a 3-dimensional method and concluded that the inter-individual variation as well as the overall curve patterns were identical between the two methods. Based on these studies, it was believed that simpler, 2-dimensional approach is appropriate for addressing our research question.

Another limitation was that all subjects were rear-foot strikers. Since the distribution of forces and differences in joint moments between joints may vary considerably between individuals with different foot strike patterns (Lieberman et al., 2010; Schache et al., 2011), generalizability can only be made to rear-foot strikers. Because most novice runners wearing conventional running shoes utilize a rear foot strike (Bertelsen et al., 2013) our suggestions may be of relevance in this population. However, among recreational runners (Kasmer et al., 2013; Larson et al., 2011) and elite runners (Hasegawa et al., 2007), foot strike patterns should be evaluated more carefully, because these runners are more prone to utilize a midfoot or a forefoot strike pattern possibly owing to a faster running pace or the use of minimalistic running shoes (Rixe et al., 2012). Although midfoot and forefoot strikers may put even more load on their plantar flexors than rear-foot strikers, hence increasing their risk of Achilles tendinopathy and m. ticepssurae injuries, we prefer to be precautious about suggesting injury mechanisms in these types of runners, since they did not partake in the present study.

Thus, more research, experimental as well as clinical, is needed to ascertain the differences in peak moments in the ankle and knee joints in midfoot and forefoot strikers, runners wearing different types of (or no) running shoes, and runners who run slow-to-fast intervals.

More importantly from an injury and rehabilitation perspective, though, we need to document our suggested link between net joint moments and loads on specific, anatomical structures, and eventually conduct prospective, clinical studies to investigate whether changes in running pace and volume are effective as injury prevention and rehabilitation.

CONCLUSION

The increase in ∆A was significantly higher than the increase in ∆K when the running pace was increased. This knowledge may be used in the design of training programs for recreational runners at risk of developing a running-related injury at the ankle or at the knee. However, research is needed to ascertain if continued running at a slow pace is an appropriate treatment strategy for injured rear-foot strikers with Achilles tendinopathy or injury in the m. triceps surae. Additionally, more research is needed to define a safe graduate increase in running pace or running distance and to identify excessive harmful increases.

REFERENCES

Alkjaer T, Simonsen EB, Dyhre-Poulsen P (2001). Comparison of Inverse Dynamics Calculated by Two- and Three-Dimensional Models during Walking. Gait Posture. 13(2): 73-77.

Belli A, Kyrolainen H, Komi PV (2002). Moment and Power of Lower Limb Joints in Running. Int. J. Sports Med., 23(2): 136-141.

Bertelsen ML, Jensen JF, Nielsen MH, Nielsen RO, Rasmussen S (2013). Footstrike Patterns among Novice Runners Wearing a Conventional, Neutral Running Shoe. Gait Posture. 38(2): 354-6.

Buist I, Bredeweg SW, Van Mechelen W, Lemmink KA, Pepping GJ, Diercks RL (2008). No Effect of a Graded Training Program on the Number of Running-Related Injuries in Novice Runners: A Randomized Controlled Trial. Am. J. Sports Med., 36(1): 33-39.

Dorn TW, Schache AG, Pandy MG (2012). Muscular Strategy Shift in Human Running: Dependence of Running Speed on Hip and Ankle Muscle Performance. J. Exp. Biol., 215(11): 1944-1956.

Eng JJ, Winter DA (1995). Kinetic Analysis of the Lower Limbs during Walking: What Information can be Gained from a Three-Dimensional Model? J. Biomech., 28(6): 753-758.

Finch C (2006). A New Framework for Research Leading to Sports Injury Prevention. J. Sci. Med. Sport. 9(1-2): 3-9.

Gill HS, O'Connor JJ (1997). A new testing rig for force platform calibration and accuracy tests. Gait & posture. 5(3):228-32.

Hamner SR, Seth A, Delp SL (2010). Muscle Contributions to Propulsion and Support during Running. J. Biomech., 43(14): 2709-2716.

Hasegawa H, Yamauchi T, Kraemer WJ (2007). Foot Strike Patterns of Runners at the 15-km Point during an Elite-Level Half Marathon. J. Strength Cond. Res., 21(3): 888-893.

Hreljac A (2005). Etiology, Prevention, and Early Intervention of Overuse Injuries in Runners: A Biomechanical Perspective. Phys. Med. Rehabil. Clin. N. Am., 16(3): 651-667.

Kasmer ME, Liu XC, Roberts KG, Valadao JM (2013). Foot-Strike Pattern and Performance in a Marathon. Int. J. Sports Physiol. Perform., 8(3): 286-292.

Koplan JP, Powell KE, Sikes RK, Shirley RW, Campbell CC (1982). An Epidemiologic Study of the Benefits and Risks of Running. JAMA. 248(23): 3118-3121.

Larson P, Higgins E, Kaminski J, Decker T, Preble J, Lyons D, McIntyre K, Normile A (2011). Foot Strike

Patterns of Recreational and Sub-Elite Runners in a Long-Distance Road Race. J. Sports Sci., 29(15): 1665-1673.

Lieberman DE, Venkadesan M, Werbel WA, Daoud AI, D'Andrea S, Davis IS, Mang'eni RO, Pitsiladis Y (2010). Foot Strike Patterns and Collision Forces in Habitually Barefoot Versus Shod Runners. Nature. 463(7280): 531-535.

Lopes AD, Hespanhol Junior LC, Yeung SS, Costa LO (2012). What are the Main Running-Related Musculoskeletal Injuries?: A Systematic Review. Sports Med. 42(10): 891-905.

Lysholm J, Wiklander J (1987). Injuries in Runners. Am. J. Sports Med., 15(2): 168-171.

Meeuwisse WH, Tyreman H, Hagel B, Emery C (2007). A Dynamic Model of Etiology in Sport Injury: The Recursive Nature of Risk and Causation. Clin. J. Sport Med., 17(3): 215-219.

Nielsen RO, Buist I, Sorensen H, Lind M, Rasmussen S (2012). Training Errors and Running Related Injuries: A Systematic Review. Int. J. Sports Phys. Ther., 7(1): 58-75.

Nielsen RO, Nohr EA, Rasmussen S, Sorensen H (2013). Classifying Running-Related Injuries Based upon Etiology, with Emphasis on Volume and Pace. Int. J. Sports Phys. Ther., 8(2): 172-179.

Nilsson J, Thorstensson A (1989). Ground Reaction Forces at Different Speeds of Human Walking and Running. Acta Physiol. Scand., 136(2): 217-227.

Rixe JA, Gallo RA, Silvis ML (2012). The Barefoot Debate: Can Minimalist Shoes Reduce Running-Related Injuries? Curr. Sports Med. Rep., 11(3): 160-165.

Schache AG, Blanch PD, Dorn TW, Brown NA, Rosemond D, Pandy MG (2011). Effect of Running Speed on Lower Limb Joint Kinetics. Med. Sci. Sports Exerc., 43(7): 1260-1271.

Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD (2002). A Retrospective Case-Control Analysis of 2002 Running Injuries. Br. J. Sports Med., 36(2): 95-101.

Van Gent RN, Siem D, Van Middelkoop M, Van Os AG, Bierma-Zeinsfra S, Koes BW (2007). Incidence and Determinants of Lower Extremity Running Injuries in Long Distance Runners: A Systematic Review. Br. J. Sports Med., 41(8): 469-480.

Winter DA (1990). Biomechanics and Motor Control of Human Movement areas (2.Ed.). New Jersey: John Wiley & Sons, Inc.