Hip and core exercise programme prevents running-related overuse injuries in adult novice recreational runners: a three-arm randomised controlled trial (Run RCT)

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ABSTRACT

Objective This study aims to investigate the efficacy of two exercise interventions in reducing lower extremity (LE) injuries in novice recreational runners.

Methods Novice runners (245 female, 80 male) were randomised into hip and core (n=108), ankle and foot (n=111) or control (n=106) groups. Interventions were completed before running and included exercise programmes focusing on either (1) hip and core or (2) ankle and foot muscles. The control group performed static stretching exercises. All groups were supervised by a physiotherapist and performed the same running programme. Injuries and running exposure were registered using weekly questionnaires during the 24-week study. Primary outcome was running-related LE injury.

Results The incidence of LE injuries was lower in the hip and core group compared with the control group (HR 0.66; 95% CI 0.45 to 0.97). The average weekly prevalence of overuse injuries was 39% lower (prevalence rate ratio, PRR 0.61, 95% CI 0.39 to 0.96), and the prevalence of substantial overuse injuries was 52% lower (PRR 0.48, 95% CI 0.27 to 0.90) in the hip and core group compared with the control group. No significant difference was observed between the ankle and foot group and control group in the prevalence of overuse injuries. A higher incidence of acute injuries was observed in the ankle and foot group compared with the control group (HR 3.60, 95% CI 1.20 to 10.86).

Conclusion A physiotherapist-guided hip and core-focused exercise programme was effective in preventing LE injuries in novice recreational runners. The ankle and foot programme did not reduce LE injuries and did not protect against acute LE injuries when compared with static stretching.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ A low number of studies have investigated exercise-based injury prevention in novice recreational runners, and the evidence is still very limited.

WHAT THIS STUDY ADDS

⇒ Physiotherapist-guided hip and core-focused exercise programme can help prevent lower extremity (LE) injuries in adult novice recreational runners. Hip and core-focused training is especially effective to prevent LE overuse injuries, which are common among novice runners. The ankle and foot focused exercise programme was not effective in reducing LE injuries and was associated with an increased incidence of acute LE injuries when compared with static stretching.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Prevention of running-related injuries is possible through hip and core-focused training. This low-cost training can be done with limited equipment and is recommended for adult novice recreational runners. This study tested the programme efficacy in ideal conditions under physiotherapist guidance. The patient-driven effectiveness of the programme should be tested in the future.

INTRODUCTION

Running is a popular form of recreational physical activity in many countries. Regular running is associated with multiple health and fitness benefits[1] but also includes high risk of running-related injuries (RRIs).[2–4] The reported injury rates in running range from 2.5 to 33.0 injuries per 1000 hours of running exposure,[3] and novice runners have shown to be at greater risk of injuries compared with experienced runners.[2 3] RRIs often require long recovery periods[5] and many novice runners stop running due to RRI[6] resulting in loss of physical[1] and mental health benefits[7] of regular running. RRIs can furthermore lead to limitations in sport and leisure time activities, increased absence from work and increased healthcare costs.[8] Therefore, finding effective methods to reduce the number and severity of injuries is important for both the individual and society.

High-quality randomised controlled trials (RCTs) have shown that exercise-based injury prevention programmes can reduce sports injuries in team sports.[9 10] However, only a few previous RCTs have investigated the effects of different training programmes on injury risk in runners. These interventions have included a graded training programme,[11] preconditioning programme,[12]

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strength training programme,[13–15] gait retraining programme[16 17] and stretching warm-up and cool-down programme.[18] A few of these exercise-based interventions have been effective to reduce RRIs. A study using foot-based and ankle-based strength training in experienced recreational long-distance runners found preventive effects.[13] In addition, recent studies focusing on gait retraining have shown promising results on injury risk in recreational runners.,[16 17] The evidence on exercise-based injury prevention in novice recreational runners is still very limited.

Strength training has been suggested to reduce the number of RRIs[13–15] and different strength training approaches have been proposed for the prevention of RRIs. A top-down approach suggests that increasing muscle strength around the hip and core reduces joint movements and external joint moments at the lower extremities during running, which would help reduce the risk of RRIs.[19 20] However, RCTs investigating running injury prevention using the top-down approach are rare,[15] and only one previous pilot study has examined this approach previously in novice runners.[14] Another theory, called a bottom-up approach,[21] advocates that strengthening the small muscles crossing the ankle joint, could affect movement and reduce moments at the ankle, knee and hip joints and thereby reducing RRIs. To date, only two studies with a low number of participants have investigated this theory in practice, with conflicting results.[13 14]

To date, the evidence to determine if the top-down and/or bottom-up approach could reduce injuries in novice recreational runners is limited. Therefore, the objective of our study was to investigate the efficacy of (1) hip and core and (2) ankle and foot focused exercise programmes on reducing the risk of all-complaint lower extremity (LE) injury in adult novice recreational runners. We hypothesised that participants in intervention groups 1 and 2 would exhibit a significantly lower number of LE injuries and a significantly lower number of severe LE injuries than participants in the control group.

METHODS

Study design

This was a three-arm randomised controlled study (Run RCT) over 2 years investigating the prevention of LE injuries among novice recreational runners in Finland. The study was registered in ISRCTN registry (ISRCTN47734782) prior to the start of intervention. The Consolidated Standards of Reporting Trials guidelines[22] were followed in the planning and reporting of the study.

Participants

Participants were adult novice recreational runners. Novice recreational runner was defined as a non-competitive runner, who had been engaging in regular running less than 2 years. To be included participants had to meet the following inclusion criteria: aged 18–55 years, with long-distance running as their primary form of exercise, less than 2 years of weekly running exposure, average weekly running exposure 20 km or less, able to run continuously 3 km or 20 min (self-assessed), no musculoskeletal injuries causing time-loss from running within 3 months prior the study onset, no LE surgery within 6 months prior the study onset, no bone fractures in the spine, pelvis or LE in the past year, and no systemic or neurological disorder potentially affecting outcomes. In addition, participants agreed to participate in a running training group held in Tampere city area twice a week. The participants were not informed about the content of the intervention when signing up for the study. Prior to the study onset, a study physiotherapist interviewed all volunteers to assess their eligibility.

All participants were asked to complete a baseline questionnaire regarding information on their health, running experience and injuries during the past 12 months. In addition, we asked the participants to name any acquaintances they knew were also taking part in the study. Participants who knew each other were assigned to the same group to avoid contamination of the groups.

Study settings

The study took place in Tampere, Finland, for two consecutive years (2021–2022). We conducted similar data collection procedures with different participants during the two study years. In January 2021, we recruited volunteer participants from the city of Tampere and its nearby areas by using announcements in newspapers, web pages and social media. We repeated the recruitment process similarly in January 2022.

Interventions

The 24-week intervention took place between May and October during 2021 and 2022. During this period, the subjects participated in organised running groups held twice a week. The participants were randomly assigned to one of three parallel groups before the start of the intervention (hip and core, ankle and foot, and control). Due to the COVID-19, groups were further divided into subgroups to limit the number of participants at a time.

Three experienced physiotherapists led the training groups, with each overseeing one group throughout both study years. In addition, three physiotherapists assisted and substituted when needed. All study physiotherapists participated in educational workshops prior to the study. The first workshop introduced three intervention programmes, the second focused on a running programme and the third emphasised proper running technique guidance.

Each training session started with a 5 min general warm-up including running drills. The warm-up was conducted indoors with indoor shoes and was similar in all three study groups. After the warm-up, the groups did their assigned programme, which included either eight strengthening and neuromuscular control exercises for the hip and core muscles (hip and core group), eight strengthening and neuromuscular control exercises for the ankle and foot muscles (ankle and foot group), or eight static stretching exercises (control group) (figure 1, online supplemental table 1). Components of the two intervention programmes were based on common physiotherapy exercises and some of them have been previously implemented in sport and recreation populations.[13 14 23–26] The intervention sessions lasted 20–35 min at a time. Resistance bands used in the programmes were available in four progressive levels of resistance. Each exercise had different variations with diverse difficulty and/or intensity (online supplemental table 1). The supervising physiotherapist instructed the level of difficulty/intensity that fit for each participant. Resistance band exercises were instructed to feel heavy but to be done with good quality (determined by the physiotherapist) until fatigue occurred. After the intervention training, the groups did their running training session outdoors (30–75 min at a time).

If a participant was unable to attend a scheduled group session, they were instructed to do their assigned training independently at home. Resistance bands, minibands and towels together with written instructions on exercises were provided to the participants for home training. In addition to supervised training twice a week, the participants were recommended to do their assigned

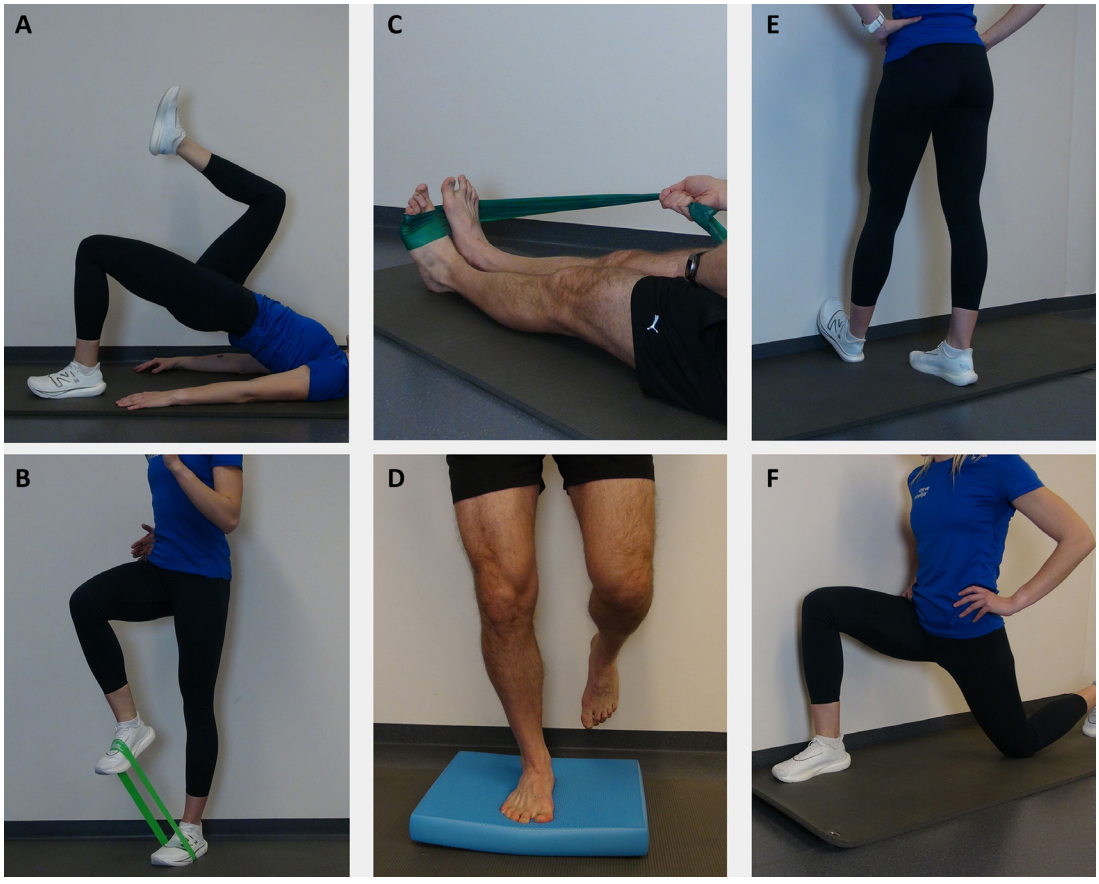

Figure 1 Examples of hip and core (A, B), ankle and foot (C, D) and control group (E, F) exercises.

training programme at home once or twice a week. We advised a minimum of two and maximum of four intervention training sessions to be done every week.

The organised training sessions were not held during the mid-summer. During this 5-week period, the participants were instructed to follow their training programme independently. This period included 3–4 training sessions per week (each session including the 5 min warm-up, eight intervention training exercises and running exercise).

Running programme

All three study groups followed the same running programme planned by an experienced endurance coach and exercise physiologist. The running programme included two organised training sessions per week and 1–2 voluntary, independently conducted sessions per week. The running programme increased in duration and level of difficulty progressively during the 24 weeks and included different types of running exercises (eg, running, brisk walking, Nordic Walking, uphill and downhill walking/running, running intervals and running coordination drills). The weekly training volume increased by approximately 30 min during a 6-week period, with weekly microcycles. Participants were also advised to increase their weekly running according to their prior training volume. Due to heterogeneous levels of aerobic fitness, participants were given verbal and written instructions on how the session should feel (online supplemental table 1) and were instructed to modify the exercise accordingly.

During the intervention, all groups including the control group had two technique-focused training sessions held by an experienced running coach, one in June and the second one in August. The running coach was advised to give basic guidance on running technique at group level and similarly to all groups (eg, focusing on upright running posture, length of stride and use of arms). Any recommendations on strike type (heel, midfoot, forefoot strike) or type of footwear were not given. Study physiotherapists were instructed to guide participants in their running technique at general group level similarly throughout the intervention.

Registration of adherence and running exposure

The physiotherapists in each group documented the execution of each intervention training session on the attendance form including date, duration and participation of each runner. In addition, participants registered their home-based training sessions using a mobile application (AthleteMonitoring, Canada). All intervention sessions (organised and home based) were used to calculate adherence to the intervention. Weekly adherence was defined as the number of participants who completed at least two training sessions each week divided by the number of participants included that week per group. Average weekly adherence was used to describe the level of adherence in each group.

Running exposure was registered using the mobile application. Participants were advised to register all running training sessions with date and duration including organised group training sessions as well as programmed and additional non-programmed running sessions.

Registration of injuries

We registered all-complaint injuries using a health survey, which participants filled in every Sunday using the mobile application (AthleteMonitoring, Canada). Response rate to the weekly

survey was calculated as the number of responses divided by the number of expected responders each week considering drop-outs. The survey included a Finnish forward-backward translation of the Oslo Sports Trauma Research Center Questionnaire on Health Problems (OSTRC-H2).[27] In case of an injury, participants were asked additional questions to report the injury location, type, recurrence and time-loss. A blinded study physiotherapist contacted all participants who reported an injury for a phone interview to check their questionnaire responses and to fill in a structured injury form for each injury. The injury form was based on previous studies[23 24 28] and followed the consensus statement.[29]

Outcomes and definitions

The primary outcome was a running-related all-complaint LE injury. The secondary outcomes included all-complaint overuse LE injuries, substantial LE overuse injuries, all-complaint acute LE injuries, acute time-loss LE injuries and injuries of the different anatomical locations. Also, we did subanalyses for acute and overuse injuries that caused more than 7-day time-loss from running.[30]

A running-related all-complaint LE injury was defined as any physical complaint including pain, ache, joint instability, stiffness or any other complaint resulting from participating in running activities, including but irrespective of the need for medical attention or time-loss (inability to complete a running training session or participate in one or more days after the onset of injury).[27] An acute injury was defined as a sudden injury resulting from a single, specific and identifiable event and overuse injury as a gradual onset injury caused by repetitive microtraumas without a single, specific and identifiable event responsible for the injury. Other than injury complaints (eg, delayed onset muscle soreness and other health complaints), injuries occurring outside running and injuries that were caused by an external reason/direct contact were excluded (online supplemental table 4).

Injuries were classified by anatomical location, type, mechanism and recurrency. The severity of acute injuries was defined as the number of time-loss days from running. The severity of overuse problems was based on the prevalence of physical complaints and its consequences on running participation and performance. A substantial overuse injury was defined as an overuse injury leading to moderate or severe modifications in training (OSTRC-H2 question 2) or moderate to major effects in performance (question 3), or an inability to participate (question 1). The participant was defined as injured until they were able to return to full running training. Recurrent injury was defined as an injury to the same body part and the same type as the index injury occurring after the participant had returned to full participation following the index injury. Recurrent overuse injuries of the same body part and same type were categorised as exacerbations and not calculated as new injuries.

Sample size

Our sample size estimation was based on a pilot study in novice recreational runners[14] where 0.4 LE injuries occurred per runner per season. We assumed that we would detect at least a 50% reduction in the incidence of LE injuries, from 0.4 injuries per person in the control group to 0.2 per person in the intervention group. An intraclass correlation due to data design of training groups as clusters were assumed to be to 0.01 and significance level was set to 0.05. We set an attrition rate of 0.30. We achieved the statistical power of 0.81 by recruiting a total of 321 recreational runners in 15 clusters (5 subgroups in each intervention group). Hence, to achieve this, the recruitment plan was 150 participants for the first year and 200 for the second year.

Randomisation

Allocation of the participants was performed by a statistician, who had no further involvement in the study. A computer-generated stratified randomisation into three groups was done according to participant's sex and age (<45 years or ≥45 years). Participants who knew each other were randomised together to minimise the risk of contamination bias between participants in different groups. First, each of the participants who knew each other was randomised together in one of the three groups. The rest of the participants were randomised to groups so that an even number of participants and similar distribution in sex and age was achieved between groups. After randomisation, a non-blinded researcher assigned participants to their intervention.

Blinding

It was not possible for blind participants and physiotherapists involved with the training groups. However, participants were not informed about the content of the other intervention groups nor participants or physiotherapists were informed that one of the groups was a control group. The study physiotherapist conducting the injury and exposure data collection and the statistician analysing the results of the interventions were blinded to group allocation.

Statistical methods

We presented baseline data with means and SDs. We calculated the incidence of all and acute LE injuries as the number of injuries per 1000 hours of running exposure. We calculated the prevalence of running-related LE overuse injuries each week by dividing the number of participants who reported an LE overuse injury by the number of respondents that week.[27] We furthermore calculated average weekly prevalence separately for different anatomic locations.[29] The average weekly prevalence of substantial injuries was calculated in the same way as described above.

In the analysis of primary outcome, we used Cox proportional hazards model to assess the HRs of LE injuries between the intervention and control groups. Similarly, subanalysis of acute LE injuries was conducted with Cox proportional hazard model. Time to first injury was used as exposure time in the models. We compared weekly prevalence of overuse injuries between the intervention groups and control group using generalised linear mixed model with binomial distribution, log link and study week as repeated measures. All comparisons were done according to the intention-to-treat principle. Data from drop-outs were included from the time they participated. Missing data were not imputed. Although subgroups were accounted as clusters in the power calculations, we did not adjust the final analyses by clusters as the participants were allowed to change their subgroup to better fit their personal schedule. The analyses of all LE injuries as well as all overuse and acute injuries were tested by adding adjustment of previous LE injury. This adjustment had no effect on the results and hence all results were presented unadjusted. All analyses were done using the SPSS (IBM SPSS Statistics, V.29). The statistical analysis and presentation are consistent with the CHAMP statement.[31]

Equity, diversity and inclusion statement

The inclusion of participants was based on preset criteria and all volunteers who filled the criteria were able to participate regardless of sex, gender, race/ethnicity or socioeconomic level. More females than males volunteered to participate. We acknowledge

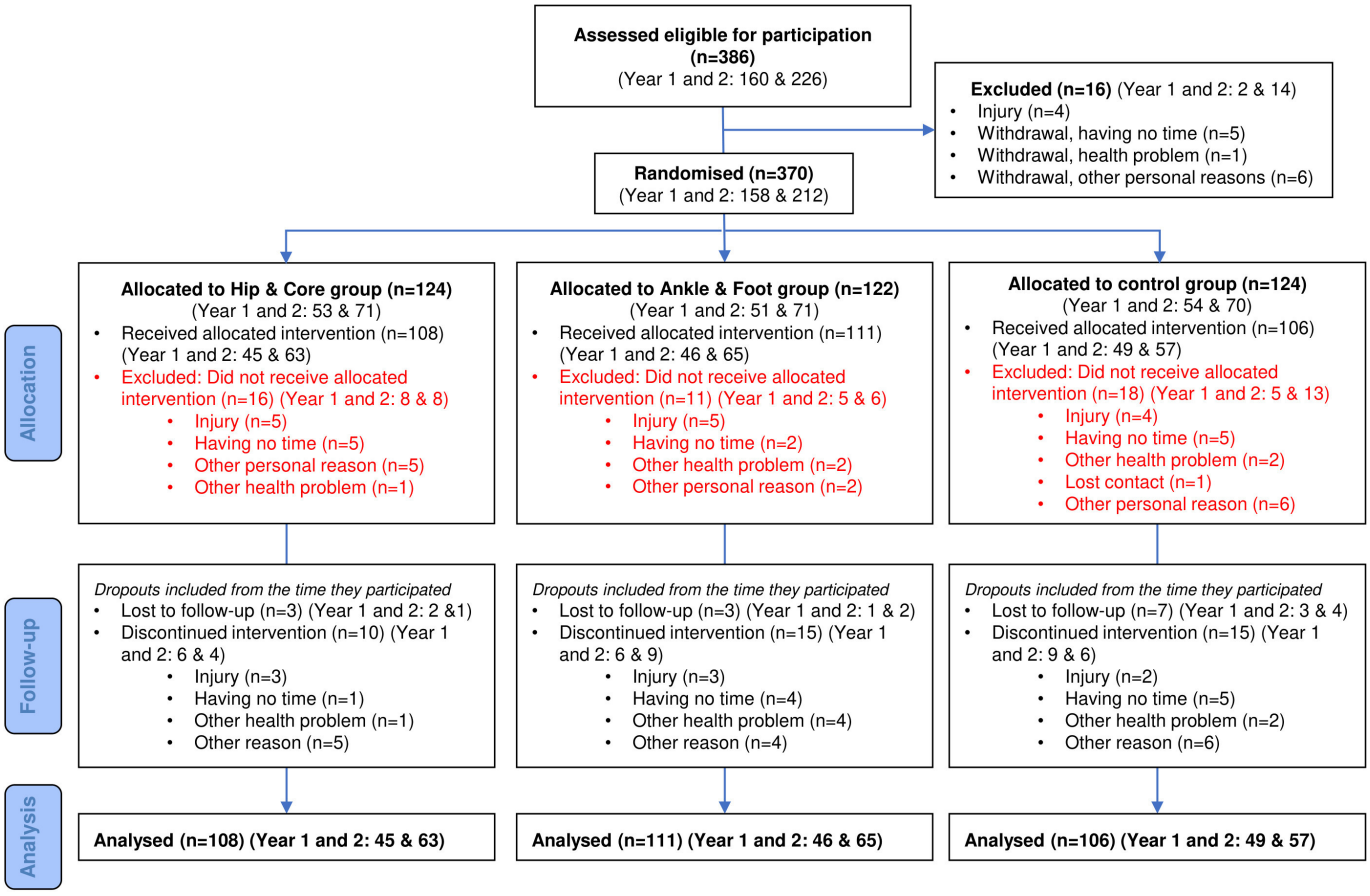

Figure 2 Flow of participants.

our study excluded participants with such physical disabilities that prevented their participation in regular running. Our author team is gender balanced and includes junior, mid-career and senior researchers and one graduate student, and represents multiple disciplines including health sciences, medicine, exercise physiology, biomechanics and statistics. Our research assistants and physiotherapists were from different genders and ages and included both experienced and beginner-level professionals.

RESULTS

Participants

A total of 386 volunteers were originally assessed eligible for participation during two study years. Of these, 16 were excluded before randomisation (figure 2). Altogether 370 participants were randomised into the hip and core group (n=124), ankle and foot group (n=122) or control group (n=124). Of these, 45 participants withdrew from the study before the start of the intervention phase and hence did not receive the allocated intervention. The 325 participants who started the intervention phase were analysed according to their originally assigned group from the time they participated (table 1).

Response rate

In total, 6736 weekly health reports were collected during the 24-week study. The average response rate to the weekly questionnaire was 94.7%. The response rate in the hip and core group was 94.1% (95.1% in females and 91.2% in males), in ankle and

Table 1 Baseline characteristics of participants in intervention groups (hip and core and ankle and foot) and control group

	Hip and core (n=108)	Ankle and foot (n=111)	Control (n=106)
Age, years, mean (SD)	39.9 (8.7)	40.6 (8.5)	39.9 (9.3)
Sex: female/male, n (%)	82 (75.9)/26 (24.1)	85 (76.6)/26 (23.4)	78 (73.6)/28 (26.4)
Height, cm, mean (SD)	168.4 (10.3)	170.1 (7.9)	169.9 (8.2)
Body mass, kg, mean (SD)	71.7 (12.9)	73.6 (13.4)	73.8 (12.8)
BMI, kg/m^2, mean (SD)	25.4 (5.4)	25.4 (3.9)	25.5 (3.9)
Running experience, months (SD)	9.3 (8.5)	9.1 (7.6)	8.2 (7.2)
Running sessions per week during past 6 weeks, mean (SD)	0.8 (0.8)	0.9 (0.9)	1.1 (1.0)
Running km per week during past 6 weeks, mean (SD)	4.6 (4.9)	5.0 (5.3)	5.2 (5.8)
LE injury/complaint during past 12 months, yes, n (%)	28 (25.9)	37 (33.3)	32 (30.2)
Any previous LE orthopaedic surgery,* yes, n (%)	15 (13.9)	15 (13.5)	13 (12.3)

*No participants had an orthopaedic surgery during the past 12 months.
BMI, body mass index; LE, lower extremity; SD, standard deviation.

foot group 95.3% (95.2% in females and 95.3% in males) and in control group 94.8% (95.8% in females and 92.1% in males).

Injury characteristics

Altogether 310 RRIs were registered, of which 283 (91%) were LE injuries. The vast majority (87%) of LE injuries were overuse injuries (n=245). The remaining 13% were acute injuries (n=38). Details of all registered injuries separately for female and male participants in three groups are represented in online supplemental table 2.

Exposure and adherence

In total, 12 441 hours of running exposure were registered (online supplemental table 3). No significant differences in running exposure hours were observed between the groups.

Hip and core group participants completed 4873 intervention training sessions (mean 2.0 per week), ankle and foot group 4811 intervention training sessions (1.9 per week) and control group 4261 training sessions (1.9 per week), with no significant group differences in the number of weekly sessions. Average weekly adherence was 89% in the hip and core group, 88% in the ankle and foot group and 87% in the control group. The hours spent on intervention training were higher in both hip and core and ankle and foot group compared with control group (online supplemental table 3).

Intervention effects on the incidence of all LE injuries

Altogether 75 LE injuries were registered in the hip and core group (17.2 injuries per 1000 hours of running exposure, 95% CI 13.6 to 21.4), 114 in ankle and foot group (26.6, 95% CI 22.0 to 31.8) and 94 in control group (24.8, 95% CI 20.2 to 30.3). Significant intervention effect in the incidence rate of all LE injuries was observed in the hip and core group compared with control group (HR 0.66; 95% CI 0.45 to 0.97, p=0.034), but not in the ankle and foot group (HR 1.06; 95% CI 0.74 to 1.50, p=0.759). In addition, a significantly lower incidence rate of time-loss injuries was observed in the hipand core group (HR 0.65; 95% CI 0.42 to 0.99, p=0.044) compared with control group. No difference was observed in the incidence rate of time-loss injuries in ankle and foot group (HR 1.05; 95% CI 0.72 to 1.54, p=0.800) compared with control group. Survival curves of the three groups are presented in figure 3.

Intervention effects on the prevalence of overuse LE injuries

45 (42%) participants in the hip and core group, 65 (59%) in the ankle and foot group and 57 (54%) in the control group reported at least one LE overuse injury episode during the study.

The average weekly prevalence of LE overuse injuries was 9.2% in the hip and core group, 12.0% in the ankle and foot group and 15.5% in the control group (figure 4). The prevalence of LE overuse injuries was 39% lower in the hip and core group compared with control group (prevalence rate ratio, PRR 0.61; 95% CI 0.39 to 0.96) (table 2). No significant difference was observed between the ankle and foot group and control group in the prevalence of LE overuse injuries (PRR 0.83; 95% CI 0.55 to 1.25).

30 (28%) participants in the hip and core group, 37 (33%) in the ankle and foot group and 34 (32%) in the control group reported at least one episode of substantial overuse injury during the study. The average weekly prevalence of substantial LE overuse injuries was 3.3%, 5.0% and 7.7% in the hip and core, ankle and foot, and control groups, respectively (figure 5). A significantly lower prevalence of substantial LE overuse injuries was observed in the hip and core group compared with control group (PRR 0.48; 95% CI 0.27 to 0.90), but not in the ankle and foot group (PRR 0.69; 95% CI 0.40 to 1.19).

When analysing body parts separately, hip and core group had significantly lower prevalence of thigh (PRR 0.21, 95% CI 0.05 to 0.92) and foot (PRR 0.31, 95% CI 0.11 to 0.83) overuse injuries (table 2) compared with the controls.

Intervention effects on the incidence of acute LE injuries

Nine (8%) participants in the hip and core group, 15 (14%) in ankle and foot group and 4 (4%) in control group had at least one acute LE injury during the study. The majority of acute injuries were muscle strains and spasms affecting the thigh and calf (online supplemental table 2). The incidence of acute LE injuries was 2.52 injuries per 1000 hours of running exposure in the hip and core group, 5.37 in ankle and foot group and 1.06 in control group (table 3). There was no significant difference in the incidence rate of acute LE injuries between the hip and core and control group (HR 2.08, 95% CI 0.64 to 6.75), whereas significantly higher incidence rate was observed in the ankle and foot group compared with control group (HR 3.60, 95% CI 1.20 to 10.86).

Similarly, when analysing acute injuries leading time-loss from running training, the incidence rate of time-loss LE injuries was significantly higher in the ankle and foot group compared with control group (HR 6.10, 95% CI 1.38 to 27.07).

Adverse events

Three acute injuries occurred during intervention training in the hip and core group. These injuries were all minor injuries and included two muscle injuries of the thigh (no time-loss) and one unspecified acute pain of the gluteal muscles (no time-loss).

No acute injuries were reported occurring in the ankle and foot group intervention training.

Two acute injuries were reported occurring during control group training, that is, static stretching: one patella dislocation (time-loss 30 days) and one muscle strain of the neck (no time-loss).

DISCUSSION

This study evaluated the efficacy of two different exercise programmes for reducing all-complaint LE injuries in adult novice recreational runners. Our study found that the hip and core training programme was effective in reducing LE injuries in novice recreational runners. However, this reduction was mainly seen in the prevalence of LE overuse injuries. The ankle and foot programme did not significantly reduce injuries in novice recreational runners.

Effects on overuse LE injuries

The most important finding of our study was a 39% lower prevalence of all and 52% lower prevalence of substantial overuse injuries in novice runners performing hip and core-focused programme compared with group performing static stretching before running. During the 24-week study, the weekly prevalence of all and substantial overuse injuries in hip and core group was nearly every study week lower than in the static stretching group. Our findings are novel and highlight the ability of hip and core strengthening exercises to prevent RRIs. We furthermore observed no substantial harms involved with the hip and core-focused programme.

Only some previous RCTs have investigated running injury prevention using the hip and core-focused, so-called top-down

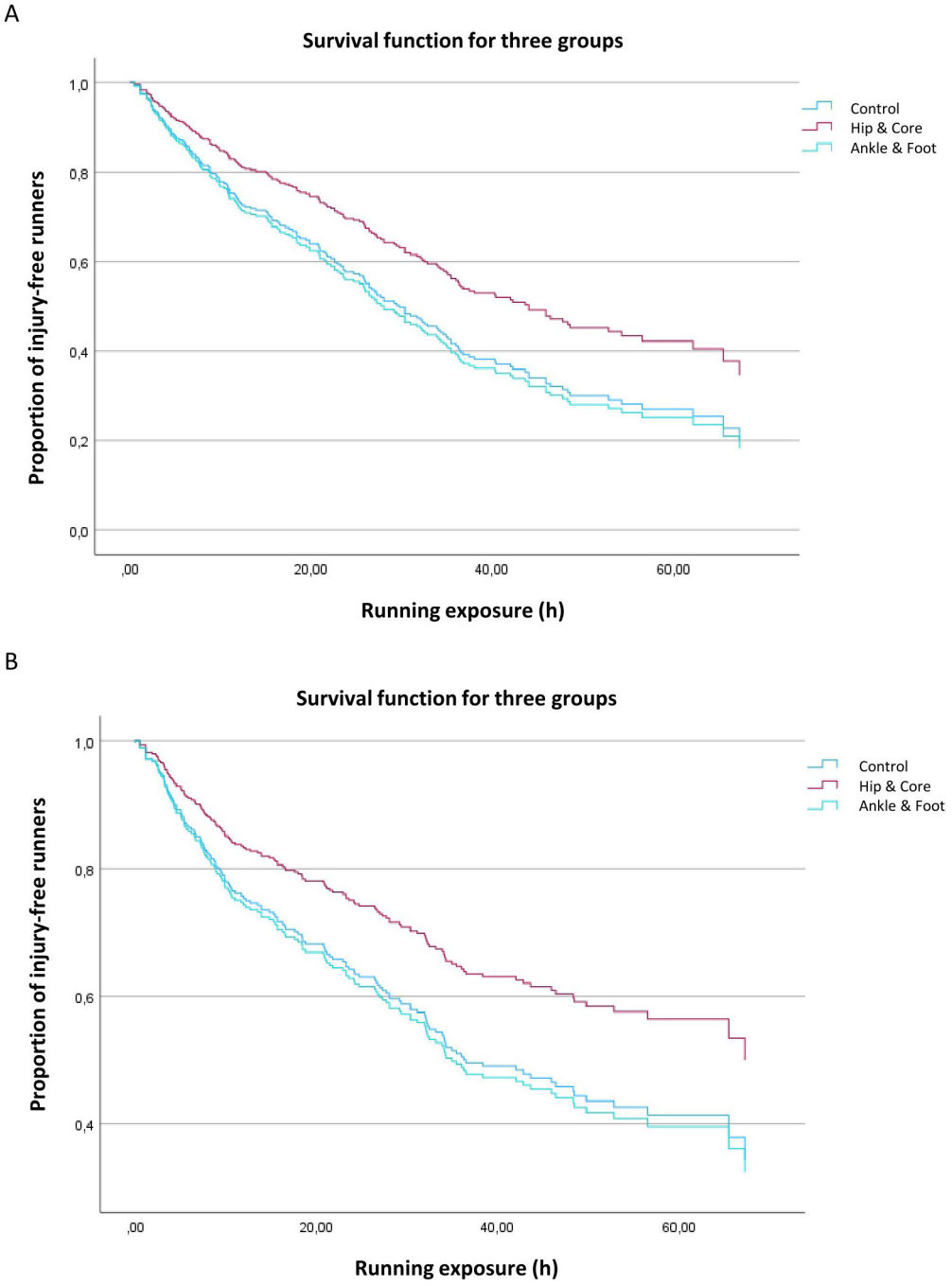

Figure 3 Survival curves of three groups without any running-related lower extremity injury (A) and without running-related lower extremity time-loss injury (B). Red line represents hip and core group, green line ankle and foot group, and blue line control group.

approach. Toresdahl *et al* reported no effect of a 12-week home-based strength training programme targeted on the quadriceps, hip abductors and core muscles on the risk of RRIs in 720 first-time marathon runners.[15] In another smaller pilot study, a home-based functional strength and balance training with BOSU-ball was not effective in reducing injuries in novice runners during 2 months training and 4 months maintenance period.[14] A major difference in relation to our study was the home-based intervention in both of these previous studies. Lack of supervision in home-based training may lead to lower adherence and incorrect training technique and intensity,[15] which may affect the outcome. In addition, the intensity of our hip and core-focused programme with using resistance and multiple progressions may have been higher compared with Toresdahl *et al*, where the programme included squats, lunges, planks and toe touches without resistance and only two levels of progression. In our study, the strength exercises were instructed to feel heavy and to be performed until fatigue, but with good quality. Also, the intervention phases in both of the two aforementioned studies were shorter compared with our 6-month follow-up.

In our study, we did not find clear evidence to support the bottom-up theory as ankle and foot focused programme did not reduce overuse injuries in our novice runners. To our knowledge, only one pilot RCT[14] and one previous RCT[13] have applied the bottom-up approach to study prevention of RRIs among recreational runners. A pilot study by Baltich *et al* in 129 novice

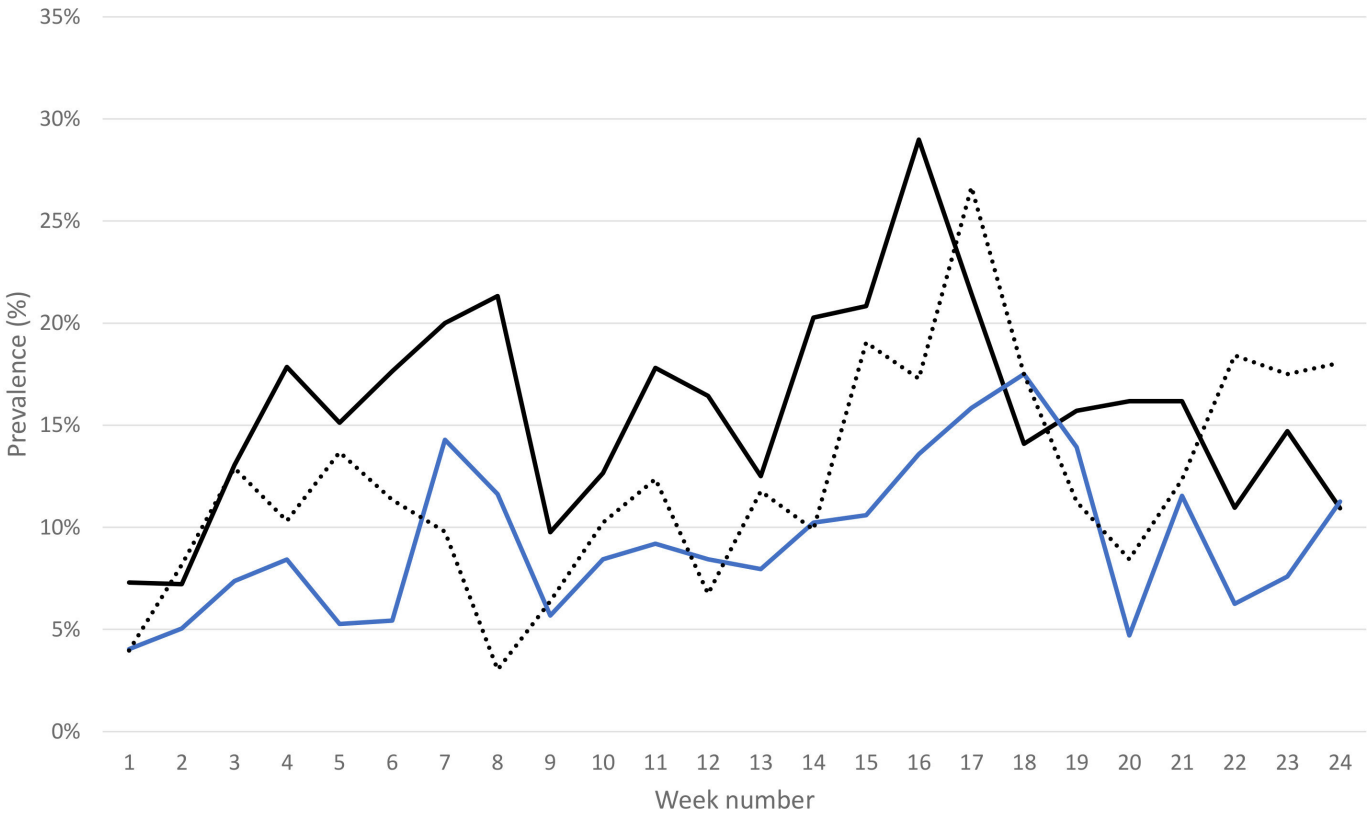

Figure 4 Prevalence of lower extremity (LE) overuse injuries in hip and core group (blue line), ankle and foot group (dashed black line), and control (black line) group during the 24 week study.

runners aimed to investigate the effects of a home-based strength training programme focusing on the muscles surrounding the ankle and found no preventive effect during 2 months training and 4 months maintenance period when compared with control group performing static stretching.[14] The study by Baltich *et al* was an exploratory study with limited statistical power and hence should not be regarded as conclusive. Taddei *et al* studied an intervention including an 8-week supervised training followed by a 10-month home-based training focused on the foot and ankle muscles.[13] The participants in the control group performing static stretching had a 2.4 times higher incidence of RRIs compared with foot strengthening group. Noteworthy, the participants in the study were more experienced runners compared with our novice runners.

It is possible that the intensity of the ankle and foot focused programme with respect to training load was not high enough to prepare for the high load demands of running, which may explain the lack of a significant preventive effect of the programme in our study. Our programme included both strengthening exercises conducted with body weight and resistance bands, but also lower intensity muscle activation and movement control exercises. The effectiveness of strength training using adequate

Table 2 Average weekly prevalence (%) of overuse lower extremity (LE) injuries and unadjusted prevalence rate ratios (PRR) with 95% CI between intervention groups and control group

	Hip and core (1) N=108	Ankle and foot (2) N=111	Control (3) N=106	(1) vs (3)	(2) vs (3)
	Prevalence (95% CI)	Prevalence (95% CI)	Prevalence (95% CI)	PRR (95% CI), p value	PRR (95% CI), p value
Overuse LE injuries	9.2 (7.9 to 10.5)	12.0 (10.6 to 13.6)	15.5 (13.8 to 17.4)	0.61 (0.39 to 0.96), 0.032*	0.83 (0.55 to 1.25), 0.372
Secondary outcomes					
Substantial overuse LE injuries†	3.3 (2.6 to 4.1)	5.0 (4.1 to 6.0)	7.7 (6.6 to 9.0)	0.48 (0.27 to 0.90), 0.021*	0.69 (0.40 to 1.19). 0.181
Overuse hip/groin injuries	0.3 (0.1 to 0.6)	0.9 (0.6 to 1.4)	1.1 (0.7 to 1.6)	0.21 (0.04 to 1.27), 0.090	0.83 (0.27 to 2.54), 0.742
Overuse thigh injuries	0.2 (0.8 to 0.5)	0.7 (0.4 to 1.1)	1.2 (0.8 to 1.8)	0.21 (0.05 to 0.92), 0.039*	0.59 (0.21 to 1.60), 0.293
Overuse knee injuries	2.4 (1.8 to 3.1)	2.2 (1.7 to 2.9)	3.4 (2.7 to 4.3)	0.84 (0.35 to 1.99), 0.688	0.66 (0.27 to 1.64), 0.372
Overuse lower leg injuries‡	3.8 (3.0 to 4.7)	4.4 (3.6 to 5.3)	4.3 (3.5 to 5.3)	0.84 (0.38 to 1.87), 0.668	1.03 (0.48 to 2.18), 0.949
Overuse ankle injuries	1.2 (0.8 to 1.7)	0.9 (0.6 to 1.4)	1.1 (0.8 to 1.7)	0.95 (0.22 to 4.13), 0.945	1.08 (0.26 to 4.43), 0.914
Overuse foot injuries§	1.0 (0.6 to 1.5)	2.1 (1.6 to 2.7)	2.9 (2.3 to 3.8)	0.31 (0.11 to 0.83), 0.020*	0.76 (0.37 to 1.62), 0.498

*P value less than 0.05.
†Substantial injuries defined as those leading to moderate to severe modifications in training and/or performance.
‡Includes injuries of tibia, fibula, calf and Achilles tendon.
§Includes injuries of foot, toes, calcaneus and plantar fascia.

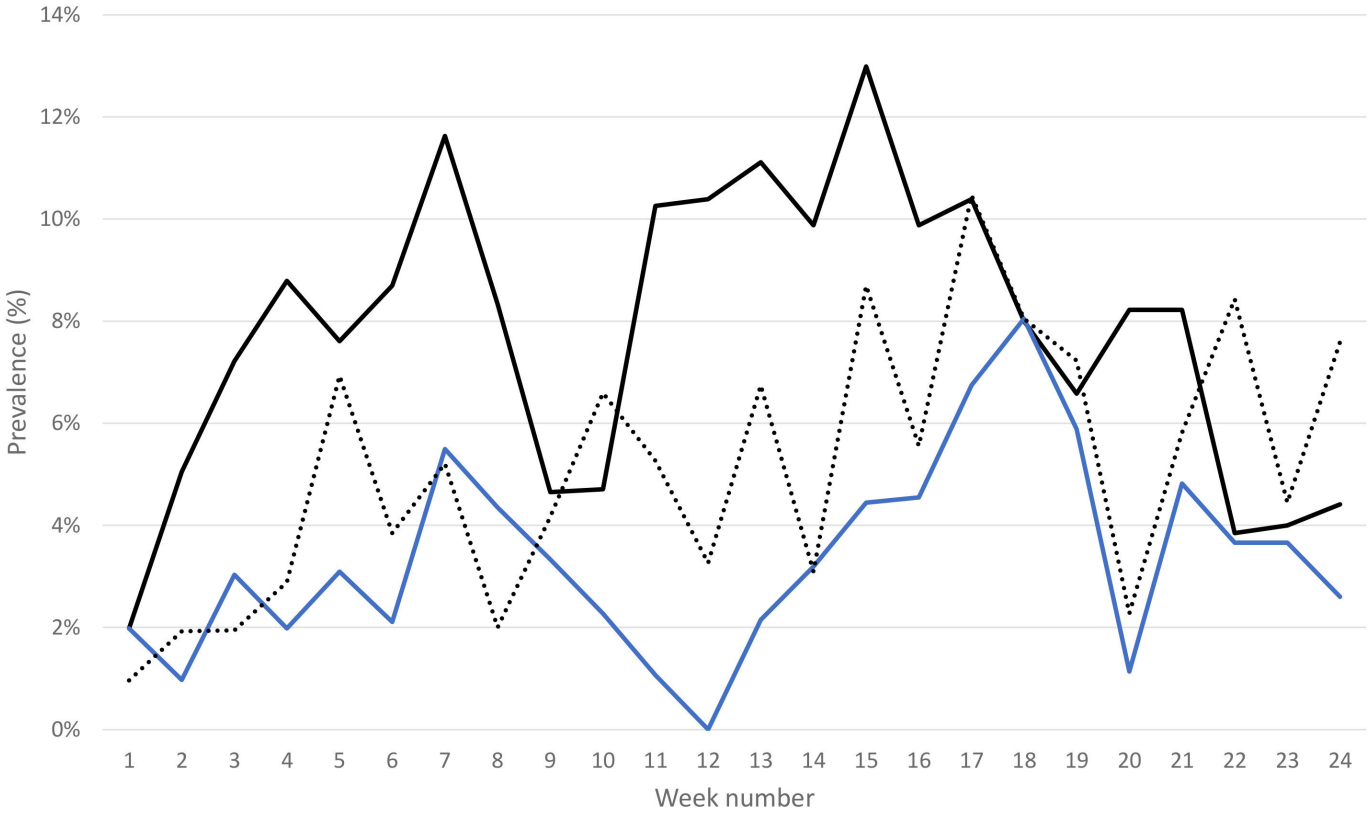

Figure 5 Prevalence of substantial lower extremity (LE) overuse injuries in hip and core group (blue line), ankle and foot group (dashed black line), and control (black line) group during the 24-week study.

external loads should be investigated in future. Another aspect to consider is the feasibility of the intervention. In relation to hip and core programme, which included many commonly used exercises such as lunges and planks, most of the exercises in ankle and foot programme were unfamiliar to participants. Participants reported some difficulties in learning the isometric and resistance band ankle and foot exercises. Hence, the intensity of training in those movements may have been lower than planned, especially at the beginning of the training period. Nevertheless, the progression of the training succeeded well in both ankle and foot and hip and core groups, at least in the supervised sessions as participants were able to increase the number of repetitions as well as increase the resistance during the training period (data are not shown). Due to the high heterogeneity of the participants and their fitness levels, it is still possible that the overall training load was too low for the most fit participants.

It should be noted that we observed a small and non-significant difference in the prevalence of overuse injuries in both intervention groups compared with control group (4.0% vs 7.3%, p=0.52) during the first intervention week (figure 4). Most likely this small difference occurred by chance and is not related to intervention effects. We ran additional analyses to determine if the difference in the prevalence during the first 2 weeks had an influence on the outcome. Deleting the first 2 weeks from all participants did not change the observed difference in the average weekly prevalence between the hip and core and the control group. Similarly, excluding those participants who reported an overuse injury at the first week did not influence the results. Therefore, we did not exclude weeks or participants from the analysis of overuse injuries.

Effects on acute LE injuries

Although the hip and core-focused training was effective in reducing the risk of overuse injuries, we did not observe the same effect on prevention of acute RRIs. In our study, 95% of acute injuries affected the hip/groin, thigh, or calf, and nearly all of these injuries were muscle strains and cramps occurring during running intervals or uphill/downhill running. Previous studies have demonstrated a protective effect of strength training

Table 3 Incidence of acute LE injuries per 1000 hours of running exposure in three study groups and unadjusted Cox proportional HR with 95% CIs between interventions and control group

	Hip and core (1) N=108		Ankle and foot (2) N=111		Control (3) N=106		(1) vs (3)	(2) vs (3)
	n	Incidence (95% CI)	n	Incidence (95% CI)	n	Incidence (95% CI)	HR (95% CI), p value	HR (95% CI), p value
Acute LE injuries	11	2.52 (1.32 to 4.38)	23	5.37 (3.48 to 7.92)	4	1.06 (0.34 to 2.55)	2.08 (0.64 to 6.75), 0.224	3.60 (1.20 to 10.86), 0.023*
Secondary outcomes								
Acute time-loss LE injuries	10	2.29 (1.16 to 4.08)	21	4.90 (3.11 to 7.36)	2	0.53 (0.09 to 1.75)	4.10 (0.89 to 18.98), 0.071	6.10 (1.38 to 27.07), 0.017*

*p<0.05.
LE, lower extremity.

on acute muscle injuries[25 32] and it is hence somewhat surprising that our hip and core-focused strengthening programme did not reduce the incidence of acute muscle injuries. However, as the overall number of acute injuries was low and the size of our study was not powered for analysing acute injuries alone any firm conclusions regarding the effect of hip and core programme on the risk of acute injuries in runners cannot be made.

In our study, we also noticed the incidence of acute injuries, specifically muscle strains, was significantly higher in the ankle and foot group compared with control group. As the number of acute foot and ankle injuries did not differ from the control group, the fatigue induced by the ankle and foot strength training is not likely to explain the higher rate of acute injuries. As a clear difference was observed in the incidence of calf and thigh muscle injuries, it can be hypothesised that ankle focused training alone does not prepare the large muscles of the LE for high-speed running where muscle injuries mainly occurred. Thus, a possible implication of our findings could be that the prerunning ankle and foot focused training without any other LE strength or stretching exercises is not recommended, especially before running training including sprints as this type of training may increase the risk of acute muscle injuries in these activities.

A general evidence-based consensus of static stretching as a part of warm-up has been that it is a harmless, but mostly ineffective sport injury prevention method[9 10] For this reason, we, among others,[13 14] decided to use static stretching in the control group. The studies where a stretching intervention has been implemented have mainly been conducted in military populations or runners where most of the injuries are overuse injuries.[33] However, there is evidence that stretching may be beneficial in reducing the risk of certain acute injury types including muscle strains.[33 34] Interestingly, the lowest incidence of both all and time-loss acute LE injuries in our study was observed in the control group performing stretching. Furthermore, the incidence of acute LE injuries was significantly lower in the stretching group compared with ankle and foot group. Although subanalysis of acute injuries by body parts or injury types was not possible in the current study, we observed a notably low number of acute thigh and calf injuries in the stretching group supporting the previous findings of possible beneficial effect of stretching on the risk of muscle injuries.[33 34] Nevertheless, as most of the RRIs are overuse injuries and the size of our study was not powered for investigation of acute injuries alone, these results of a possible preventive effect of stretching in relation to acute injuries should be taken as preliminary rather than conclusive.

Strengths and limitations

Our study is the first RCT that evaluates the effect of both top-down and bottom-up approaches in prevention of RRIs among novice recreational runners. We had a long intervention period with supervised exercise interventions and supervised stretching programme as a control group. Our interventions included only limited equipment with low costs increasing the feasibility of the programme. We used validated questionnaires and methodology to register and analyse all complaint injuries. We collected individual data on exposure and adherence, and we contacted every participant reporting an injury for a telephone interview. In addition, the response rate to the weekly injury questionnaires was very high and the dropout rate was planned for and manageable.

Some limitations existed. For obvious reasons, the blinding of the participants and physiotherapists responsible for the training groups was not possible. However, the upside was that the participants and physiotherapists were not informed about the existence of a control group and the participants were also not informed about the contents of other groups. Therefore, we believe we were able to avoid contamination between the groups. We were not able to rule out the effect of the physiotherapist on the outcome. However, we aimed to minimise this effect by instructing the physiotherapists to guide the running training in all groups as similarly as possible. This meant that all instructions on level of intensity, training volume and running technique were given at a group level without individualising the instructions to any participants. Therefore, we believe the effect of the physiotherapist was small and most importantly, similar in all groups. It is important to acknowledge that our study aimed to investigate the efficacy of the exercise programmes in ideal conditions. Future studies should investigate the real-world effectiveness of the hip and core programme ideally separately for female and male novice runners to determine if the same effect can be achieved without the guidance from the physiotherapist.

Using injury registration based on self-reported questionnaires and not being able to diagnose injuries is a limitation of our study. We also acknowledge that the OSTRC questionnaire was originally developed for competitive athletes and has not been validated for recreational runners. Especially the questions regarding performance and modified training may have been difficult for non-competitive participants. Average adherence to the training was a little less than recommended 3–4 times a week, but nearly similar in all groups. Grouping of known acquaintances was necessary to avoid the risk of contamination between groups. This may have caused some risk of bias in case the participants who knew each other were influenced by each other for example to report or not report an injury. Ideally, the intervention results would have been calculated separately for females and males, but due to a low number of male volunteers, this was not possible. While our sample size was sufficient to detect between group differences in primary outcome, secondary analyses on acute injuries and injuries of different body parts may not have been sufficiently powered and should be regarded as preliminary. Finally, the generalisability of the findings is limited to novice recreational runners, and mostly females, and the results cannot be generalised to other cohorts or more experienced runners.

CONCLUSIONS

The hip and core-focused exercise programme when compared with static stretching was effective in preventing LE overuse injuries in novice recreational runners. The ankle and foot focused programme was not effective in reducing injuries in novice recreational runners and seemed to be associated with a higher incidence of acute muscle injuries when compared with static stretching.

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