JOURNAL OF SPORTS SCIENCES, 2016
http://dx.doi.org/10.1080/02640414.2015.1137343

Routledge
Taylor & Francis Group

Effects of strengthening and stretching exercise programmes on kinematics and kinetics of running in older adults: a randomised controlled trial

Reginaldo K. Fukuchi[a], Darren J. Stefanyshyn[b], Lisa Stirling[c] and Reed Ferber[d]

[a]Biomedical Engineering, Centre for Engineering, Modelling and Applied Social Sciences (CECS), Federal University of ABC (UFABC), Sao Bernardo do Campo-SP, Brazil; [b]Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Calgary, Canada; [c]Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Calgary, Canada; [d]Faculties of Kinesiology and Nursing, University of Calgary, Calgary, Canada

ABSTRACT

The aim of this study was to investigate the effects of strengthening and stretching exercises on running kinematics and kinetics in older runners. One hundred and five runners (55–75 years) were randomly assigned to either a strengthening ($n = 36$), flexibility ($n = 34$) or control ($n = 35$) group. Running kinematics and kinetics were obtained using an eight-camera system and an instrumented treadmill before and after the eight-week exercise protocol. Measures of strength and flexibility were also obtained using a dynamometer and inclinometer/goniometer. A time effect was observed for the excursion angles of the ankle sagittal ($P = 0.004$, $d = 0.17$) and thorax/pelvis transverse ($P < 0.001$, $d = 0.20$) plane. Similarly, a time effect was observed for knee transverse plane impulse ($P = 0.013$, $d = 0.26$) and ground reaction force propulsion ($P = 0.042$, $d = -0.15$). A time effect for hip adduction ($P = 0.006$, $d = 0.69$), ankle dorsiflexion ($P = 0.002$, $d = 0.47$) and hip internal rotation ($P = 0.048$, $d = 0.30$) flexibility, and hip extensor ($P = 0.001$, $d = -0.48$) and ankle plantar flexor ($P = 0.01$, $d = 0.39$) strength were also observed. However, these changes were irrespective of exercise group. The results of the present study indicate that an eight-week stretching or strengthening protocol, compared to controls, was not effective in altering age-related running biomechanics despite changes in ankle and trunk kinematics, knee kinetics and ground reaction forces along with alterations in muscle strength and flexibility were observed over time.

ARTICLE HISTORY
Accepted 24 December 2015

KEYWORDS
Running; biomechanics; ageing; exercise; clinical trial

Introduction

There has been an increased running participation among older individuals in the last decade (Jokl, Sethi, & Cooper, 2004) along with an observed increased rate of running-related injuries in older runners compared to young (McKean, Manson, & Stanish, 2006; Taunton et al., 2003). Older runners are more likely to have multiple injuries and soft-tissue type lower extremity injuries (e.g., calf and Achilles tendon injuries) (McKean et al., 2006). These increased injury rates have been associated with age-related running gait changes (DeVita et al., 2015; Fukuchi & Duarte, 2008; Fukuchi, Eskofier, Duarte, & Ferber, 2011). Several age-related running biomechanical features have also been observed in injured runners, both prospectively and retrospectively, such as an increased knee angular impulse (Stefanyshyn, Stergiou, Lun, Meeuwisse, & Worobets, 2006), increased vertical ground reaction force (Hreljac, 2004) and reduced lower extremity joint range of motion (Grau et al., 2011). These age-related gait changes are, in turn, presumably caused by the observed muscle weakness and lack of flexibility associated with biological ageing (Fukuchi, Stefanyshyn, Stirling, Duarte, & Ferber, 2014; McGibbon, 2003). Hence, one may speculate that restoring the impaired muscle strength or flexibility in older runners could alter these age-related running biomechanics and potentially prevent running injuries. However, this hypothesis has not been specifically addressed.

Muscle strengthening and flexibility exercises have been recommended to mitigate the effects of biological ageing (Cyarto, Moorhead, & Brown, 2004). These exercises have also been recommended to prevent injuries in runners (Johnston, Taunton, Lloyd-Smith, & McKenzie, 2003). Despite these facts, few studies have attempted to examine the effects of strengthening or stretching exercises on running biomechanics despite claims that atypical running patterns could be modifiable through these exercises. For example, little to no changes in running biomechanical variables were observed following a hip-muscle strengthening programme for younger runners with (Earl & Hoch, 2011) and without injuries (Snyder, Earl, O'Connor, & Ebersole, 2009). Regarding stretching exercises, the evidence is even more scarce as previous studies have focused on only the effects on running kinematics in healthy younger runners (Davis Hammonds, Laudner, McCaw, & McLoda, 2012). Considering these aforementioned studies investigated only younger runners, the ability to extrapolate results in an older population is limited.

Although regular running may benefit general health in older adults, it seems that running is not sufficient to

CONTACT Reed Ferber rferber@ucalgary.ca Running Injury Clinic, Faculties of Kinesiology and Nursing, University of Calgary. 2500 University Drive NW, T2N 1N4, Canada, phone: (403) 210-6468, fax: (403) 289-9117.
Supplemental data for this article can be accessed here.

restore either age-related muscle function or gait impairments. Marcell, Hawkins, and Wiswell (2014) found that running alone was not sufficient to prevent the loss of muscle strength with ageing. In agreement with this finding, our previous study observed reduced muscle strength and flexibility in older runners compared to young runners (Fukuchi et al., 2014). In regards to the gait biomechanical patterns Savelberg, Verdijk, Willems, and Meijer (2007) observed that the age-related gait changes are recalcitrant to regular running practice suggesting that running itself may not be sufficient to alter age-related gait changes and more specific exercises should be incorporated in the older runners' training.

Several studies have reported substantial increases in muscle strength and flexibility following an exercise-training programme in older sedentary adults which have been supporting the prescription of these exercises to counteract the ageing effects (Chodzko-Zajko et al., 2009). However, the effects of these exercises in preventing the effects of ageing on strength and flexibility in older runners remain poorly understood.

Therefore, the purpose of this study was to investigate the effects of strengthening and stretching exercises on running kinematic and kinetic variables in older runners. Our overarching hypothesis is that both strengthening and stretching exercises, compared to controls, would be effective at modifying age-related changes in running biomechanics.

Methods

Study design and participants

Recreational runners, between 55 and 75 years, were recruited from local races and posted flyers to participate in a randomised controlled trial study investigating the effect of strengthening (n = 36) and flexibility (n = 34) exercises with respect to a control group (n = 35). Participants were screened by a certified athletic therapist and excluded if they presented any of the following conditions: lower extremity injury within the last 3 months, surgery to the lower extremity within the last 8 months, head injury/vestibular disorder within the last 6 months and inability to speak or read English. All participants were injury-free and participated in running a minimum 10–20 km · week^{-1}. All the participants included in the study reported they were comfortable with treadmill running. Additionally, a 3-min treadmill familiarisation period was allowed for the participants to adapt to the testing condition (Pohl, Lloyd, & Ferber, 2010). Assessments were performed at baseline and at 8 weeks. The study was approved by the Conjoint Health Research Ethics Board (#23344) and was registered with clinicaltrials.gov.

Thirty-five participants per group were required to power the study based on an a priori power analysis using an effect size of 0.3 (Cohen, 1988), α = 0.05; β = 0.20; three-group intervention, two measurements and approximately 15% dropout. One hundred and five participants were randomised into strengthening, flexibility or control groups (Figure 1). The

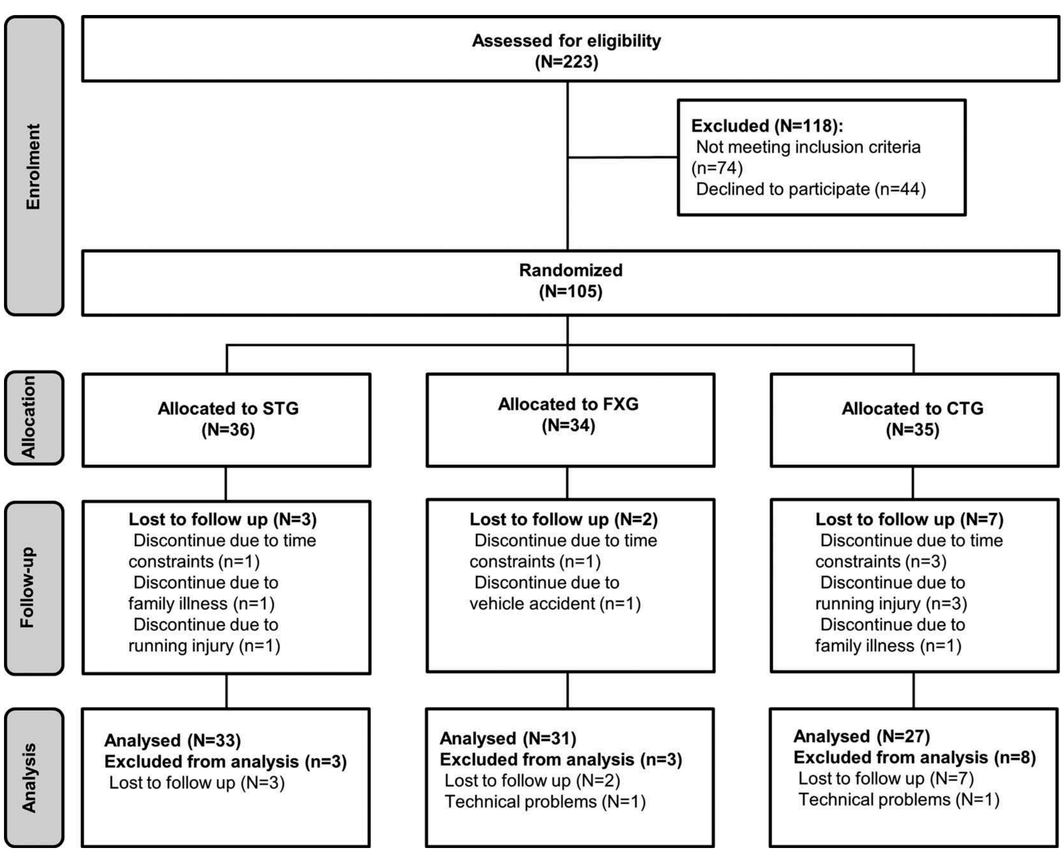

Figure 1. Flow diagram of the participants through the phases of the randomised controlled trial of three groups.

randomisation, using the minimisation procedure (Scott, McPherson, Ramsay, & Campbell, 2002), was used to optimise balance across groups for the factors of age, sex, body mass index, overall flexibility and strength. An administrator, not involved in the recruitment or evaluation of trial participants, managed the randomisation procedure and the results were stored electronically. The randomisation procedure was concealed from the research personnel and an athletic therapist who could not, by definition, be blinded carried out the weekly appointments.

Running biomechanical measures

The primary outcome variables were age-related running biomechanical variables identified in a previous study (Fukuchi et al., 2014). Biomechanical data were collected using an eight-camera motion capture system (MX3, Vicon Inc., Oxford, UK). A combination of anatomical and tracking markers was used to determine the position and orientation of the segments in 3D space. This gait model has displayed good reliability and a detailed description of the model can be found elsewhere (Fukuchi et al., 2014; Pohl et al., 2010). Following a standing calibration trial, the participants were requested to run at 2.7 $m \cdot s^{-1}$ on an instrumented treadmill (Bertec, Columbus, OH, USA) while wearing standard neutral shoes (Nike Air Pegasus, Nike, Portland, OR, USA). A 30-s running trial was recorded at the target speed after the accommodation period.

The kinematic and the ground reaction forces data were collected at 200 and 1000 Hz, respectively. Heel strike and toe off were identified when the vertical ground reaction force crossed a 40 N threshold. Kinematic and ground reaction forces data were filtered using a fourth order low-pass Butterworth filter with cut-off frequencies of 10 and 50 Hz, respectively. Three-dimensional angles of the trunk–pelvis (Tho/Pel), hip, knee and ankle were calculated using Euler angles adopting the following convention: the first rotation was described occurring in the medio-lateral axis (*z*-axis, perpendicular to the sagittal plane) which defines the flexion–extension movement; the third rotation was described around the longitudinal axis (*y*-axis, perpendicular to the transverse plane) which defines the internal/external rotations; and the second rotation was described around an axis perpendicular to the previous, which in the anatomic position represents the anterior–posterior axis (*x*-axis, perpendicular to the frontal plane) where abduction/adduction occur. This convention is simply defined as *Z*–*X*–*Y* convention and is frequently used to describe the lower extremity rotations (Cappozzo, Catani, Croce, & Leardini, 1995). Additionally, internal joint moments and joint powers were calculated using a standard inverse dynamics approach and Visual3D software (C-motion Inc., Germantown, MD, USA). Joint power was calculated as the product of the moment and angular velocity, and joint impulse and work were computed as the area under the moment–time and power–time curves, respectively. The joint kinetic and the ground reaction force variables were normalised by the participant's body mass.

Individual and group mean parameters were obtained, from 10 footfalls, using custom-written software developed in Matlab 7.12 (Mathworks Inc., Natick, MA, USA). The excursion angle of the hip, ankle and the trunk/pelvis during running were extracted and the knee abduction, knee external rotation and ankle abduction impulses were quantified. The knee and ankle positive work along with the ground reaction force vertical active peak, the maximal ground reaction force loading rate and the ground reaction force propulsion peak were also measured. These biomechanical variables were considered since they have been consistently examined in running studies and have been associated with both biological ageing and running-related injuries (Fukuchi et al., 2014; Hreljac, 2004; Stefanyshyn et al., 2006).

Strength and flexibility measures

Maximal isometric voluntary contraction was measured using a hand-held dynamometer (Lafayette Instruments, Model01163, Lafayette, IN, USA). Three trials were obtained for the following muscle groups: hip abductor, hip extensor and ankle plantar flexor. The dynamometer was stabilised by non-elastic straps, which, in turn, were anchored to the testing bed to remove any potential influence from the tester (Figure 2). The strength measurement procedure for hip extensor and hip abductor muscle groups are shown in Figure 2(a) and (b), respectively. Passive joint range of motion was obtained using either a universal goniometer or a digital inclinometer (Pro360, SmartTool-Technology, Oklahoma-city, OK, USA) for hip adduction, hip external and internal rotation, and ankle dorsiflexion. Figure 2(c) and (d) shows the flexibility testing procedure taken for hip adduction and hip internal rotation, respectively. The coefficient of variation was employed to examine the test–retest reliability, in five participants prior the study, following a heterocedasticity examination by inspecting Bland–Altman plots and positive correlations between measurement differences against corresponding means (Nevill, 1996). A log transformation of the data was performed whenever a heterocedastic error was noticed (Nevill & Atkinson, 1997). The coefficient of variation ranged 22.1–41.6% and 23.7–43.1% for flexibility and strength measures, respectively.

Exercise intervention protocol

Participants allocated into the strengthening group performed progressive resistance exercise training that included bilateral hip, knee and ankle joints and that are generally recommended in clinical practice, involving both open and closed-kinetic chain exercise (see details in the Supplemental data). The participants were instructed to perform the exercises 6 $days \cdot week^{-1}$ for 8 weeks. For some of the strengthening exercises, elastic bands (Theraband, Hygenic-Corporation, Akron, OH, USA) were used as an external resistance method based on their feasibility in a home-based exercise programme. Instructions were given to the participants by the athletic therapist describing the desired way to move as well as how they should adjust the resistance such that the desired intensity of the exercise were within 5–8 on a 10-point perceived exertion scale (Colado et al., 2012).

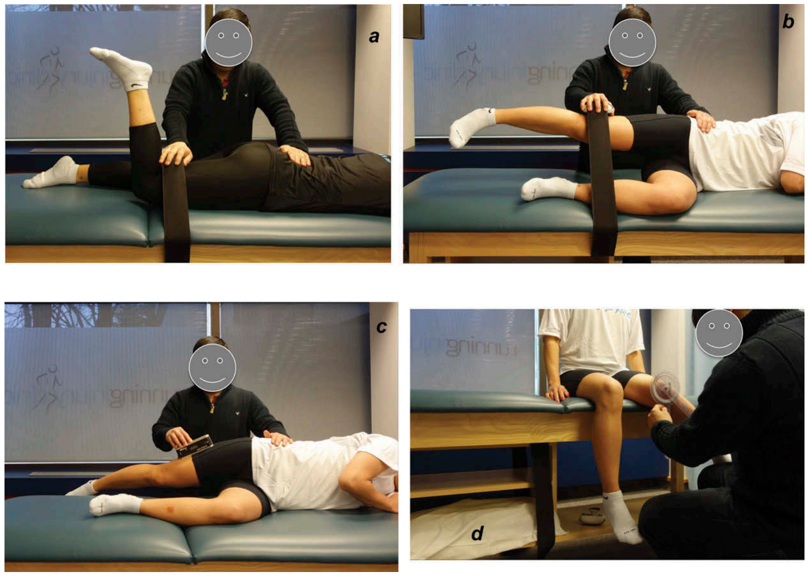

Figure 2. Maximum isometric voluntary contraction measures for hip extensors (a) and hip abductors (b). Joint flexibility measures for hip adduction (c) and hip internal rotation (d).

The participants allocated to the flexibility group performed bilateral static stretching exercises for lower extremity muscle groups. These participants were instructed to slowly stretch their targeted muscle groups until a position of mild discomfort was achieved (see Supplemental data for details). At this position, they were instructed to hold the position for approximately 15–30 s and they were asked to perform three consecutive stretching exercises for each flexibility exercise, 6 days · week^{-1} for 8 weeks, and alternating legs.

Both strengthening group and flexibility group participants initially received an individual orientation session wherein they had a chance to familiarise themselves with the exercises with assistance from the athletic therapist. To enhance adherence to the home-based exercise programme, the participants in the strengthening and flexibility groups received a comprehensive illustrated exercise booklet wherein each exercise was detailed and described in non-technical terminology along with pictures of the exercises. This booklet also served as a logbook wherein the participants were asked to indicate the frequency that they performed the weekly exercises. They also reported back to the clinic on a weekly basis to ensure they were doing the exercises properly and the athletic therapist reviewed the participants' exercise booklet. Participants in the control group did not receive any instructions regarding any exercises during 8 weeks. The control group participants were, however, strongly advised to not engage in any new exercise programme during the intervention period. At the eight-week appointment, the control group participants were asked to report any modification in their training habits or engagement in any exercises after the baseline assessment.

Statistical analysis

Generalised linear mixed models for the between group independent factors (intervention) with three levels (strengthening, flexibility and control groups) and a repeated measures factor (time) with two levels (pre- and post-intervention) were performed on a per-protocol basis. The homogeneity of variances assumption of the dependent variables was assessed through Bartlett's test. Non-orthogonal contrasts were set for the group factor, since there were three levels, to yield pairwise comparison between levels. The Cohen's *d* model-based effect size (Feingold, 2013) was quantified whenever a statistical effect was found. A significance level of 0.05 was adopted and the statistical analyses were performed using R software 3.1.2 (R-Foundation, Vienna, Austria).

Results

Of the 223 participants that were initially contacted between April and December of 2012, 74 did not meet the inclusion criteria and 44 declined to participate (Figure 1). Of the 105 participants, 93 returned for their eight-week follow-up appointment resulting in a retention rate of 88.7%. Twelve participants did not return for their post-intervention appointments and they withdrew from the study at different time periods due to a variety of reasons (Figure 1). In addition, data from two participants could not be analysed due to technical problems. Therefore, 91 participants were included in the final analysis (33 in the strengthening group, 31 in the flexibility group and 27 in the control group). The participants' demographic and anthropometric information are presented in Table 1.

Table 1. Mean (1SD) of the baseline characteristics.

Variable	Strength group	Flexibility group	Control group
Age (years)	59.8 (4.7)	59.8 (4.0)	59.9 (3.6)
Body mass (kg)	72.7 (13.4)	72.3 (11.5)	72.5 (12.1)
Body height (m)	1.72 (0.10)	1.72 (0.09)	1.72 (0.08)
BMI (kg · m^{-2})	24.4 (3.1)	24.3 (2.5)	24.3 (3.3)
Experience (years)	18.9 (15.2)	16.4 (13.6)	15.1 (12.4)
Weekly running training (h)	3.7 (1.8)	4.7 (3.3)	4.1 (2.4)

#Abbreviations: BMI: body mass index; SD: standard deviation.

None of the participants reported participation in a systematic strengthening or stretching exercise programme prior the study. However, 61.8%, 55.6% and 51.4% of the participants allocated to the flexibility, strengthening and control groups, respectively, reported they had performed some of the stretching exercises as part of their regular training routine. Similarly, 50.0%, 50.0% and 45.7% of the participants (in flexibility, strengthening and control groups, respectively) indicated previous experience performing some of the strengthening exercises. Nevertheless, the proportion of participants who reported previous experience with these protocols were similar across the strengthening ($\chi^2(2) = 0.171$, $P = 0.918$) and stretching groups ($\chi^2(2) = 0.757$, $P = 0.685$).

The participants allocated to the exercise groups presented similar frequency (strengthening group: 5.8 ± 0.7 days · week^{-1}, flexibility group: 6.1 ± 0.8 days · week^{-1}, $P = 0.233$) and weekly attendance (strengthening group: 7.0 ± 1.2 sessions, flexibility group: 6.7 ± 1.3 sessions, $P = 0.340$) indicating that they dedicated the same amount of time and received similar instructions and attention from the athletic therapist during their eight-week programme. The strengthening group participants were asked to record their perceived exertion at the end of each exercise session. On average, the participants in the strengthening group reported 6.2 (1.3) in a 10-point exertion scale, thus indicating that they were within the recommended range (5–8). Although no scale was used to monitor the dosage of the stretching exercises for the participants allocated in the flexibility group, their exercise booklet was reviewed in a weekly basis by the athletic therapist.

The flexibility and strength variables presented an overall main effect for time (pre vs. post) but no group or interaction effect was measured (Table 2). Specifically, increased flexibility for hip adduction ($\chi^2(1) = 7.68$, $P = 0.006$, $d = 0.69$), ankle soleus ($\chi^2(1) = 9.76$, $P = 0.002$, $d = 0.47$), ankle gastrocnemius ($\chi^2(1) = 8.65$, $P = 0.003$, $d = 0.43$) and hip internal rotation ($\chi^2(1) = 3.89$, $P = 0.048$, $d = 0.30$) were measured whereas hip external rotator ($\chi^2(1) = 2.35$, $P = 0.125$) flexibility remained the same compared to baseline values. Muscle strength measures exhibited increased ankle plantar flexor ($\chi^2(1) = 6.41$, $P = 0.011$, $d = 0.39$) but reduced hip extensor ($\chi^2(1) = 10.38$, $P = 0.001$, $d = -0.48$) and hip abductor strength remained unaltered ($\chi^2(1) = 0.46$, $P = 0.497$) following 8 weeks of intervention and compared to baseline values.

Significant main effects for time were observed, but a group or interaction effect was not measured for some running biomechanical variables (Table 2). Specifically, increased ankle sagittal excursion angle ($\chi^2(1) = 8.43$, $P = 0.004$, $d = 0.17$), thorax/pelvis transverse excursion angle ($\chi^2(1) = 14.53$, $P < 0.001$, $d = 0.20$) and knee transverse impulse ($\chi^2(1) = 6.24$, $P = 0.012$, $d = 0.26$) were measured. On the other hand, a reduced ground reaction force propulsion peak was measured following intervention and compared to baseline values ($\chi^2(1) = 4.12$, $P = 0.042$, $d = -0.15$). These results indicate that the observed changes in the dependent variables after intervention were not related to exercise intervention. The overall similarity of the running biomechanical patterns across groups can be observed in the ensemble average time-series curves (Supplemental data, Figure-S1). In addition, the lack of interaction effects between independent factors for the clinical and biomechanical variables is highlighted in interaction plots (Supplemental data, Figure-S2). A detailed description of the descriptive and inferential statistics for the complete list of variables is offered in Table 2.

Table 2. Mean pre-, post-intervention and change (post–pre) values for flexibility, strength and gait biomechanical measures in the intervention groups. Generalised linear mixed models (GLMM) results (χ^2) for the group effect, time effect and interaction effect (group × time) along with their corresponded *P*-values are presented. Bold font indicates significant differences.

										GLMM effects					
Variable	Strength group			Flexibility group			Control group			Group		Time		Interaction	
Flexibility	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*	χ^2	*P*	χ^2	*P*	χ^2	*P*
Hip adduction (°)	−26.34	−29.09	−2.75	−27.57	−29.23	−1.66	−26.09	−28.99	−2.90	0.476	0.788	7.678	**0.006**	1.361	0.506
Ankle gastrocnemius (°)	88.06	90.33	2.27	89.52	91.26	1.74	89.56	92.22	2.67	3.486	0.175	8.646	**0.003**	0.251	0.882
Ankle soleus (°)	96.06	99.42	3.36	98.77	99.77	1.00	96.56	99.85	3.30	2.512	0.285	9.766	**0.002**	1.915	0.384
Hip ER (°)	35.58	33.82	−1.76	35.23	34.87	−0.35	36.44	35.15	−1.30	1.043	0.594	2.352	0.125	0.651	0.722
Hip IR (°)	35.76	35.82	0.06	35.32	38.32	3.00	35.56	38.70	3.15	1.314	0.518	3.895	**0.048**	2.150	0.341
Strength															
Hip abductors (%BW)	31.56	31.44	−0.12	30.94	29.28	−1.66	30.16	30.38	0.21	2.075	0.354	0.462	0.497	1.024	0.599
Hip extensors (%BW)	23.69	21.18	−2.50	24.08	20.34	−3.74	22.79	20.38	−2.41	0.588	0.745	10.379	**0.001**	0.477	0.788
Ankle PF (%BW)	37.65	41.53	3.88	38.28	38.26	−0.02	35.23	40.36	5.13	1.725	0.422	6.410	**0.011**	3.646	0.162
Biomechanics															
Hip ADD–ABD angle (°)	7.29	7.13	−0.16	7.51	7.62	0.11	7.70	7.47	−0.23	0.592	0.744	0.263	0.608	0.663	0.718
Ankle DF–PF angle (°)	34.65	35.23	0.58	35.51	35.91	0.40	34.35	35.45	1.09	0.810	0.667	8.431	**0.004**	1.624	0.444
Tho/Pel EXT–FLX angle (°)	9.55	9.70	0.15	8.92	9.29	0.37	8.91	9.30	0.39	0.803	0.669	1.353	0.245	0.185	0.912
Tho/Pel IR–ER angle (°)	19.25	20.88	1.63	19.46	20.55	1.09	18.92	19.78	0.86	0.281	0.869	14.537	**0.000**	1.128	0.569
Knee ABD impulse (N · m · s · kg^{-1})	−0.29	−0.32	−0.03	−0.27	−0.24	0.03	−0.24	−0.25	−0.01	2.676	0.262	0.071	0.790	2.345	0.310
Knee ER impulse (N · m · s · kg^{-1})	−0.07	−0.08	−0.02	−0.07	−0.07	0.00	−0.06	−0.08	−0.03	0.127	0.939	6.245	**0.013**	3.697	0.158
Ankle INV impulse (N · m · s · kg^{-1})	0.07	0.07	0.00	0.07	0.08	0.02	0.07	0.08	0.01	0.042	0.979	1.135	0.287	0.879	0.644
Ankle ABD impulse (N · m · s · kg^{-1})	−0.25	−0.28	−0.03	−0.26	−0.24	0.02	−0.26	−0.30	−0.04	0.970	0.616	2.107	0.147	4.248	0.120
Knee positive work (J · kg^{-1})	1.11	1.19	0.08	1.09	1.10	0.01	1.05	1.07	0.02	0.855	0.652	1.819	0.177	1.245	0.537
Ankle positive work (J · kg^{-1})	2.59	2.55	−0.03	2.57	2.46	−0.10	2.45	2.46	0.01	0.521	0.771	2.120	0.145	2.349	0.309
GRF propulsion peak (N · kg^{-1})	0.19	0.18	0.00	0.18	0.17	−0.01	0.18	0.18	0.00	1.036	0.596	4.118	**0.042**	1.361	0.506
GRF vertical active peak (N · kg^{-1})	2.18	2.17	−0.01	2.19	2.17	−0.02	2.16	2.15	−0.01	0.209	0.901	2.568	0.109	0.868	0.648
GRF maximal loading rate (BW · s^{-1})	40.70	41.04	0.33	43.43	42.26	−1.17	44.52	43.47	−1.05	0.868	0.648	2.711	0.100	3.957	0.138

Abbreviations: ABD: abduction, ADD: adduction, DF: dorsiflexion, EXT: extension, ER: external rotation, FLX: flexion, INV: inversion IR: internal rotation, PF: plantar flexion, Tho/Pel: joint angle between thorax and pelvic segments. For the Tho/Pel joint: trunk bending towards posterior (EXT) and anterior (FLX) side of the body, trunk axial rotation to the right (ER) side and left (IR). GRF: ground reaction force.

Discussion

The purpose of this study was to examine the effects of a strengthening or stretching exercise protocol on running biomechanics in older runners. Despite the fact that older individuals exhibit increased running participation, impaired musculoskeletal function and altered running gait (DeVita et al., 2015; Fukuchi & Duarte, 2008; Fukuchi et al., 2011; Lilley, Dixon, & Stiles, 2011), the effects of these exercises on running biomechanics in older individuals remain poorly understood. To our knowledge, this is the first randomised controlled trial study aimed to investigate these effects in older runners.

Overall running biomechanical changes were measured following intervention but, contrary to our hypothesis, they were irrespective of the type of exercise. In contrast, previous studies on either healthy or injured young runners have postulated that a reduced knee abduction moment in running could be achieved through strengthening exercises (Earl & Hoch, 2011; Snyder et al., 2009). However, the research design small sample sizes and the statistical approaches adopted in previous studies were unlikely robust enough to infer those associations. Regrettably, these potential biases are commonly presented in biomechanics research and this problem has been highlighted earlier (Mullineaux, Bartlett, & Bennett, 2001). Therefore, the validity of previous investigations examining the effects of exercises on running biomechanics is limited and may yield misleading results, not to mention that only young runners have been considered in previous studies. The design of the present randomised controlled trial study likely minimised the influence of these aforementioned biases and, therefore, it is reasonable to speculate that the present study may yield more conservative and robust results compared to previous studies. Regardless, the results of the present study suggest that the age-related running biomechanics were not influenced by an eight-week flexibility or strengthening exercise regime. Future studies need to further investigate this topic.

To broaden our understanding of the underlying factors behind running biomechanical changes, muscle strength and flexibility were also quantified. Similarly to running biomechanics, overall changes in flexibility and strength variables were observed after 8 weeks but these changes were independent of the exercise intervention. Previous studies have demonstrated that strengthening and stretching exercises improve muscle strength and flexibility in older sedentary individuals (Kerrigan, Xenopoulos-Oddsson, Sullivan, Lelas, & Riley, 2003; Silva, Oliveira, Fleck, Leon, & Farinatti, 2014). However, studies involving active older participants, and particularly randomised controlled trial studies, are scarce and have not provided conclusive results (Chmelo et al., 2015; González-Ravé, Delgado, Vaquero, Juarez, & Newton, 2011). The lack of exercise effects on muscle strength and flexibility may be simply explained by the fact that the training programme and testing were significantly different. Morrissey, Harman, and Johnson (1995) postulated that the greatest resistance training effects were induced when the same exercise type is used for both testing and training. Joint angles, movement velocity and the rate of force application are some of the factors that affect the differences observed between muscle strength training and testing and these parameters should be standardised. Similarly, dynamic assessments have been proposed for flexibility measures (Fredericson, White, Macmahon, & Andriacchi, 2002; Miller, Lowry, Meardon, & Gillette, 2007) and may help to overcome these issues. Despite these differences, static flexibility and maximal isometric voluntary contraction were measured in the present study, as opposed to more functional or dynamic assessments, to enhance the external validity of the study since these measurements are widely used in a clinical setting and in previous studies (Earl & Hoch, 2011; Ferber, Kendall, & McElroy, 2010; Fukuchi et al., 2014). Future studies should therefore address whether more dynamic and/or functional assessments or neuromuscular control assessment would produce different results.

The lack of group-effects observed in the present study also suggests that simplistic approaches, such as analysing several discrete kinematic and/or kinetic variables, are not robust enough to detect changes in running biomechanics. Moreover, these results also suggest that high-dimensional analyses are necessary in future investigations due to the multivariate and complex nature of gait biomechanical data (Lapham & Bartlett, 1995). This postulation is consistent with previous work that also suggests the interrelationship amongst many variables (e.g., gait kinematics, kinetics, muscle strength, etc.) is a complex classification problem (Ferber, Hreljac, & Kendall, 2009; Phinyomark, Hettinga, Osis, & Ferber, 2014). Future research is therefore necessary to better understand these associations between clinical and biomechanical variables in older and younger runners.

The exercise protocol adopted in the present study was based on previous studies that aimed at modifying running biomechanics in younger runners (Davis Hammonds et al., 2012; Earl & Hoch, 2011; Snyder et al., 2009). In addition, these exercises have been generally recommended by both clinicians and the literature to prevent running-related injuries (Johnston et al., 2003) and to counteract the ageing effects in general older population (Chodzko-Zajko et al., 2009). Surprisingly, a lack of group and interaction effects were found in the present study indicating that the exercises were ineffective in altering either clinical or biomechanical variables. In contrast, Kerrigan et al. (2003) observed positive changes in ankle kinematics and kinetics along with increased range of motion following a 10-week hip and ankle stretching exercise programme in older sedentary individuals. Similarly, Lopopolo, Greco, Sullivan, Craik, and Mangione (2006) supported the use of strength training on improving walking speed, although these effects were highly dependent on exercise intensity and dosage, in community-dwelling elderly people. These contrasting results may be simply explained by the fact that previous studies have only considered sedentary older individuals and walking analysis whereas the present randomised controlled trial analysed older runners. It is well known that running places a higher mechanical loading demand in the musculoskeletal system (Ounpuu, 1994) and changes in running biomechanics following either strengthening or stretching exercises would, therefore, be minimal. Moreover, it is important to note that the older runners in this study were relatively active, which leads us to speculate that the exercise protocols may not have been strenuous enough to elicit a physiological response. Nevertheless, the mechanism by which improvements in muscle function can alter gait in older adults remains poorly understood and needs to be further addressed (Beijersbergen, Granacher, Vandervoort, DeVita, & Hortobágyi, 2013).

Several strengths are apparent in this study compared to previous literature including a large sample of participants, low dropout rate and the inclusion of both clinical and biomechanical measures yielding a more comprehensive research investigation. Although the exercise programmes were home based, the adherence of the participants was comparable between exercise groups. In addition, the weekly appointment with the certified athletic therapist helped ensure the exercises were performed consistently among participants. Furthermore, the combined information provided by both clinical and biomechanical measures in a randomised controlled trial design allows for the understanding of potential underlying mechanisms of running-related injuries among older runners while minimising bias.

Regardless of these strengths, several limitations in the present study are acknowledged. First, the participants in the control group did not receive any intervention and therefore were not required to visit the clinic on a weekly basis. Hence, the control group may have adopted a slightly different training regime compared to the other groups. Nevertheless, they were strongly encouraged to not engage in any new exercises as well as to maintain the same training levels. Second, previous experience in performing either the stretching or strengthening exercises was not controlled in the study and could have influenced the results. However, based on the randomised allocation procedure, and given that a similar proportion of individuals who reported previous experience with the exercise were equally allocated across groups, the likelihood this factor would influence the results was minimal. Third, given the nature of the biomechanical measures and the current literature, we decided to compare several dependent variables as opposed to a single primary outcome measure that is commonly employed in randomised controlled trial studies. Hence, this may have increased the chance of type I error. However, this was unlikely given the lack of group and interaction effects found in the present study. Future randomised controlled trial studies should be conducted to determine the optimal exercise intervention and dose response considering the interplay between clinical and biomechanical variables and their ability to positively influence age-related changes in runners.

Conclusion

The results of the present randomised controlled trial study indicate that an eight-week home-based stretching or strengthening exercise protocol, compared to controls, was not effective in altering age-related running biomechanics. Specifically, despite changes in ankle and trunk kinematics, knee kinetics and ground reaction force variables, concomitant with improvements in muscle strength and flexibility following the eight-week programme, these changes were observed in both the stretching and strengthening groups. Future studies should investigate appropriate intensity and dosage for these types of exercises in older runners and utilise more complex analysis methods.

Acknowledgement

We thank Jill Baxter and Melissa Benson for helping with data collection and we thank Kent Bates and Martin Parnell for helping with participant recruitment. Finally, we thank Marcos Duarte for many fruitful discussions regarding this research.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the CAPES Foundation, Ministry of Education of Brazil (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) under Grant [number 0614/092]; and the Alberta Innovates: Health Solution (AI:HS) under Grant [number 200700478]. We declare that these organisations did not influence any part of this study from the conception to the decision regarding its publication.

References

Beijersbergen, C. M., Granacher, U., Vandervoort, A. A., DeVita, P., & Hortobágyi, T. (2013). The biomechanical mechanism of how strength and power training improves walking speed in old adults remains unknown. *Ageing Research Reviews*, *12*, 618–627. doi:10.1016/j.arr.2013.03.001

Cappozzo, A., Catani, F., Croce, U. D., & Leardini, A. (1995). Position and orientation in space of bones during movement: Anatomical frame definition and determination. *Clinical Biomechanics*, *10*, 171–178. doi:10.1016/0268-0033(95)91394-T

Chmelo, E. A., Crotts, C. I., Newman, J. C., Brinkley, T. E., Lyles, M. F., Leng, X., & Nicklas, B. J. (2015). Heterogeneity of physical function responses to exercise training in older adults. *Journal of the American Geriatrics Society*, *63*, 462–469. doi:10.1111/jgs.13322

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). Exercise and physical activity for older adults. *Medicine & Science in Sports & Exercise*, *41*, 1510–1530. doi:10.1249/MSS.0b013e3181a0c95c

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: L. Erlbaum Associates.

Colado, J. C., Garcia-Masso, X., Triplett, T. N., Flandez, J., Borreani, S., & Tella, V. (2012). Concurrent validation of the OMNI-resistance exercise scale of perceived exertion with Thera-band resistance bands. *The Journal of Strength & Conditioning Research*, *26*, 3018–3024. doi:10.1519/JSC.0b013e318245c0c9

Cyarto, E. V., Moorhead, G. E., & Brown, W. J. (2004). Updating the evidence relating to physical activity intervention studies in older people. *Journal of Science and Medicine in Sport*, *7*, 30–38. doi:10.1016/S1440-2440(04)80275-5

Davis Hammonds, A. L., Laudner, K. G., McCaw, S., & McLoda, T. A. (2012). Acute lower extremity running kinematics after a hamstring stretch. *Journal of Athletic Training*, *47*, 5–14. doi:10.4085/1062-6050-47.1.5

DeVita, P., Fellin, R. E., Seay, J. F., Ip, E., Stavro, N., & Messier, S. P. (2015). The relationships between age and running biomechanics. *Medicine & Science in Sports & Exercise*. doi:10.1249/MSS.0000000000000744

Earl, J. E., & Hoch, A. Z. (2011). A proximal strengthening program improves pain, function, and biomechanics in women with patellofemoral pain syndrome. *American Journal of Sports Medicine*, *39*, 154–163. doi:10.1177/0363546510379967

Feingold, A. (2013). A regression framework for effect size assessments in longitudinal modeling of group differences. *Review of General Psychology*, *17*, 111–121. doi:10.1037/a0030048

Ferber, R., Hreljac, A., & Kendall, K. D. (2009). Suspected mechanisms in the cause of overuse running injuries: A clinical review. *Sports Health: A Multidisciplinary Approach*, *1*, 242–246. doi:10.1177/1941738109334272

Ferber, R., Kendall, K. D., & McElroy, L. (2010). Normative and critical criteria for iliotibial band and iliopsoas muscle flexibility. *Journal of Athletic Training*, *45*, 344–348. doi:10.4085/1062-6050-45.4.344

Fredericson, M., White, J. J., Macmahon, J. M., & Andriacchi, T. P. (2002). Quantitative analysis of the relative effectiveness of 3 iliotibial band stretches. *Archives of Physical Medicine and Rehabilitation*, *83*, 589–592. doi:10.1053/apmr.2002.31606

Fukuchi, R. K., & Duarte, M. (2008). Comparison of three-dimensional lower extremity running kinematics of young adult and elderly runners. *Journal of Sports Sciences*, *26*, 1447–1454. doi:10.1080/02640410802209018

Fukuchi, R. K., Eskofier, B. M., Duarte, M., & Ferber, R. (2011). Support vector machines for detecting age-related changes in running kinematics. *Journal of Biomechanics*, *44*, 540–542. doi:10.1016/j.jbiomech.2010.09.031

Fukuchi, R. K., Stefanyshyn, D. J., Stirling, L., Duarte, M., & Ferber, R. (2014). Flexibility, muscle strength and running biomechanical adaptations in older runners. *Clinical Biomechanics*, *29*, 304–310. doi:10.1016/j.clinbiomech.2013.12.007

González-Ravé, J. M., Delgado, M., Vaquero, M., Juarez, D., & Newton, R. U. (2011). Changes in vertical jump height, anthropometric characteristics, and biochemical parameters after contrast training in master athletes and physically active older people. *The Journal of Strength & Conditioning Research*, *25*, 1866–1878. doi:10.1519/JSC.0b013e3181e4f9da

Grau, S., Krauss, I., Maiwald, C., Axmann, D., Horstmann, T., & Best, R. (2011). Kinematic classification of iliotibial band syndrome in runners. *Scandinavian Journal of Medicine & Science in Sports*, *21*, 184–189. doi:10.1111/j.1600-0838.2009.01045.x

Hreljac, A. (2004). Impact and overuse injuries in runners. *Medicine & Science in Sports & Exercise*, *36*, 845–849. doi:10.1249/01.MSS.0000126803.66636.DD

Johnston, C. A., Taunton, J. E., Lloyd-Smith, D. R., & McKenzie, D. C. (2003). Preventing running injuries. Practical approach for family doctors. *Canadian Family Physician*, *49*, 1101–1109. Retrieved from http://www.cfp.ca/content/49/9/1101.long

Jokl, P., Sethi, P. M., & Cooper, A. J. (2004). Master's performance in the New York City Marathon 1983–1999. *British Journal of Sports Medicine*, *38*, 408–412. doi:10.1136/bjsm.2002.003566

Kerrigan, D. C., Xenopoulos-Oddsson, A., Sullivan, M. J., Lelas, J. J., & Riley, P. O. (2003). Effect of a hip flexor-stretching program on gait in the elderly. *Archives of Physical Medicine and Rehabilitation*, *84*, 1–6. doi:10.1053/apmr.2003.50056

Lapham, A. C., & Bartlett, R. M. (1995). The use of artificial intelligence in the analysis of sports performance: A review of applications in human gait analysis and future directions for sports biomechanics. *Journal of Sports Sciences*, *13*, 229–237. doi:10.1080/02640419508732232

Lilley, K., Dixon, S., & Stiles, V. (2011). A biomechanical comparison of the running gait of mature and young females. *Gait & Posture*, *33*, 496–500. doi:10.1016/j.gaitpost.2011.01.002

Lopopolo, R. B., Greco, M., Sullivan, D., Craik, R. L., & Mangione, K. K. (2006). Effect of therapeutic exercise on gait speed in community-dwelling elderly people: A meta-analysis. *Physical Therapy*, *86*, 520–540. Retrieved from http://ptjournal.apta.org/content/86/4/520.long

Marcell, T. J., Hawkins, S. A., & Wiswell, R. A. (2014). Leg strength declines with advancing age despite habitual endurance exercise in active older adults. *The Journal of Strength & Conditioning Research*, *28*, 504–513. doi:10.1519/JSC.0b013e3182a952cc

McGibbon, C. A. (2003). Toward a better understanding of gait changes with age and disablement: Neuromuscular adaptation. *Exercise and Sport Sciences Reviews*, *31*, 102–108. doi:10.1097/00003677-200304000-00009

McKean, K. A., Manson, N. A., & Stanish, W. D. (2006). Musculoskeletal injury in the masters runners. *Clinical Journal of Sport Medicine*, *16*, 149–154. doi:10.1097/00042752-200603000-00011

Miller, R. H., Lowry, J. L., Meardon, S. A., & Gillette, J. C. (2007). Lower extremity mechanics of iliotibial band syndrome during an exhaustive run. *Gait & Posture*, *26*, 407–413. doi:10.1016/j.gaitpost.2006.10.007

Morrissey, M. C., Harman, E. A., & Johnson, M. J. (1995). Resistance training modes: Specificity and effectiveness. *Medicine & Science in Sports & Exercise*, *27*, 648–660. doi:10.1249/00005768-199505000-00006

Mullineaux, D. R., Bartlett, R. M., & Bennett, S. (2001). Research design and statistics in biomechanics and motor control. *Journal of Sports Sciences*, *19*, 739–760. doi:10.1080/026404101317015410

Nevill, A. (1996). Validity and measurement agreement in sports performance. *Journal of Sports Sciences*, *14*, 199. doi:10.1080/02640419608727704

Nevill, A. M., & Atkinson, G. (1997). Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. *British Journal of Sports Medicine*, *31*, 314–318. doi:10.1136/bjsm.31.4.314

Ounpuu, S. (1994). The biomechanics of walking and running. *Clinical Sports Medicine*, *13*, 843–863. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7805110

Phinyomark, A., Hettinga, B. A., Osis, S. T., & Ferber, R. (2014). Gender and age-related differences in bilateral lower extremity mechanics during treadmill running. *PLoS One*, *9*, e105246. doi:10.1371/journal.pone.0105246

Pohl, M. B., Lloyd, C., & Ferber, R. (2010). Can the reliability of three-dimensional running kinematics be improved using functional joint methodology? *Gait & Posture*, *32*, 559–563. doi:10.1016/j.gaitpost.2010.07.020

Savelberg, H. H., Verdijk, L. B., Willems, P. J., & Meijer, K. (2007). The robustness of age-related gait adaptations: Can running counterbalance the consequences of ageing? *Gait & Posture*, *25*, 259–266. doi:10.1016/j.gaitpost.2006.04.006

Scott, N. W., McPherson, G. C., Ramsay, C. R., & Campbell, M. K. (2002). The method of minimization for allocation to clinical trials. a review. *Controlled Clinical Trials*, *23*, 662–674. doi:10.1016/S0197-2456(02)00242-8

Silva, N. L., Oliveira, R. B., Fleck, S. J., Leon, A. C., & Farinatti, P. (2014). Influence of strength training variables on strength gains in adults over 55-year-old: A meta-analysis of dose-response relationships. *Journal of Science and Medicine in Sport*, *17*, 337–344. doi:10.1016/j.jsams.2013.05.009

Snyder, K. R., Earl, J. E., O'Connor, K. M., & Ebersole, K. T. (2009). Resistance training is accompanied by increases in hip strength and changes in lower extremity biomechanics during running. *Clinical Biomechanics*, *24*, 26–34. doi:10.1016/j.clinbiomech.2008.09.009

Stefanyshyn, D. J., Stergiou, P., Lun, V. M., Meeuwisse, W. H., & Worobets, J. T. (2006). Knee angular impulse as a predictor of patellofemoral pain in runners. *American Journal of Sports Medicine*, *34*, 1844–1851. doi:10.1177/0363546506288753

Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2003). A prospective study of running injuries: The Vancouver sun run "In Training" clinics. *British Journal of Sports Medicine*, *37*, 239–244. doi:10.1136/bjsm.37.3.239