Original Article

Significant effusion in the joints of the lower extremity after running an ultramarathon in extreme conditions

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ABSTRACT

Introduction: The "Brocken challenge" ultramarathon takes place in the cold of February over 80 km with 1,900 m of elevation change. The purpose of this study was to evaluate the effects of an ultramarathon under extreme conditions on the lower extremities. Methods: Out of the 182 starters, 44 athletes were included into the study (n = 44). We examined these athletes using a questionnaire, by measuring circumferences of their lower extremities and by standardized sonographic measurement of joint effusion of knee and ankle joints before and after the run. Results: After the run, the right leg and both feet significantly increased in circumference. Knee joints on both sides and the left ankle joint showed significantly more effusion after the run (right knee: 84%, right ankle: 43%; left knee: 80%, left ankle: 48%). Heavier and less trained athletes showed significantly more effusion in sonographic assessment of the knee and ankle. Neither swelling, nor effusion had a measurable influence on finishing time. Conclusions: Running an ultramarathon in the cold overloads the fluid draining capacity in the muscles and joints of the legs especially in heavier and less trained athletes without measurable immediate effect on performance.

Keywords: Marathon; Physiology; Swelling; Effusion; Sonography.

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INTRODUCTION

With the recent surge in running activity, worldwide races are more popular every year.(Hoffman, Ong, & Wang, 2010; Hoffman & Wegelin, 2009; Knechtle, Knechtle, & Lepers, 2011; Visconti, Capra, Carta, Forni, & Janin, 2015) For some individuals participating in a marathon is not challenging enough and they decide to join ultramarathons. In general, ultramarathons are defined as races which exceed the traditional marathon distance of 42.2 km. (Millet et al., 2011; Millet & Millet, 2012) Ultramarathons are divided into single-stage events, in which the whole distance is covered in a single run, and multistage ultramarathons, in which the distance is typically covered in multiple days.

The Brocken challenge (bc) is one of these single run ultramarathons known as one of the hardest races in Northern Germany. Initiated in 2001, the event is traditionally held at the beginning of February each year. The contestants have to run from the city of Göttingen to the peak of the highest mountain in Northern Germany, the Brocken mountain which is 1,141 m (3,747 ft) above sea level and is usually covered in snow at this time of the year. The bc itself features a course of 80 km in length, with 1,900 m of elevation change. In 2018 the average daytime temperature for the bc was -6 °C.

The most common problems during an ultra-marathon arise from the gastrointestinal (GI) tract, affecting up to 80% of the runners. (Costa, Snipe, Camões-Costa, Scheer, & Murray, 2016; Scheer & Murray, 2011; Stuempfle & Hoffman, 2015; Stuempfle, Hoffman, & Hew-Butler, 2013)(Stuempfle et al., 2013; Stuempfle, Valentino, Hew-Butler, Hecht, & Hoffman, 2016) Other well established research topics include energy expenditure (Vernillo et al., 2015b; Vernillo et al., 2016; Vernillo, Millet, & Millet, 2017), cardiac function (Rundfeldt et al., 2018; Vassalle et al., 2018; Vitiello et al., 2013) as well as lung function (Scrimgeour, Noakes, Adams, & Myburgh, 1986; Vernillo et al., 2015a; Warren, Cureton, & Sparling, 1989). The continuous muscular exertion during the run results in elevation of creatine kinase (CK) and there is evidence of type I-fibre sarcomere disruptions throughout mountain ultramarathons. (Magrini, Khodaee, San-Millán, Hew-Butler, & Provance, 2017),(Carmona et al., 2015) Previously, researchers examined the Swiss Alpine Marathon (Davos, 67 km) and reported muscle soreness and elevated levels of C-reactive protein (CRP) and CK after the run. (Frey et al., 1994) Surprisingly, anthropometric data and data on lower extremities is scarce for ultramarathons, although these are frequently studied topics in other running disciplines especially in classic marathons. (Proft et al., 2016; Salinero et al., 2017; Tanda & Knechtle, 2013; Theysohn et al., 2013; Vernillo et al., 2013; Yang, Wang, Bao, & Hu, 2015) Leg circumference changes and contractile function were measured in mountain ultra-marathons with electrical stimulation, suggesting the increase in calf circumference and hydric volume were associated with contractile impairment in the calf of ultramarathon runners. (Vitiello et al., 2015) Increases in circumference can be associated with increased joint effusion. (Christodoulou et al., 2010; Soderberg, Ballantyne, & Kestel, 1996) Joint effusion of the metatarsalophangeal joint was evaluated by magnetic resonance imaging (MRI) in 2009 after a short 30-min run and no effect of running on synovial volume could be detected. (Kingston, Toms, Ghosh-Ray, & Johnston-Downing, 2009) Munich marathon participants were examined in 2016 where joint effusion was evaluated sonographically at the patellar tendon and no significant change of joint effusion was found after running a marathon. (Proft et al., 2016) It has been shown that running in hot and extreme hot conditions can lead to higher post-competition core temperatures and higher levels of muscle damage occurred. (Bergeron, 2014; Del Coso et al., 2014) Cold conditions in ultramarathons have been reported to lead to higher average running speed, loss of weight and hyponatremia more frequently (Case, Evans, Tibbets, & Miller, 1995; Parise & Hoffman, 2011; Stuempfle et al., 2002). We have not found any literature on joint effusion and leg circumference changes after an ultramarathon in the cold.

The main intention of our study was therefore to collect anthropometric data and determine whether there are measurable changes in leg circumferences and measurable effusion of the joints after participating in an ultramarathon in cold conditions and if this influenced race performance.

Our hypothesis was that acute joint effusions in ultramarathoners occur more frequently than reported and that these do not effect race performance.” (Proft et al., 2016).

METHODS

Ethics and trial registry

The present study was approved by the institutional review board (IRB) of the University Medical Center Göttingen (Ethikkommission der Universitätsmedizin Göttingen, Von-Siebold-Str.3, 37075 Göttingen). The protocol of this trial was registered with the German Clinical Trials Register (Deutsches Register Klinischer Studien DRKS, Stefan-Meier-Straße 26, 79104 Freiburg, www.drks.de) with the reference number DRKS00014364. The German Clinical Trials Register is the approved WHO Primary Register in Germany and thus meets the requirements of the International Committee of Medical Journal Editors (ICMJE). The approach of our study is summarized in Figure 1.

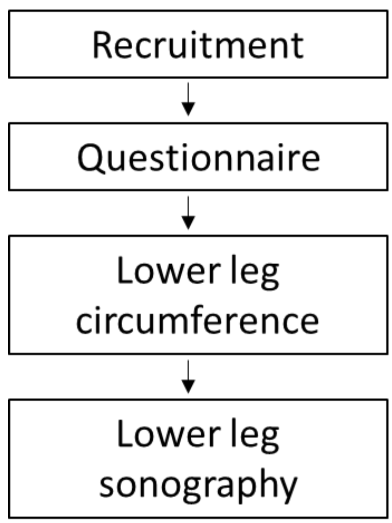

Figure 1. Graphical overview of the methods applied in this study.

Recruiting methods

Participants were recruited on the briefing day which took place the evening before the bc. Inclusion criteria were participation in the bc and willingness to participate in the study. Exclusion criteria were no official participation in the bc.

Questionnaire

A questionnaire was designed for all participants in the ultramarathon to fill out either the day before the run at the final briefing or directly before the beginning of the run. In this questionnaire, 3 aspects were analysed for this study: “demographic data (sex, age, height, weight)”, “training in preparation for the ultramarathon (how often and how many kilometres do you run/week, since when do you run, how many marathons and ultramarathons did you complete)" and "subjective feeling of swelling after the run (do your feet or knees feel swollen after participating in the ultramarathon)".

Circumference measurement

One day prior to the start of the run at 4 p.m. (-4° C) and 1 hour after finishing the 80 km ultramarathon (around 1 p.m. to 4 p.m.) (-6° C), circumference of the lower extremities was assessed bilaterally at eight predefined landmarks according to the Association of Occupational Accident Insurance Funds and adapted from formula F4224: 20 cm above medial tibial plateau, 10 cm above medial tibial plateau, middle of patella, 15 cm below medial tibial plateau, lower leg smallest circumference, ankle above greatest diameter between both malleoli, instep above navicular bone, forefoot ball. Measures were taken with a measuring tape lying directly on the skin without tension. This yielded a total of 16 circumferential measurements of the lower extremities at each time point. All measurements were carried out by 2 independent and experienced surgeons. No matchings for daytime or temperature have been carried out.

Sonography

To evaluate a possible effusion in the knee and ankle joints, we performed semiquantitative sonographic measurements based on the Hartung score (Table 2).(Hartung et al., 2012).

One day before the start of the ultramarathon and at the end on top of the mountain (finish), knees and ankles of the runners were sonographically assessed for effusion with SonoSite iViz and a 10-5 MHz 38 mm-broadband-linear ultrasound head (FujiFilm SonoSite European Headquarters, Amsterdam, Netherlands) by a DEGUM (German society for sonography in medicine)-certified investigator. The athletes were asked to lay flat on an examination cot. For gathering information on effusion in the knee, suprapatellar longitudinal and infrapatellar medial and lateral longitudinal sectional planes were analysed. For ankle effusion, planes in the longitudinal and transversal axis of the talocrural joint were assessed. (Gaulrapp; Jacobson, Ruangchaijatuporn, Khoury, & Magerkurth, 2017; Kane, Balint, & Sturrock, 2003; Terslev et al., 2012) The effusion was graded 0-3 according to Hartung et al – an ultrasound score originally developed for patients with rheumatoid arthritis, which has also been used to evaluate other populations, including marathon runners. (Hartung et al., 2012; Proft et al., 2016). The grading in knee and ankle was as follows: Grade 1: joint capsule distension parallel to bone, Grade 2: joint capsule distension straight, Grade 3: joint capsule distension convex.

Statistics

Statistical analysis was conducted with Microsoft Excel 2010 and GraphPad Prism 5.04 for Windows (GraphPad Software, La Jolla California USA). Measured values are depicted as mean and standard deviation (SD). . Fisher's exact test (two-sided) was performed to test whether the study group differed from the complete athlete group in demographic data. Differences between pre and post run observations were assessed with paired two-tailed t-test with 95% confidence interval. Subgroup analysis was performed first by D'Agostino Pearson test to evaluate Gaussian distribution, followed by two-tailed t-test. Linear regression analysis was conducted with 95% confidence interval for swelling and effusion in relation to finishing time.

To test if the severity of joint effusions after the race were related to racer characteristics or amount or intensity of training, we performed subgroup analyses based on frequency of running ultramarathons (> 10 vs. ≤ 10 ultramarathons), age (> 45 y vs. ≤ 45 y), frequency of training (> 18 vs. times per mo ≤ 18), training volume (< 65 km per wk vs. ≥ 65 km per wk), BMI (> 22.0 kg·m^{-2} vs. ≤ 22.0 kg·m^{-2}) and running experience (> 10 y vs. ≤ 10 y).

For indication of significant differences, p-values were classified exactly and by *p ≤ .05.

RESULTS

On the day of the ultramarathon, the ambient temperature on the route was -6° C with calm wind, a third of the route was snow-covered.

Study population

Out of all 182 starters we were able to recruit 44 runners for this study. 172 (95%) finished the ultramarathon including all recruited runners. For all starters, average time was 10 hours and 37 minutes or 638 minutes. The participants of our study finished in an average of 10 h 25 m or 612 minutes on average, which is not significantly different from the other finishing runners (p = .44).

Out of all 172 finishers, 84% were male and 16% female. All the non-finishers were male. Participants of our study were 82% male and 18% female. Sex of study participants was comparable to all runners (p = .65).

Among the participants of our study, average age was 45 ± 10 y. Average weight in our study population was 69.8 ± 10 kg with a height of 175.2 ± 19 cm resulting in a BMI of 22.3 ± 2 $kg \cdot m^{-2}$. Mean experience in running was 14 ± 9 y. The participants practiced 4 ± 2 times per week with an average of 68 ± 4 km over the seven days. For preparation, cross training was used by 66%. In the year before, an average of 9 ± 16 marathons were completed and the average number of lifetime ultramarathons run was 27 ± 52. Injuries in the year before the event were experienced by 26%.

Swelling

The differences in circumferences of the legs between start and finish are reported in Table 1.

Table 1 Circumference at different points of interest. The confidence interval is presented in brackets after the p-value.

Point of interest lower extremity	Difference after-before in cm (± SD) *left*	p-value	Difference after-before in cm (± SD) *right*	p-value
20 cm above medial tibial plateau	+1.0 (± 4)	.2172 [-2.52-0.60]	+1.7 (± 4)	.043 * [-3.36- -0.06]
10 cm above medial tibial plateau	+0.1 (± 4)	.8719 [-1.71-1.46]	+1.8 (± 4)	.0287 * [-3.30- -0,20]
Middle of patella	+0.3 (± 2)	.5884 [-1.19- 0.69]	+0.2 (± 3)	.7675 [-1.32-0.99]
15 cm below medial tibial plateau	-0.7 (± 1)	.0261 * [0.09-1.33]	+0.0 (± 2)	.9153 [-0.84-0.76]
Lower leg, smallest circumference	-0.1 (± 1)	.7701 [-0.50-0.67]	-1.0 (± 2)	.0140 * [0.22-1.78]
Ankle	+0.1 (± 2)	.7370 [-0.89-0.64]	+0.4 (± 2)	.1871 [-1.05-0.22]
Instep above navicular bone	+1.3 (± 2)	.0017 * [-1.98- -0.52]	+0.1 (± 2)	.0148 * [-1.71- -0.21]
Forefoot ball	+1.8 (± 2)	< .0001 * [-2.56- 1.02]	+1.0 (± 2)	.0087 * [-1.79- -0.29]

Above the knee, both right (20cm above medial tibial plateau: +1.7 ± 4 cm*; 10cm above medial tibial plateau: +1.8 ± 4 cm*) and left legs (20cm above medial tibial plateau: +1.0 ± 4 cm; 10cm above medial tibial plateau: +0.1 ± 4 cm) had a larger circumference after the race, with the right leg being significantly larger after the race compared to before. At the patella (right: +0.2 ± 3 cm; left: +0.3 ± 2 cm) and the ankle there were no significant changes in circumference in either leg. In the feet of both legs, the circumference was significantly larger after the race (left: +1.8 ± 2 cm*; right: +1.0 ± 2 cm*). The only area of the leg to show a decreased circumference after the race was the smallest circumference of the lower leg, which was on average smaller in the left leg (-0.1 ± 1 cm) and significantly smaller in the right leg (-1.0 ± 2 cm*) after the race. (Table 1). The quantitative amount of circumference increase was the greatest in the left foot (1.8 ± 2 cm*).

Effusion in knee and ankle

Compared to pre-run measurements, 84% of the participants had more effusion in the right knee, 42% more effusion in the right ankle. On the left side, 79% had more effusion in the knee and 47% more effusion in the ankle.

Table 2. Semiquantitative measurements of joint effusion.

Point of interest (POI) lower extremity	**Semi quantitatively (± SD) *left***	**p-value**	**Semi quantitatively (± SD) *right***	**p-value**
Knee joint				
Before	0.29 (± 0.55)		0.29 (± 0.46)	
After	1.46 (± 0.72)		1.38 (± 0.49)	
Difference	+1.17 (± 0.87)	< .0001 *	+1.08 (± 0.65)	< .0001 *
Ankle joint				
Before	0.21 (± 0.41)		0.25 (± 0.44)	
After	0.79 (± 0.66)		0.54 (± 0.59)	
Difference	+0.58 (± 0.72)	.0006 *	+0.29 (± 0.75)	.0695

Table 3. Comparison of semiquantitative effusion measurements between certain groups. The p values are for comparisons of the semiquantitative measurements in the respective joint on the respective side.

Compared Groups	**Joint**	**Left**	**Right**
Rare runners (≤ 10 ultramarathons) vs. frequent runners (> 10 ultramarathons)	Knee	0.18 [-1.08 - 0.08]	0.32 [-0.82 - 0.12]
	Ankle	0.38 [-0.43 - 0.50]	0.28 [-0.35 - 0.69]
Light (BMI < 22 kg·m⁻²) vs. heavy athletes (BMI ≥ 22 kg·m⁻²)	Knee	0.36 [-1.10 - 0.62]	0.31 [-0.57 - 0.76]
	Ankle	0.03 * [-1.36 - -0.09]	0.30 [-0.98 - 0.49]
Young (< 45 y) vs. old (≥ 45 y) runners	Knee	0.20 [-0.34 - 0.52]	0.44 [-0.62 - 0.38]
	Ankle	0.20 [-0.34 - 0.52]	0.43 [-0.47 - 0.31]
Frequent (≥ 18 times per mo) vs. rare (< 18 times per mo) training	Knee	0.35 [-0.68 - 0.54]	0.48 [-0.49 - 0.51]
	Ankle	0.23 [-0.52 - 0.34]	0.19 [-0.52 - 0.24]
Much (≥ 65 km per wk) vs. little (< 65 km per wk) training	Knee	0.02 * [-0.71 - 0.49]	0.27 [-0.11 - 0.84]
	Ankle	0.50 [-0.26 - 0.58]	0.43 [-0.26 - 0.51]
Long-term (> 10 y) vs. short-term runners (≤ 10 y)	Knee	0.50 [-0.13 - 1.07]	0.39 [-0.03 - 0.94]
	Ankle	0.13 [-0.37 - 0.50]	0.18 [-0.45 - 0.34]

We found a significant correlation of BMI with effusion of the left ankle with significantly more swelling in the heavier athletes ≥ 22 kg·m⁻². High volume training with more than 65 km per week was correlated with significantly less induction of effusions in the left knee compared to people who ran less than 65 km (Table

3). All other racer characteristics and training amounts investigated showed no significant differences in joint effusions after the race.

Joint effusion and performance

To determine if swelling and joint effusion were correlated with performance of the athletes, we correlated our observations with the time until the finishing line. None of the abovementioned parameters did significantly correlate with finishing time (Table 4).

Table 4. Correlation of effusion and swelling with finishing time.

Parameter	R^2	p-value
Measurements left	.14 - .00	.07 - .75 [- .001 - .029 & - .014 - .019]
Measurements right	.12 - .01	.1- .73 [- .013 - .001 & - .008 - .006]
Effusion right knee difference	.12	.10 [- .005 - .000]
Effusion left knee difference	.00	.93 [- .004 - .004]
Effusion right ankle difference	.75	.29 [- .002 - .005]
Effusion left ankle difference	.02	.48 [- .002 - .004]

DISCUSSION

Overall, we found swelling of the upper legs and feet as well as increased joint effusions in the knees and ankles of runners of an ultramarathon in cold conditions.

Increasing volume of muscles after extreme exercise through muscle architectural changes due to fatigue seems to be accompanied by loss of muscular strength and peaks 2 days after the exertion. (Ishikawa et al., 2006) In the event itself, the fluid overload just seems to be related to rising limb volumes. (Bracher et al., 2012; Cejka, Knechtle, Knechtle, Rüst, & Rosemann, 2012).

An effect on the muscle could just be indirectly confirmed by our measurements showing elevated circumferences, which may be attributed to a swelling of the muscle as well as surrounding tissue, muscle inflammation, increased extracellular fluid or peripheral edema. Possible muscle damage was assumed by another study, where immunological parameters were assessed in a 100 km ultramarathon (Plzen city, Czeck, 100 km), in which markers of acute inflammation (neutrophils) and markers of muscle damage (CK) were increased significantly. (Žákovská et al., 2017).

The girth difference which we describe was similarly analysed in a mountain ultra-marathon ("Tor des Géants" 2011 Italy, 330 km, n = 11). Increased lower leg circumference was reported after the run, but upper leg did not show differences. The lower leg got bigger, while feet increased in circumference on both sides. (Vitiello et al., 2015) In our measurements, the right upper leg gained circumference, while the left upper leg did not. One reason for the different observations could be the higher number of non-professional participants in our study, another the cold temperature in our ultramarathon, which might have intensified the side-differences. These differences between left and right in our study with more effusion in left than right ankle is consistent with the anatomically impaired venous drain on the left side. The underlying reason is the compression of the V. iliaca communis sinistra by the overcrossing A. iliaca communis dextra. (Aumüller, 2007; Schünke, Schulte, & Schumacher, 2015; Thijs, Rabe, Rosendaal, & Middeldorp, 2010; Virchow, 1851) We detected increased circumference in the right upper leg, which could also be due to the impaired venous drain.

Swollen legs are a common issue in long runs and probably a result of increased fluid intake and subsequent edema. (Bracher et al., 2012; Cejka et al., 2012; Williams et al., 1979) In our study, we found a significant increase in lower leg circumference for most measuring points. The question whether knees feel subjectively swollen after a run, was answered positively by just 18%. Swelling of feet was felt by 28% of the participants. Subjective “feeling of swollen feet” compared to sonography with depicted effusion in this particular run showed that positive predictive values (PPV) of this statement was 63% with a sensitivity of 59%. This PPV was 100% for knee swelling, while sensitivity was just 43%.

Regarding race performance at marathon distance (Basel Marathon, Switzerland, 42 km, n = 29), circumference of upper leg and lower leg was related to race time. (Schmid et al., 2012) In contrast and similar to our study there was no association detected between anthropometric properties (circumference of extremities) and race performance at the 24 h run in Basel. (Knechtle, Wirth, Knechtle, Zimmermann, & Kohler, 2009) Number of finished marathons and 24-h-runs had no significant effect as well. This limited data suggests that while at marathon distance changes in leg circumference still play a role for the performance of the athlete, this influence vanishes at the more challenging conditions of ultramarathons or is dominated by other factors. However, a causal connection between speed and swelling cannot be drawn since the former could affect the latter or vice versa.

Our results demonstrate that both knee joints contained significantly more effusion after the run compared to the status before the run. The ankle joints presented with significantly more effusion on the left side, whereas the changes on the right were not significantly different.

One such factor indicating race performance could be the function of the joints. We found significant joint effusion in the runners of the bc. These effusions were however not correlated to racing time. At the Munich Marathon, sonographic joint effusion was assessed. (Proft et al., 2016) The authors did not find any differences of joint effusion before and after the marathon, while more sensitive MRI measurements of runners before and after marathons showed increases of knee effusion in some of the participants. (Krampla et al., 2001; Schueller-Weidekamm, Schueller, Uffmann, & Bader, 2006a) Our findings of significant amounts of effusion in most ultramarathon runners with sonography suggest a more pronounced effect of the more strenuous exercise on the lower extremities. MRI-analysis of ankle cartilage was performed in an ultramarathon (TransEurope FootRace, 4486 km, n = 22) showing hints for partial regeneration of cartilage matrix during a multistage ultramarathon. (Schütz et al., 2014) However, the clinical relevance of MRI abnormalities after marathon has been questioned since few of the pathologies measured immediately after the run persisted or caused problems afterwards. (Lohman et al., 2001) There is not yet enough data available to decide, if the more severe findings in ultramarathon runners will have an impact on joint function over longer periods of time. The question to which extent the effusion is physiological cannot be answered by our study since underlying pathophysiological conditions have not been assessed.

From our results, we could determine predictors for greater joint effusion: higher BMI for the left ankle and lower training volume for the left knee. While obesity has been stratified as risk factor for knee effusion in a healthy population (Hung et al., 2016), in an athlete community this correlation has not been reported so far to our knowledge. A BMI of 22 is undoubtedly far away from obesity (≥ 25 $kg \cdot m^{-2}$) (Weltgesundheitsorganisation, 1995; World Health Organization (WHO), 2004), but it seems conceivable that lighter runners have a smaller risk to develop ankle effusion after running an ultramarathon.

Less training seems to produce more knee effusion after an ultra-endurance race in our cohort. In normal volunteers, MRI could reveal knee joint effusion after jogging. (Kursunoglu-Brahme, Schwaighofer, Gundry, Ho, & Resnick, 1990) Comparing highly-trained and lowly-trained runners after their training, a MRI-study demonstrated similar amounts of joint effusion in both groups, while other pathologies were affected by training level, but not training pace. (Schueller-Weidekamm, Schueller, Uffmann, & Bader, 2006b) Another morphological MRI-study proposes adaption mechanisms of the knee in long-distance runners compared to recreational runners, while the former do not demonstrate meniscal signal intensity and visible joint effusions that were found in recreational runners. (Shellock & Mink, 1991) The data of our study largely seem to confirm these findings.

LIMITATIONS

The study did not evaluate physiological parameters throughout the run, which is why conclusions about performance can just be taken indirectly through the measurements and questionnaire. Furthermore, participants for our study were limited and not all the 182 starters were included (n = 44). There are no follow-up questions nor is there a follow-up examination which could hint to any long-term effects of the swelling and effusion in joints or extremities. Due to the study design, no mechanistical insights can be shown and the underlying reasons for swelling and effusion need to remain unexplained for now. Additionally, no observations regarding symptomatic pain or functional limitation have been collected. Inter- and intra-observer reliability for semi-quantitative joint effusion was reported to be poor and this depicts a major limitation of this study. (Chávez-López et al., 2013).

The use of a semiquantitative score that was initially developed for rheumatoid arthritis and has been used in only one marathon study before depicts another limitation of our study. (Proft et al., 2016).

CONCLUSIONS

The present study revealed the significant increase in joint effusions of the lower extremity after running an ultramarathon in extreme conditions.

So far it was unclear if joint effusion increased after an ultramarathon in the cold. Now we show here that joint effusion in knee and ankle was significantly increased after a cold mountain ultramarathon. Swelling of the lower extremity in some parts is common but does not negatively influence the athletes' performance. We suggest further investigation with a longer follow-up period, additional serum analyses and possibly different running conditions.

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AUTHORS CONTRIBUTIONS

Study concept and design: DS and GS. Obtaining funding: -. Acquisition of the data: DS, SH and GS. Analysis of the data: DS, SH and GS. Drafting of the manuscript: DS and GS. Critical revision of the manuscript: DS, SH, JH, TH, AFS and GS. Approval of the final manuscript: DS, SH, JH, TH, AFS and GS.

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None.

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None.

REFERENCES

Aumüller, G. (2007). Anatomie: 208 Tabellen ; [mit CD-ROM zum Präp-Kurs]. Duale Reihe. Stuttgart: Thieme.

Bergeron, M. F. (2014). Heat stress and thermal strain challenges in running. The Journal of orthopaedic and sports physical therapy, 44(10), 831-838. https://doi.org/10.2519/jospt.2014.5500

Bracher, A., Knechtle, B., Gnädinger, M., Bürge, J., Rüst, C. A., Knechtle, P., & Rosemann, T. (2012). Fluid intake and changes in limb volumes in male ultra-marathoners: Does fluid overload lead to peripheral oedema? European journal of applied physiology, 112(3), 991-1003. https://doi.org/10.1007/s00421-011-2056-3

Carmona, G., Roca, E., Guerrero, M., Cussó, R., Irurtia, A., Nescolarde, L., et al. (2015). Sarcomere Disruptions of Slow Fiber Resulting From Mountain Ultramarathon. International journal of sports physiology and performance, 10(8), 1041-1047. https://doi.org/10.1123/ijspp.2014-0267

Case, S., Evans, D., Tibbets, G., & Miller, D. (1995). Dietary intakes of participants in the IditaSport Human Powered Ultra-marathon. Alaska medicine, 37(1), 20-24.

Cejka, C., Knechtle, B., Knechtle, P., Rüst, C. A., & Rosemann, T. (2012). An increased fluid intake leads to feet swelling in 100-km ultra-marathoners - an observational field study. Journal of the International Society of Sports Nutrition, 9(1), 11. https://doi.org/10.1186/1550-2783-9-11

Chávez-López, M. A., Hernández-Díaz, C., Moya, C., Pineda, C., Ventura-Ríos, L., Möller, I., et al. (2013). Inter- and intra-observer agreement of high-resolution ultrasonography and power Doppler in assessment of joint inflammation and bone erosions in patients with rheumatoid arthritis. Rheumatology international, 33(1), 173-177. https://doi.org/10.1007/s00296-011-2297-9

Christodoulou, A. G., Givissis, P., Antonarakos, P. D., Petsatodis, G. E., Hatzokos, I., & Pournaras, J. D. (2010). Knee joint effusion following ipsilateral hip surgery. Journal of orthopaedic surgery (Hong Kong), 18(3), 309-311. https://doi.org/10.1177/230949901001800310

Costa, R. J. S., Snipe, R., Camões-Costa, V., Scheer, V., & Murray, A. (2016). The Impact of Gastrointestinal Symptoms and Dermatological Injuries on Nutritional Intake and Hydration Status During Ultramarathon Events. Sports medicine - open, 2, 16. https://doi.org/10.1186/s40798-015-0041-9

Del Coso, J., González, C., Abian-Vicen, J., Salinero Martín, J. J., Soriano, L., Areces, F., et al. (2014). Relationship between physiological parameters and performance during a half-ironman triathlon in the heat. Journal of sports sciences, 32(18), 1680-1687. https://doi.org/10.1080/02640414.2014.915425

Frey, W., Wassmer, P., Frey-Rindova, P., Braun, D., Schwarz, F., Arnold, M., et al. (1994). Muskelschmerzen und biochemische Veränderungen nach einem Ultramarathon in der Kälte--Beeinflussung durch Diclofenac [Muscle aches and biochemical changes following a ultra-marathon in the cold--modification by diclofenac]. Schweizerische Zeitschrift fur Medizin und Traumatologie = Revue suisse pour medecine et traumatologie. (2), 30-36.

Gaulrapp, H. Funktionelle sonografische Diagnostik bei fibularer Kapselbandläsion: Gaulrapp H. Functional sonography in lateral ankle joint sprains. Unpublished manuscript, OUP 2014, 3: 100-104.

Hartung, W., Kellner, H., Strunk, J., Sattler, H., Schmidt, W. A., Ehrenstein, B., et al. (2012). Development and evaluation of a novel ultrasound score for large joints in rheumatoid arthritis: One year of experience in daily clinical practice. Arthritis care & research, 64(5), 675-682. https://doi.org/10.1002/acr.21574

Hoffman, M. D., Ong, J. C., & Wang, G. (2010). Historical analysis of participation in 161 km ultramarathons in North America. The International journal of the history of sport, 27(11), 1877-1891. https://doi.org/10.1080/09523367.2010.494385

Hoffman, M. D., & Wegelin, J. A. (2009). The Western States 100-Mile Endurance Run: Participation and performance trends. Medicine and science in sports and exercise, 41(12), 2191-2198. https://doi.org/10.1249/MSS.0b013e3181a8d553

Hung, A., Sayre, E. C., Guermazi, A., Esdaile, J. M., Kopec, J. A., Thorne, A., et al. (2016). Association of Body Mass Index With Incidence and Progression of Knee Effusion on Magnetic Resonance Imaging and on Knee Examination. Arthritis care & research, 68(4), 511-516. https://doi.org/10.1002/acr.22714

Ishikawa, M., Dousset, E., Avela, J., Kyröläinen, H., Kallio, J., Linnamo, V., et al. (2006). Changes in the soleus muscle architecture after exhausting stretch-shortening cycle exercise in humans. European journal of applied physiology, 97(3), 298-306. https://doi.org/10.1007/s00421-006-0180-2

Jacobson, J. A., Ruangchaijatuporn, T., Khoury, V., & Magerkurth, O. (2017). Ultrasound of the Knee: Common Pathology Excluding Extensor Mechanism. Seminars in musculoskeletal radiology, 21(2), 102-112. https://doi.org/10.1055/s-0037-1599204

Kane, D., Balint, P. V., & Sturrock, R. D. (2003). Ultrasonography is superior to clinical examination in the detection and localization of knee joint effusion in rheumatoid arthritis. The Journal of rheumatology, 30(5), 966-971.

Kingston, A.-R., Toms, A. P., Ghosh-Ray, S., & Johnston-Downing, S. (2009). Does running cause metatarsophalangeal joint effusions? A comparison of synovial fluid volumes on MRI in athletes before and after running. Skeletal radiology, 38(5), 499-504. https://doi.org/10.1007/s00256-008-0641-2

Knechtle, B., Knechtle, P., & Lepers, R. (2011). Participation and performance trends in ultra-triathlons from 1985 to 2009. Scandinavian journal of medicine & science in sports, 21(6), e82-90. https://doi.org/10.1111/j.1600-0838.2010.01160.x

Knechtle, B., Wirth, A., Knechtle, P., Zimmermann, K., & Kohler, G. (2009). Personal best marathon performance is associated with performance in a 24-h run and not anthropometry or training volume. British journal of sports medicine, 43(11), 836-839. https://doi.org/10.1136/bjsm.2007.045716

Krampla, W., Mayrhofer, R., Malcher, J., Kristen, K. H., Urban, M., & Hruby, W. (2001). MR imaging of the knee in marathon runners before and after competition. Skeletal radiology, 30(2), 72-76. https://doi.org/10.1007/s002560000296

Kursunoglu-Brahme, S., Schwaighofer, B., Gundry, C., Ho, C., & Resnick, D. (1990). Jogging causes acute changes in the knee joint: An MR study in normal volunteers. AJR. American journal of roentgenology, 154(6), 1233-1235. https://doi.org/10.2214/ajr.154.6.2110734

Lohman, M., Kivisaari, A., Vehmas, T., Kallio, P., Malmivaara, A., & Kivisaari, L. (2001). MRI abnormalities of foot and ankle in asymptomatic, physically active individuals. Skeletal radiology, 30(2), 61-66. https://doi.org/10.1007/s002560000316

Magrini, D., Khodaee, M., San-Millán, I., Hew-Butler, T., & Provance, A. J. (2017). Serum creatine kinase elevations in ultramarathon runners at high altitude. The Physician and sportsmedicine, 45(2), 129-133. https://doi.org/10.1080/00913847.2017.1280371

Millet, G. Y., Banfi, J. C., Kerherve, H., Morin, J. B., Vincent, L., Estrade, C., et al. (2011). Physiological and biological factors associated with a 24 h treadmill ultra-marathon performance. Scandinavian journal of medicine & science in sports, 21(1), 54-61. https://doi.org/10.1111/j.1600-0838.2009.01001.x

Millet, G. P., & Millet, G. Y. (2012). Ultramarathon is an outstanding model for the study of adaptive responses to extreme load and stress. BMC medicine, 10, 77. https://doi.org/10.1186/1741-7015-10-77

Parise, C. A., & Hoffman, M. D. (2011). Influence of temperature and performance level on pacing a 161 km trail ultramarathon. International journal of sports physiology and performance, 6(2), 243-251. https://doi.org/10.1123/ijspp.6.2.243

Proft, F., Grunke, M., Reindl, C., Schramm, M. A., Mueller, F., Kriegmair, M., et al. (2016). The influence of long distance running on sonographic joint and tendon pathology: Results from a prospective study with marathon runners. BMC musculoskeletal disorders, 17, 272. https://doi.org/10.1186/s12891-016-1223-4

Rundfeldt, L. C., Maggioni, M. A., Coker, R. H., Gunga, H.-C., Riveros-Rivera, A., Schalt, A., & Steinach, M. (2018). Cardiac Autonomic Modulations and Psychological Correlates in the Yukon Arctic Ultra: The Longest and the Coldest Ultramarathon. Frontiers in physiology, 9, 35. https://doi.org/10.3389/fphys.2018.00035

Salinero, J. J., Soriano, M. L., Lara, B., Gallo-Salazar, C., Areces, F., Ruiz-Vicente, D., et al. (2017). Predicting race time in male amateur marathon runners. The Journal of sports medicine and physical fitness, 57(9), 1169-1177.

Scheer, B. V., & Murray, A. (2011). Al Andalus Ultra Trail: An observation of medical interventions during a 219-km, 5-day ultramarathon stage race. Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine, 21(5), 444-446. https://doi.org/10.1097/JSM.0b013e318225b0df

Schmid, W., Knechtle, B., Knechtle, P., Barandun, U., Rüst, C. A., Rosemann, T., & Lepers, R. (2012). Predictor variables for marathon race time in recreational female runners. Asian journal of sports medicine, 3(2), 90-98. https://doi.org/10.5812/asjsm.34704

Schueller-Weidekamm, C., Schueller, G., Uffmann, M., & Bader, T. R. (2006a). Does marathon running cause acute lesions of the knee? Evaluation with magnetic resonance imaging. European radiology, 16(10), 2179-2185. https://doi.org/10.1007/s00330-005-0132-y

Schueller-Weidekamm, C., Schueller, G., Uffmann, M., & Bader, T. (2006b). Incidence of chronic knee lesions in long-distance runners based on training level: Findings at MRI. European journal of radiology, 58(2), 286-293. https://doi.org/10.1016/j.ejrad.2005.11.010

Schünke, M., Schulte, E., & Schumacher, U. (2015). Innere Organe (4., überarbeitete und erweiterte Auflage). Prometheus: LernAtlas der Anatomie / Michael Schünke, Erik Schulte, Udo Schumacher ; Illustrationen von Markus Voll, Karl Wesker. Stuttgart, New York: Georg Thieme Verlag.

Schütz, U. H. W., Ellermann, J., Schoss, D., Wiedelbach, H., Beer, M., & Billich, C. (2014). Biochemical cartilage alteration and unexpected signal recovery in T2* mapping observed in ankle joints with mobile MRI during a transcontinental multistage footrace over 4486 km. Osteoarthritis and cartilage, 22(11), 1840-1850. https://doi.org/10.1016/j.joca.2014.08.001

Scrimgeour, A. G., Noakes, T. D., Adams, B., & Myburgh, K. (1986). The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultramarathon runners. European journal of applied physiology and occupational physiology, 55(2), 202-209. https://doi.org/10.1007/BF00715006

Shellock, F. G., & Mink, J. H. (1991). Knees of trained long-distance runners: MR imaging before and after competition. Radiology, 179(3), 635-637. https://doi.org/10.1148/radiology.179.3.2027965

Soderberg, G. L., Ballantyne, B. T., & Kestel, L. L. (1996). Reliability of lower extremity girth measurements after anterior cruciate ligament reconstruction. Physiotherapy research international : The journal for researchers and clinicians in physical therapy, 1(1), 7-16. https://doi.org/10.1002/pri.43

Stuempfle, K. J., Hoffman, M. D., & Hew-Butler, T. (2013). Association of gastrointestinal distress in ultramarathoners with race diet. International journal of sport nutrition and exercise metabolism, 23(2), 103-109. https://doi.org/10.1123/ijsnem.23.2.103

Stuempfle, K. J., Lehmann, D. R., Case, H. S., Bailey, S., Hughes, S. L., McKenzie, J., & Evans, D. (2002). Hyponatremia in a cold weather ultraendurance race. Alaska medicine, 44(3), 51-55.

Stuempfle, K. J., Valentino, T., Hew-Butler, T., Hecht, F. M., & Hoffman, M. D. (2016). Nausea is associated with endotoxemia during a 161-km ultramarathon. Journal of sports sciences, 34(17), 1662-1668. https://doi.org/10.1080/02640414.2015.1130238

Stuempfle, K. J., & Hoffman, M. D. (2015). Gastrointestinal distress is common during a 161-km ultramarathon. Journal of sports sciences, 33(17), 1814-1821. https://doi.org/10.1080/02640414.2015.1012104

Tanda, G., & Knechtle, B. (2013). Marathon performance in relation to body fat percentage and training indices in recreational male runners. Open access journal of sports medicine, 4, 141-149. https://doi.org/10.2147/OAJSM.S44945

Terslev, L., D'Agostino, M. A., Brossard, M., Aegerter, P., Balint, P., Backhaus, M., et al. (2012). Which knee and probe position determines the final diagnosis of knee inflammation by ultrasound? Results from a European multicenter study. Ultraschall in der Medizin (Stuttgart, Germany : 1980), 33(7), E173-8. https://doi.org/10.1055/s-0031-1281973

Theysohn, J. M., Kraff, O., Maderwald, S., Kokulinsky, P. C., Ladd, M. E., Barkhausen, J., & Ladd, S. C. (2013). MRI of the ankle joint in healthy non-athletes and in marathon runners: Image quality issues at 7.0 T compared to 1.5 T. Skeletal radiology, 42(2), 261-267. https://doi.org/10.1007/s00256-012-1454-x

Thijs, W., Rabe, K. F., Rosendaal, F. R., & Middeldorp, S. (2010). Predominance of left-sided deep vein thrombosis and body weight. Journal of thrombosis and haemostasis : JTH, 8(9), 2083-2084. https://doi.org/10.1111/j.1538-7836.2010.03967.x

Vassalle, C., Masotti, S., Lubrano, V., Basta, G., Prontera, C., Di Cecco, P., et al. (2018). Traditional and new candidate cardiac biomarkers assessed before, early, and late after half marathon in trained subjects. European journal of applied physiology, 118(2), 411-417. https://doi.org/10.1007/s00421-017-3783-x

Vernillo, G., Rinaldo, N., Giorgi, A., Esposito, F., Trabucchi, P., Millet, G. P., & Schena, F. (2015a). Changes in lung function during an extreme mountain ultramarathon. Scandinavian journal of medicine & science in sports, 25(4), e374-80. https://doi.org/10.1111/sms.12325

Vernillo, G., Schena, F., Berardelli, C., Rosa, G., Galvani, C., Maggioni, M., et al. (2013). Anthropometric characteristics of top-class Kenyan marathon runners. The Journal of sports medicine and physical fitness, 53(4), 403-408.

Vernillo, G., Millet, G. P., & Millet, G. Y. (2017). Does the Running Economy Really Increase after Ultra-Marathons? Frontiers in physiology, 8, 783. https://doi.org/10.3389/fphys.2017.00783

Vernillo, G., Savoldelli, A., Skafidas, S., Zignoli, A., La Torre, A., Pellegrini, B., et al. (2016). An Extreme Mountain Ultra-Marathon Decreases the Cost of Uphill Walking and Running. Frontiers in physiology, 7, 530. https://doi.org/10.3389/fphys.2016.00530

Vernillo, G., Savoldelli, A., Zignoli, A., Skafidas, S., Fornasiero, A., La Torre, A., et al. (2015b). Energy cost and kinematics of level, uphill and downhill running: Fatigue-induced changes after a mountain ultramarathon. Journal of sports sciences, 33(19), 1998-2005. https://doi.org/10.1080/02640414.2015.1022870

Virchow, R. (1851). Ueber die Erweiterung kleinerer Gefäfse. Archiv für Pathologische Anatomie und Physiologie und für Klinische Medicin, 3(3), 427-462. https://doi.org/10.1007/BF01960918

Visconti, L., Capra, G., Carta, G., Forni, C., & Janin, D. (2015). Effect of massage on DOMS in ultramarathon runners: A pilot study. Journal of bodywork and movement therapies, 19(3), 458-463. https://doi.org/10.1016/j.jbmt.2014.11.008

Vitiello, D., Degache, F., Saugy, J. J., Place, N., Schena, F., & Millet, G. P. (2015). The increase in hydric volume is associated to contractile impairment in the calf after the world's most extreme mountain ultra-marathon. Extreme physiology & medicine, 4, 18. https://doi.org/10.1186/s13728-015-0037-6

Vitiello, D., Rupp, T., Bussière, J.-L., Robach, P., Polge, A., Millet, G. Y., & Nottin, S. (2013). Myocardial damages and left and right ventricular strains after an extreme mountain ultra-long duration exercise. International journal of cardiology, 165(2), 391-392. https://doi.org/10.1016/j.ijcard.2012.08.053

Warren, G. L., Cureton, K. J., & Sparling, P. B. (1989). Does lung function limit performance in a 24-hour ultramarathon? Respiration physiology, 78(2), 253-263.

Weltgesundheitsorganisation (1995). Physical status: the use and interpretation of anthropometry: Report of a WHO expert committee. Technical report series / World Health Organization: Vol. 854. Geneva.

Williams, E. S., Ward, M. P., Milledge, J. S., Withey, W. R., Older, M. W., & Forsling, M. L. (1979). Effect of the exercise of seven consecutive days hill-walking on fluid homeostasis. Clinical science (London, England : 1979), 56(4), 305-316. https://doi.org/10.1042/cs0560305

World Health Organization (WHO) (2004). BMI classification. Retrieved April 13, 2018, from http://apps.who.int/bmi/index.jsp

Yang, X.-G., Wang, Y., Bao, D.-P., & Hu, Y. (2015). Anthropometric Characteristics of Chinese Professional Female Marathoners and Predicted Variables for Their Personal Bests. Collegium antropologicum, 39(4), 899-905.

Žákovská, A., Knechtle, B., Chlíbková, D., Miličková, M., Rosemann, T., & Nikolaidis, P. T. (2017). The Effect of a 100-km Ultra-Marathon under Freezing Conditions on Selected Immunological and Hematological Parameters. Frontiers in physiology, 8, 638. https://doi.org/10.3389/fphys.2017.00638