

## 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, Khodaei, 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](http://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.

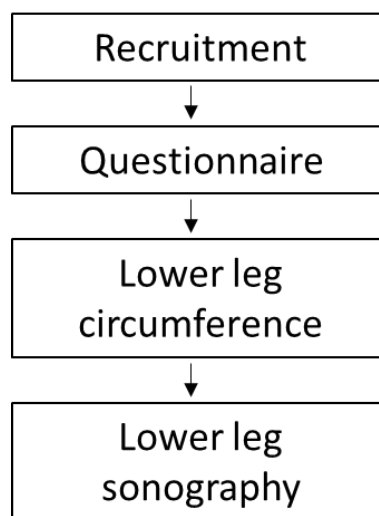


Figure 1. Graphical overview of the methods applied in this study.

### ***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. ( $-4^{\circ}\text{C}$ ) and 1 hour after finishing the 80 km ultramarathon (around 1 p.m. to 4 p.m.) ( $-6^{\circ}\text{C}$ ), 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.  $\leq 10$  ultramarathons), age ( $>45$  y vs.  $\leq 45$  y), frequency of training ( $>18$  vs. times per mo  $\leq 18$ ), training volume ( $<65$  km per wk vs.  $\geq 65$  km per wk), BMI ( $>22.0$   $\text{kg}\cdot\text{m}^{-2}$  vs.  $\leq 22.0$   $\text{kg}\cdot\text{m}^{-2}$ ) and running experience ( $>10$  y vs.  $\leq 10$  y).

For indication of significant differences, p-values were classified exactly and by \* $p \leq 0.05$ .

## RESULTS

On the day of the ultramarathon, the ambient temperature on the route was  $-6^{\circ}$  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 ( $p=0.44$ ).

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 ( $p=0.65$ ).

Among the participants of our study, average age was  $45 \pm 10$  y. Average weight in our study population was  $69.8 \pm 10$  kg with a height of  $175.2 \pm 19$  cm resulting in a BMI of  $22.3 \pm 2$   $\text{kg} \cdot \text{m}^{-2}$ . Mean experience in running was  $14 \pm 9$  y. The participants practiced  $4 \pm 2$  times per week with an average of  $68 \pm 4$  km over the seven days. For preparation, cross training was used by 66%. In the year before, an average of  $9 \pm 16$  marathons were completed and the average number of lifetime ultramarathons run was  $27 \pm 52$ . 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 ( $\pm$ SD) <i>left</i>	p-value	Difference after-before in cm ( $\pm$ SD) <i>right</i>	p-value
20 cm above medial tibial plateau		+1.0 ( $\pm$ 4)	0.2172 [-2.52-0.60]	+1.7 ( $\pm$ 4)	0.043 * [-3.36- -0.06]
10 cm above medial tibial plateau		+0.1 ( $\pm$ 4)	0.8719 [-1.71-1.46]	+1.8 ( $\pm$ 4)	0.0287 * [-3.30- -0.20]
Middle of patella		+0.3 ( $\pm$ 2)	0.5884 [-1.19- 0.69]	+0.2 ( $\pm$ 3)	0.7675 [-1.32-0.99]
15 cm below medial tibial plateau		-0.7 ( $\pm$ 1)	0.0261 * [0.09-1.33]	+0.0 ( $\pm$ 2)	0.9153 [-0.84-0.76]
Lower leg, smallest circumference		-0.1 ( $\pm$ 1)	0.7701 [-0.50-0.67]	-1.0 ( $\pm$ 2)	0.0140 * [0.22-1.78]
Ankle		+0.1 ( $\pm$ 2)	0.7370 [-0.89-0.64]	+0.4 ( $\pm$ 2)	0.1871 [-1.05-0.22]
Instep above navicular bone		+1.3 ( $\pm$ 2)	0.0017 * [-1.98- -0.52]	+0.1 ( $\pm$ 2)	0.0148 * [-1.71- -0.21]
Forefoot ball		+1.8 ( $\pm$ 2)	<0.0001 * [-2.56- 1.02]	+1.0 ( $\pm$ 2)	0.0087 * [-1.79- -0.29]

Above the knee, both right (20cm above medial tibial plateau:  $+1.7\pm 4$  cm\*; 10cm above medial tibial plateau:  $+1.8\pm 4$  cm\*) and left legs (20cm above medial tibial plateau:  $+1.0\pm 4$  cm; 10cm above medial tibial plateau:  $+0.1\pm 4$  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:  $+0.2\pm 3$  cm; left:  $+0.3\pm 2$  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:  $+1.8\pm 2$  cm\*; right:  $+1.0\pm 2$  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 ( $-0.1\pm 1$  cm) and significantly smaller in the right leg ( $-1.0\pm 2$  cm\*) after the race. (Table 1). The quantitative amount of circumference increase was the greatest in the left foot ( $1.8\pm 2$  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 ( $\pm$ SD) left	p-value	Semi quantitatively ( $\pm$ SD) right	p-value
<b>Knee joint</b>				
Before	0.29 ( $\pm$ 0.55)		0.29 ( $\pm$ 0.46)	
After	1.46 ( $\pm$ 0.72)		1.38 ( $\pm$ 0.49)	
Difference	+1.17 ( $\pm$ 0.87)	<0.0001 *	+1.08 ( $\pm$ 0.65)	<0.0001 *
<b>Ankle joint</b>				
Before	0.21 ( $\pm$ 0.41)		0.25 ( $\pm$ 0.44)	
After	0.79 ( $\pm$ 0.66)		0.54 ( $\pm$ 0.59)	
Difference	+0.58 ( $\pm$ 0.72)	0.0006 *	+0.29 ( $\pm$ 0.75)	0.0695

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 ( $\leq 10$ 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 <sup>-2</sup> ) vs. heavy athletes (BMI $\geq 22$ kg·m <sup>-2</sup> )	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 ( $\geq 45$ 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 ( $\geq 18$ 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 ( $\geq 65$ 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 ( $\leq 10$ 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  $\geq 22$  kg·m<sup>-2</sup>. 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 <sup>2</sup>	p-value
Measurements left	0.14-0.00	0.07-0.75 [-0.001-0.029 & -0.014-0.019]
Measurements right	0.12-0.01	0.1-0.73 [-0.013-0.001 & -0.008-0.006]
Effusion right knee difference	0.12	0.10 [-0.005-0.000]
Effusion left knee difference	0.00	0.93 [-0.004-0.004]
Effusion right ankle difference	0.75	0.29 [-0.002-0.005]
Effusion left ankle difference	0.02	0.48 [-0.002-0.004]

## **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, Czech, 100 km), in which markers of acute inflammation (neutrophils) and markers of muscle damage (CK) were increased significantly. (Žáková 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 ( $\geq 25 \text{ kg}\cdot\text{m}^{-2}$ ) (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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