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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

# Effects of a trail mountain race on neuromuscular performance and hydration status in trained runners

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## ABSTRACT

BACKGROUND: The aims of this study were to examine the effects of a trail mountain race (TMR) on hydration status and neuromuscular performance of recreational trail runners, and to determine the relationship among these parameters, subject's characteristics and competitive performance.

METHODS: Thirty-five male recreational trail runners (age 38.1±9.5 years; height 177.3±5.8 cm; body mass 73.8±8.4 kg) were assessed before and after a 21.1-km TMR. Hydration status (urine color [$U_{col}$] and body mass [BM]) and neuromuscular performance (countermovement jump [CMJ] and rebound jumps [RJ]) were assessed.

RESULTS: Significant changes following the TMR included RJ mean contact time ($RJ_{MCT}$) (12%, ES=-0.35, P<0.05) and dehydration status increases (BM reductions -2.7%, ES=0.24, P<0.001; $U_{col}$: 147% increase, ES=-1.8, P<0.001). Low to moderate positive correlations were found between pre- and post-TMR BM ($r$=0.5-0.54; P<0.01), post-race $U_{col}$ ($r$=0.37; P<0.05), age ($r$=0.57; P<0.01) and TMR performance. Participants' age combined with $U_{col}$ and the $RJ_{MJH}$ post-TMR, explained 65% of the variance in the final running time ($r$=0.81; P=0.000).

CONCLUSIONS: Participation in a 21.1-km TMR in recreational runners results in small reductions of the neuromuscular function and increases in dehydration levels. The hydration status ($U_{col}$) and the $RJ_{MJH}$ post-TMR combined with the runners' chronological age seemed to be good predictors of the final running performance.

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**Key words:** Running - Dehydration - Muscle strength.

Mountain trail running is a sport event performed outdoor that has become popular as a strenuous and fatiguing form of endurance exercise.[1] These competitions consist of running/walking on mountain trails involving extensive vertical displacement (uphill and downhill) and have experienced an important growth in recent years.[2] One of the main characteristics of trail running events is the large proportion of eccentric muscular actions performed while running downhill,[1] accentuating muscle damage and inflammation [3, 4] and affecting muscular performance and locomotion efficiency.[5] The neuromuscular fatigue after a mountain race can be well quantified trough maximum strength decline,[6, 7] additionally, significant declines in maximal isometric force after a 55-km (≈7 hours, 6000 m of vertical displacement) or 30-km (≈2.5 hours, 800 m of vertical displacement) trail running events have been confirmed.[1, 6]

Endurance exercise imposes a physical load on the organism, leading to thermal stress, decreases in fat mass [5] and fluid loss.[8] In ultra-endurance (>3 hours) sports, an adequate fluid and electrolyte balance is determinant for optimal exercise performance and health preservation.[9] On this matter, is it well known that one of the most important aspects during the races is to individualize the fluid consumption to avoid this dehydration.[10] An adequate thermoregulation allows the organism to maintain the core internal temperature and it can be severely altered by hydration status.[10] Dehydration can also be associated to an increased physiologic strain, higher core temperature, increased heart rate and augmented perceived exertion responses when performing exercise under these conditions, added to a degraded performance and increased susceptibility to heat injury.[11, 12] During long endurance events (*i.e.*, mountain races), sweat losses can considerably reduce the amount of body water, and ultra-endurance athletes often do not consume enough fluids to balance fluid losses during exercise.[9] A correct hydration strategy is specially important in prolonged duration exercise lasting greater than 3 hours.[12] Specifically, it has been proposed that a dehydration >2% of the body mass (BM) reduces aerobic exercise and cognitive/mental performance.[12] The effects of fatigue induced by different types of exercise on hydration status has been studied on various team (water polo, basketball, soccer or American football) racquet (tennis and squash) and endurance sports (half marathon running, cross-country running or ironman triathlon) [12] and has also been studied during trail running [13] but there is still much unknown concerning to its effect during mountain races.

Stretch-shortening cycle (SSC) is considered as the most common type of muscle function, defined as the successive combination of eccentric and concentric actions and it is well known because of its potentiating effect on sport performance.[14] The optimal utilization of the SSC requires adequate levels of stiffness and viscoelastic properties of leg muscles.[15] In this sense, it has been demonstrated that vertical jump performances (countermovement jump [CMJ]) decrease significantly after a 65-km ultra-marathon ($P<0.01$) [16] or after an ironman triathlon (-8.8±9.7%).[5] However there is little information about the effects of mountain races on neuromuscular performance quantified as a decline in reactive strength (SSC) and power assessed by vertical jumps (*i.e.* CMJ).

Thus, the first purpose of the study was to examine the effects of a 21-km mountain race on the hydration status and neuromuscular performance assessed by jump test of recreational trail mountain runners. The second purpose was to determine the relationship between these parameters, subject's characteristics and competitive performance.

## Materials and methods

Thirty-five male recreational trail runners (age 38.1±9.5 years; height 177.3±5.8 cm; body mass 73.8±8.4 kg) volunteered to participate in this study. The mean training volume of the runners registered in hours ($TV_H$) and sessions per week ($TV_S$) was 6.6±3.0 h/week and 4.0±1.6 sessions/week. The mean competition volume (CV) during the last 3 years was 14.4±10.9 competitions per year and the experience in mountain races (EMR) was 4.6±3.7 years. The participants were fully informed about all the procedures and the associated risks and completed a running history survey before enrolling in the study. Before participation, all subjects were provided with a written informed consent and the experimental procedures and potential risks were totally explained. The study was approved by the Research Ethics Committee of the Research and Health Education Foundation of Osona (no. 2015881) and it was in accordance with the Helsinki Declaration.

### *Procedures*

The total distance of the race was 21.1 km, beginning at 9:00 a.m. and starting and finishing at the same point. The accumulated positive and negative slope was 1940 m, thus making a total gain of 3880 m. The starting point of the race was set at 1964 m. Maximum altitude was 2913 m, with 72% of the race over 2700 m and 14 peaks covered along the race. A single race food station was available at the starting and finishing point; athletes were carrying their own liquids to ingest during the race. Due to the competitive nature of the intervention, each subject was well motivated to perform maximally over the entire distance.

The assessment was carried out on the same day of the race and was divided into two phases; pre-testing to determine the sample baseline characteristics (non-fatigued state), and post-testing immediately after the race (fatigued state) (Figure 1). Warm-up was free, the clothes and shoes worn were the ones used during the race and no restrictions or instructions were given for fluid replacement and supplement strategies.

Hydration status was evaluated by registering the BM

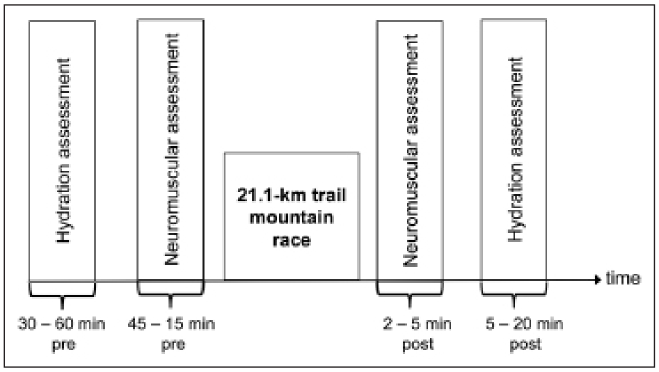


Figure 1.—A schematic representation of the experimental protocol.

weighed on a scale (Bosch, precision ±50 g) and using urine color grade ($U_{col}$) were dark colors are related to severe and light colors to a small to none dehydration.[17] This method has been considered a valid index of hydration status in previous research and is recommended when urine specific gravity and osmolality are impractical.[17-19] Each urine specimen was collected in an inert polypropylene container. All $U_{col}$ measurements were performed within 10 minutes of collection and were verified by three experienced researchers. $U_{col}$ was analyzed by holding each specimen container next to a color state. The eight-color scale included colors ranging from very pale yellow to brownish green.[18] Additionally, dehydration was determined by the difference of weight at the beginning and at the end of the race. We consider that, mainly, the loss of BM after the race can be attributed to decreases in total body water. BM losses due to glycogen or fat mass are ignored following Cheuvront *et al.*[20] and Armstrong *et al.*[18] Athletes did not receive any specific instruction regarding water intake during the mountain race.

Neuromuscular performance was assessed by means of a vertical jump test consisting of a countermovement jump with arms akimbo (CMJ) and a 15-seconds rebound jump test (RJ) performed on a contact mat (Chronojump BoscoSystem, precision ±0.001 s). No previous familiarization was done with the vertical jump protocol assessment following the criteria proposed by Arteaga *et al.*[21] From the two valid attempts in the CMJ the highest jump was recorded for further analysis. On the rebound jump test, subjects were encouraged to jump as high as possible for 15 seconds. Hands were placed on the hips and subjects should bend their knees (90°) between jumps. Care was taken to ensure that the subjects landed with straight legs. In order to minimize trunk movements, the researchers controlled the position of the upper body. The subjects were asked to jump as high as possible and the best CMJ and RJ performance was analyzed. The participants were instructed to keep their knees as stiff as possible ("ankle jumps") and to have as brief a contact time as possible. The variables obtained from the CMJ were the jump height ($CMJ_H$), the power ($CMJ_P$) and the relative power ($CMJ_{RP}$). The variables obtained from the RJ were the jumps' mean contact time ($RJ_{MCT}$), the mean jump height for the set of jumps ($RJ_{MJH}$) and the number of jumps ($RJ_J$). Height of jump was indirectly calculated by means of flight time using the following equation:[22]

$$h = g \times \frac{t^2}{8} \quad (1)$$

where $h$ is jump height, $g$ is gravity acceleration, and $t$ is flight time.

Power output during the CMJ was indirectly calculated using Lewis equation:[23]

$$P = \sqrt{4.9} \times 9.8 \times BW_{kg} \times \sqrt{h_{cm}} \quad (2)$$

where $BW$ is body weight in kg, and $h$ jump height in cm.

### *Statistical analysis*

The Kolmogorov-Smirnov test was used to assess the Gaussian, distribution of the data. Specified outcome measures are presented as mean, standard deviation (±SD), mean difference (diff.), and 95% confidence interval (95% CI) when appropriate. Differences between Pre- *vs.* post-mean values of the variables measured were assessed using the paired Student's *t*-test. The magnitude of the differences in mean was shown as effect size and interpreted according to the criteria used by Cohen (1988):[24] <0.2 trivial; 0.2-0.4 small, 0.5-0.7 moderate, >0.7 large. The relationship between quantitative variables was described using Pearson's product-moment correlations coefficients ($r$). The multivariate analysis was carried out using a multiple regression model (stepwise method), with running time as the predicted variable and neuromuscular performance, hydration status, body mass and training volume variables as predictors. Significance was tested at 95% confidence level ($P<\alpha\leq0.05$). All statistical analyses were performed using SPSS for Windows v. 23.0.0.2 (SPSS, Inc., Chicago, IL, USA).

## Results

All of the participants completed the race within the time cut (5 hours), the average running race time was 227.5±32.8 min and the average running speed was 5.68±0.82 km/h. The time of the winner of the race was 120.7 min and the average running speed was 10.5 km/h, the average time of the subjects participating in the study was 188.4% higher than the winning time.

### *Pre- to post-race measurements*

Changes to neuromuscular performance and hydration status (BM and $U_{col}$) are reported in Table I. Pre- and post-test showed that after the mountain race there were significant increases in the $RJ_{MCT}$ (12.0%, ES=small, P<0.05), reductions in BM (-2.7%, ES=small, P<0.001) and increases in $U_{col}$ (147%, ES=large, P<0.001). No changes were found after the mountain race in any of the remaining analyzed variables (*i.e.*, $CMJ_H$, $CMJ_P$, $CMJ_{PH}$, $RJ_{MJH}$ and $RJ_J$).

### *Correlations between neuromuscular performance, hydration status and race performance*

The relationship among neuromuscular performance (CMJ and RJ), hydration status (BM and $U_{col}$) and mountain race performance (race duration) is reported in Table II. Regarding to the neuromuscular performance, low positive significant relationship was found between post-race $CMJ_{RP}$ and race performance and low negative relationship between $RJ_{MJH}$ in the pre- and post-race and race performance. Regarding to the hydration status, a moderate positive relationship was found between BM pre- and post-race and race performance, and a low positive relationship between $U_{col}$ post-race and race performance.

### *Correlations between subject's characteristics and race performance*

Table III shows the relationship among subject's characteristics (biometric characteristics, training and competition volume and experience in mountain races) and race performance (race duration). A moderate positive

TABLE II.—*Pre- and post-race relationship between neuromuscular performance (CMJ and RJs) and hydration status (BM and $U_{col}$) with mountain race performance (min).*

| Variables | Correlation coefficient (*r*) | | Coefficient of determination ($R^2$) | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| Neuromuscular performance | | | | |
| $CMJ_H$, cm | -0.28 | -0.01 | 0.08 | 0.00 |
| $CMJ_P$, W | 0.16 | 0.32 | 0.03 | 0.10 |
| $CMJ_{RP}$, W/kg | -0.12 | 0.44* | 0.01 | 0.19 |
| $RJ_{MCT}$, s | 0.11 | 0.10 | 0.01 | 0.01 |
| $RJ_{MJH}$, cm | -0.40* | -0.42* | 0.16 | 0.18 |
| $RJ_J$, N. | 0.18 | 0.08 | 0.03 | 0.01 |
| Hydration status | | | | |
| BM, kg | 0.50** | 0.54** | 0.25 | 0.30 |
| $U_{col}$, N. | 0.10 | 0.37* | 0.01 | 0.14 |

$CMJ_H$: countermovement jump height; $CMJ_P$: countermovement jump power; $CMJ_{RP}$: countermovement jump relative power; $RJ_{MCT}$: rebound jumps mean contact time; $RJ_{MJH}$: rebound jump mean jump height; $RJ_J$: rebound jump number of jumps; BM: body mass; $U_{col}$: urine color.
*P<0.05; **P<0.01 as statistically significant difference pre- *vs*. post-race.

TABLE I.—*Pre- and post-mountain race differences between neuromuscular performance (CMJ and RJ) and hydration status (BM and $U_{col}$).*

| Variables | N. | Pre-race (95% CI) | Post-race (95% CI) | P value | Difference (95% CI) | % change | Effect size | Qualified effect |
|---|---|---|---|---|---|---|---|---|
| Neuromuscular performance | | | | | | | | |
| $CMJ_H$, cm | 35 | 23.6±6.8 (21.2-25.9) | 23.1±6.8 (20.1-25.4) | 0.697 | -0.46±6.9 (-2.9-1.9) | -2.0 | 0.07 | Trivial |
| $CMJ_P$, W | 35 | 744.3±121.5 (702.6-786.0) | 733.2±128.4 (689.0-777.3) | 0.582 | -11.0±116.9 (-51.2-29.2) | -1.5 | 0.09 | Trivial |
| $CMJ_{RP}$, W/kg | 26 | 9.9±1.5 (9.3-10.5) | 10.2±1.5 (9.6-10.9) | 0.256 | 0.36±1.5 (-0.28-0.99) | 3.6 | -0.19 | Trivial |
| $RJ_{MCT}$, s | 29 | 0.35±0.12 (0.30-0.40) | 0.39±0.11* (0.35-0.43) | 0.046 | 0.042±0.11 (0.001-0.083) | 12.0 | -0.35 | Small |
| $RJ_{MJH}$, cm | 29 | 18.9±5.9 (16.6-21.1) | 18.1±4.3 (16.4-19.7) | 0.305 | -0.80±4.1 (-2.4-0.8) | -4.2 | 0.15 | Trivial |
| $RJ_J$, N. | 29 | 19.9±3.9 (18.5-21.3) | 18.8±3.1 (17.7-20.1) | 0.139 | -1.2±4.0 (-2.6-0.3) | -6.0 | 0.31 | Small |
| Hydration status | | | | | | | | |
| BM, kg | 26 | 73.8±8.4 (70.4-77.1) | 71.7±8.5** (68.3-75.2) | 0.000 | -2.0±1.5 (-2.6--1.4) | -2.7 | 0.24 | Small |
| $U_{col}$, N. | 31 | 1.9±0.7 (1.6-2.1) | 4.7±2.1** (3.9-5.5) | 0.000 | 2.8±2.1 (2.0-3.6) | 147.3 | -1.8 | Large |

Values are presented as mean±SD.
$CMJ_H$: countermovement jump height; $CMJ_P$: countermovement jump power; $CMJ_{RP}$: countermovement jump relative power; $RJ_{MCT}$: rebound jumps mean contact time; $RJ_{MJH}$: rebound jump mean jump height; $RJ_J$: rebound jump number of jumps; BM: body mass; $U_{col}$: urine color.
*P<0.05; **P<0.001 as statistically significant difference pre- *vs*. post-race.

TABLE III.—*Relationship between subjects' characteristics and mountain race performance (min).*

| Variables | Correlation coefficient (*r*) | Coefficient of determination ($R^2$) |
|---|---|---|
| Biometric characteristics | | |
| Age, years | 0.57** | 0.32 |
| Height, cm | 0.24 | 0.04 |
| Training and competition volume | | |
| $TV_H$, h/week | -0.34 | 0.06 |
| $TV_S$, sessions/week | -0.43* | 0.18 |
| CV, competitions/year | -0.18 | 0.03 |
| Experience | | |
| EMR, years | -0.23 | 0.05 |

$TV_H$: training volume, h/week; $TV_S$: training volume, sessions/week; CV: competition volume; EMR: experience in mountain running.
*P<0.05; **P<0.01.

relationship was found between age and race performance and a low negative relationship between $TV_S$ and race performance. No correlation was found between the rest of training and competition volume and experience variables ($TV_H$, CV, EMR) and race performance.

### *Multivariate analysis*

Three stages of multiple regression analysis were carried out. In the first stage, the model only took into account the age, explaining 32% of running time variability (*r*=0.57; P=0.000). In the second stage, the model took into account the age and the $U_{col}$ in the post-test, explaining 53% of running time variability (*r*=0.73; P=0.001). The final model using the stepwise method showed that the major predictors of performance status were age and $U_{col}$ and $RJ_{MJH}$ post-race and explained 65% of the variance of running time (r=0.81; P=0.000).

## Discussion

The main results of this study indicate that there were small decreases in neuromuscular function (shown by increases in post-$RJ_{MCT}$) and increases in the dehydration levels (displayed as small decreases in post-BM and large increases in post-$U_{col}$) after a 21.1-km mountain race event in recreational trail runners. Additionally, we found moderate and low relationship between this parameters and race performance. Moreover, the $U_{col}$ and the $RJ_{MJH}$ post-race combined with the participants' age seemed to be good predictors of running performance, explaining 65% of the variance of the running time.

The mountain running competition analyzed had a 3880 m vertical displacement (1940-m uphill and 1940-m downhill) along its 21.1-km itinerary, and the average race time was 3:47±0:33 h:min. The etiology of fatigue depends on the type, the intensity and the duration of the exercise or the activation patterns and types of muscle contractions performed.[7] Although it is well known that long-duration events produce declines in neuromuscular activity,[25] and large proportion of eccentric work in mountain races produces, as shown in previous studies, severe muscle structural damage,[1] we have only found small decreases in the neuromuscular function through a small increase in the $RJ_{MCT}$ (12.0%; P<0.05) and we did not find any changes in pre- and post-CMJ levels. The changes in the neuromuscular activation pattern under fatigue may be due to a decrease in lower-limb stiffness, but it cannot be attributed to a decrease in compliance and elastic strength of the muscle-tendon complex. In this regard, it is well known that leg stiffness is negatively correlated with contact time and positively correlated with maximal ground reaction force.[5] Contrary to these results, significantly decreases in the CMJ after a 65-km ultra-marathon (P<0.01) have been observed.[16] These discrepancies may be due to the different distances (*e.g.* 21.1 *vs.* 65 km) or the vertical displacement (*e.g.* 1940 *vs.* 2500 m) of the races. On the other hand, although it has been proposed that it is not necessary a session of familiarization in the assessment of vertical jump in active subjects,[21] in this case, there may be a learning effect in the post-test that minimizes the reduction in neuromuscular performance (CMJ and RJ) resulting from fatigue. Our results match those from Millet *et al.*[16] which showed significantly shorter contact time during hopping in non-fatigued marathon athletes than in those performing jumps in fatigued condition (P<0.01). If we consider that contact times during hopping depend upon both the stiffness of the tendon-muscle complex and the neural command, it has been speculated that the increase in contact time may be a result of neuromuscular activation failure [16] or leg muscle damage.[5] In our results, $RJ_{MJH}$ did not differ after the race (18.9±5.9 *vs.* 18.1±4.3; P>0.05) from the tests conducted before, meaning that the increase in contact time probably implies a decrease in peak force but maintains the total impulse. Performance in the vertical jumps is totally related to the impulse produced. If the duration of the contact time phase is increased, to generate the required impulse a lower peak of ground reaction force must be generated.[26] Furthermore, we found negative correlations between the total race duration (race performance) and the $RJ_{MJH}$ pre- and post-race, highlighting the relative importance of the stiffness of the tendon-muscle complex in the mountain race outcome. As a result, no correlations were found between the CMJ variables and race performance.

For practical constrains, in the present study the hydration status was evaluated by the analysis of BM and $U_{col}$. Although this simple biomarkers have some limitations, when used together in the proper context, they can provide valuable observations.[12] Changes in BM have been proposed as the gold standard, the simplest and most accurate method to evaluate the hydration status [18, 27] and the $U_{col}$ has been considered a valid marker of hydration status because of the strength of the relationship between $U_{col}$ and specific gravity and osmolality.[18, 19] Significant alterations were found in BM and $U_{col}$ after the mountain race. Loss in BM (an average of 2 kg; -2.7% of BM) can have negative effects on athletes' performances. It has been reported in the past that running performance decreases while physiologic strain increases when water loss exceeds 2% of BM [10, 11] and a dehydration of ≈ 2% can produce symptoms of thirst, flushing, dry mouth, fatigue and weakness.[10] Recent evidence suggests that dehydrated runners (2.5% of BM loss at the end of the run) had greater physiologic strain, the effort was perceived to be greater and the post-run heart rate (HR) and body core temperature were higher (0.5° and 15 beats·min$^{-1}$).[13] If we consider that the objective of drinking during exercise is to prevent >2% body weight loss from water deficit,[12] it might be considered that, on average, the athletes in our sample did not ingest sufficient amounts to offset the fluid losses and did not plan well the fluid replacement rate during the race. The large increase in the $U_{col}$ in the post-race also highlights the inadequate levels of hydration of the average athlete after the mountain race. The $U_{col}$ pre-race was in the range we would consider of proper hydration, however the $U_{col}$ post-race would be considered a hypohydration status ($U_{col} \geq 3$).[19] Moreover, the positive correlation between the total race duration and the $U_{col}$ post-race indicates that the slower athletes, who competed for more time, tend to finish the race more dehydrated. Nevertheless, many studies have shown that increased dehydration often does not degrade performance [13, 28, 29] and even that fastest runners seemed to be the most dehydrated.[30] In the case of recreational runners we think that the performance can be decreases specifically during the last kilometers of the race.

The positive correlation between performance and BM in the pre- and post-race shows that a proper body mass is an important variable in the final outcome of mountain races. Consequently, the positive correlation between $CMJ_{RP}$ post-race and performance it is due to the fact that the slower athletes decrease in greater proportion their BM and their relative power tends to increase, even though this fact has no positive effect on their performance. Regarding to the training volume, no significant relationship was found between the $TV_H$ and the race performance. Nevertheless, a negative correlation between $TV_S$ and race performance was found. It seems that in recreational mountain athletes it is more efficient to distribute the training volume in an increased frequency of sessions than to perform training sessions with a great duration. In addition, it seems that a greater number of competitions per year or a deeper experience in mountain races did not contribute to improve the final performance in a 21.1-km mountain race. The multivariate analyses used to predict performance showed that a large part of the variability in the race duration can be explained by the age combined with neuromuscular ($RJ_{MJH}$) and hydration ($U_{col}$) variables. These results suggest that these parameters showed a moderate ability to predict a mountain race performance, largely is mostly because there are some other important variables not evaluated (*i.e.*, physiological characteristics: maximal oxygen uptake ($VO_{2max}$).

### *Limitations of the study*

There were several additional limitations of the current study. We cannot describe the physiological intensity of the race. The exercise intensity will modify the adverse effects of hypohydration making its physiologic impact more severe with higher exercise intensity.[11] As such, optimal processing and data gathering were difficult because all of the assessments were conducted in the mountain and that fact, likely explains the variability between and among samples.

## Conclusions

The participation in a 21.1-km mountain race resulted in small reductions in the neuromuscular function and increases in the dehydration in recreational runners, and theses parameters are low to moderate related to race final performance. Moreover, the $U_{col}$ and the $RJ_{MJH}$ after the race combined with the participants' age seemed to be good predictors of running performance.

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