International Journal of EXERCISE SCIENCE

Original Research

Impact of Hydration Status on Jump Performance in Recreationally Trained Males

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ABSTRACT

International Journal of Exercise Science 13(4): 826-836, 2020. The vertical jump is commonly used as a means of evaluating athlete readiness. Athletes have been shown to arrive to training and competition in a hypohydrated state. Thus, this investigation sought to examine the impact of hydration status on both countermovement (CMJ) and squat jump (SJ) performance. Twenty-five recreationally trained males completed three CMJ and SJ in a euhydrated, hypohydrated and control condition. Conditions were separated by a minimum of 24 hours. Hydration status was assessed using urine specific gravity. Jump performance was evaluated using both kinematic and kinetic data obtained from a force platform. A repeated-measures ANOVA was performed for each variable of interest in both the CMJ and SJ. CMJ peak and mean force values were significantly greater in the euhydrated condition compared to the hypohydrated condition ($p < 0.05$), with no differences between the control condition and either experimental condition. SJ showed reductions in jump height, peak and mean velocity, peak and mean power and impulse from control and euhydrated conditions ($p < 0.05$). The findings of this investigation show that when performing jump testing, specifically SJ, that hydration status of the individual may impact commonly used variables to assess the readiness of the individual for a given day.

KEY WORDS: Dehydration, vertical jump, fluid balance, anaerobic power

INTRODUCTION

Previous research has shown that athletes arrive to both training sessions and competitions in a hypohydrated state and continue further into that hypohydration during training sessions (24, 25, 31). Once in the hypohydrated state it becomes difficult to rehydrate before subsequent sessions regardless of fluid consumption during activity (24, 27, 31). A substantial body of literature exists into the effects of poor hydration practices on aerobic based performance, however the same cannot be said for anaerobic performance (20). The vertical jumping task is commonly used as a method to assess the effect of hydration on anaerobic power with conflicting findings as to how much impact hypohydration has on task performance (7, 16–18).

With the exception of one investigation (30), in which jump performance was improved, jump performance seems to be unaffected by hypohydration. The vertical jumping task is performed against the resistance of one's own body mass, thus a reduction in body mass due to hypohydration should improve vertical jump performance as long as strength or power is maintained as this would then improve the strength to mass ratio (7). This is interesting as it has appeared that muscular strength independent of body mass, indicates a small negative impact (1-3%) which may not impact the strength to mass ratio (6, 20, 27). However, it is seen consistently in the literature that jump height is not significantly different between hydration classifications (16–18). There has been one investigation that has taken the change in body mass into consideration and held body mass constant across hydration classifications with the finding that jump height, peak velocity, and impulse were reduced in a hypohydrated state during the countermovement jump (CMJ) (7).

As competition and training schedules have become more dense, jump testing has become a common tool used in the assessment of athletes to have an understanding of their level of neuromuscular fatigue and/or readiness for subsequent training and competition (8,14,33). Specifically the CMJ and the squat jump (SJ) are the most commonly used as tools in the assessment and monitoring of athletes by strength and conditioning professionals (29). This is due to the ease of implantation and the lack of additionally fatigue that the test generates. The CMJ consist of starting in a standing position and begins with a downward movement, which is immediately followed by an explosive upward motion leading to takeoff from the ground. SJ begins with moving into a semi-squatting position and holding this position for a period of time, typically about 3 seconds. This is then followed by an explosive concentric only upward movement to achieve takeoff. The use of variables outside of jump height for both jumping techniques have been suggested as jump height may not provide the sensitivity needed to understand neuromuscular fatigue, as well as allowing for a more precise examination as to how a particular jump height was obtained (11, 14, 15). It has been shown that jump height alone may stay constant though a change in strategy during the movement itself obtain a given height (2,36). While maintaining jump height seems to be important, a shift in strategy to achieve a given height may not be optimal during sport-specific situations where temporal restrictions may be placed on an individual. Typical variables include the use of peak and mean values of force, velocity and power, as well as other time related variables such as time to peak, contraction time and reactive strength index modified (RSIm) (12, 14).

With the increase in popularity of using assessments such as CMJ and SJ testing, it is important to have an understanding of potential factors that could influence the results of the assessment. As discussed previously, athletes have a tendency to arrive at training sessions hypohydrated and perform either the CMJ or SJ or both to assess their neuromuscular fatigue. While it is seen that jump height itself may not change significantly based on hypohydration, other variables such as jump velocity and impulse appear be impacted. Thus, the purpose of this investigation is to examine the impact of hydration status on measurements commonly used in the assessment of neuromuscular fatigue with both the CMJ and SJ.

METHODS

A counterbalanced crossover design was used to assess the effect of hydration status on selected variables associated with both countermovement and squat jump performance. Participants visited the laboratory for a total of four times, one familiarization session and three experimental sessions. During the first visit participants were screened for exclusionary criteria and were familiarized with test protocols for both the countermovement (CMJ) and squat jump (SJ).

Participants

Twenty-five (n = 25) recreationally trained males (height 180.236 ± 8.00 cm, body mass 85.15 ± 12.23 kg) between the age of 18 and 35 (age 23.85 ± 2.81 years) participated in this investigation. All subjects were physically active for the 6 months preceding data collection and where deemed to be free of injury and cleared for physical activity by the physical activity readiness questionnaire (PAR-Q). Informed consent approved from the University Institutional Review Board was obtained. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (23). Sample size estimation was conducted based on previous investigations using a repeated measures design similar to the present investigation (7). The use a conventional $\alpha = 0.05$ and $\beta = 0.80$ and moderate effect size of 0.5 were used in the calculation.

Protocol

Hydration Testing: Following familiarization participants were randomized into one of three hydration conditions for the first experimental visit. Participants were also given instructions to refrain from exercise in the 12 hours prior to testing. Instructions were also provided as to further dietary restriction, such as a reduction in carbohydrate intake prior to all sessions as well as no alcohol consumption in the 12 hours prior to all laboratory visits. Participants were also instructed to only consume water prior to the testing session and this was confirmed verbally at the beginning of the session.

For hypohydrated sessions participants were restricted to five-hundred milliliters (500 ml) of water in the 12 hours prior to arrival in the laboratory with no fluid to be consumed in the two hours immediately prior to visit. Testing sessions began between the hours of 0800 and 1000 am. This allowed for a predominately passive overnight fluid restriction to reduce potential confounding effects of exercise and/or heat in the achievement of a hypohydrated status. Additionally, the overnight fluid restriction provided a scenario similar to that when jump testing would have performed, as testing typically occurs upon arrival to a session and/or competition. As it has previously been shown that overnight rest can reduce the effects of heat exposure induced hypohydration (13, 27), the goal of this hypohydration protocol was to induce hypohydration without the loss of body mass. As stated previously, the only findings in which variables have been impacted by hypohydration came when body mass was held constant (7). During euhydrated sessions the participants were encouraged to consume water at a rate higher than they would typically consume on a normal day. While on the control day participants were given no instruction in regard to fluid intake.

After arriving to the laboratory for the experimental sessions participants were provided a sterile urine specimen cup to provide a mid-stream urine sample of less than one hundred milliliters (100 ml). Once the urine sample was collected, urine specific gravity (USG) was assessed using a digital pen refractometer (Atago USA Inc, Bellevue, WA) to ensure that the participants are in within the value range to be classified as being hypohydrated, (USG $\geq$ 1.022) or euhydrated (USG $<$ 1.015) for that given session. While the traditional criteria value for hypohydration using USG is $\geq$ 1.020 in the literature, to ensure differences between sessions a higher threshold for hypohydration was used as well as a lower value for euhydration sessions (3). In the event that the hydration status for that given session was not achieved participants were asked to return to the laboratory in two hours to reassess hydration status and determine if testing can be conducted on that day. Of the 75 total laboratory visits, 5 occasions existed in which a participate had not reached threshold values. During each of those instances the follow up test at 2 hours met criterion levels. Once classification had been deemed acceptable participants completed the standardized warm up consisting of dynamic lower body movements and 5 submaximal CMJ and SJ attempts.

Jump Testing: Both CMJ and SJ were performed using a wooden dowel (1.0 kg) placed across the shoulders in a high bar squat position. Participants completed one set of three jumps at a self-selected foot position and to a self-selected depth. They were instructed to jump as explosively as possible to achieve maximal height (1). It has been shown that when using a self-selected depth that both maximal force and power were higher than using a standardized starting position in the SJ (26). Participants were also instructed to maintain contact between the wooden dowel and the upper back at times throughout the movement. Participants were instructed to remain as still as possible prior to the initiation of the jump to allow for body mass to be determined and then used in the calculation of variables of interest during data analysis (22). The use of a 3, 2, 1, jump countdown was used for each trial.

Data Analysis: Ground reaction force data was collected using a 600 x 400-mm force platform (Bertec Corp, Columbus, OH, USA). Force data was collected at 1000 Hz. All variables derived from the force platform where calculated using the impulse – momentum method. The propulsive phase of each CMJ trial was identified using methods described by Chavda et al. (4) and McMahon et al. (22). Similar processing was adapted to SJ trials with the exclusion of an unweighting and braking phase. Thus, finding the mean of one second of weighting once at the self-selected depth and then identifying the first instance in which GRF was greater than 5 standard deviations (SD) above the mean of the one second weighting to signify the initiation of movement. From this point forward methods were identical to those used in the CMJ and described by Chavda et al. (4). Only the propulsive phase of the CMJ was used in determination of peak and mean values of the force, velocity, and power. Time to peak for each of the previous mentioned variables occurred from the initiation of the propulsive phase to the point at which the peak value was measured.

Additionally, impulse was calculated using force data collected from the force platform. The impulse was calculated at each frame as the mean net force of the current frame and the previous frame multiplied by 0.001 as this was the period of time between frames. All impulse calculations were then summed together from the initiation of the propulsive phase through takeoff to determine propulsive impulse (4). Reactive strength index was calculated as a ratio of the jump height over time to takeoff (12). Time to takeoff consisted of the time from which movement was detected to the time of takeoff using the methods described by Chavda et al. (4). Finally, propulsive duration was calculated as the time from initiation of the propulsive phase to the time of takeoff.

Statistical Analysis

A within-subject repeated measures analysis of variance was used to assess the effect hydration on each variable of interest in both the CMJ and SJ. Mauchly's Test of sphericity was used test the assumption of sphericity for each variable. If the assumption was violated a Greenhouse – Geisser correction was used. Least squared difference post hoc analysis was used to determine where differences existed. All statistics were run in SPSS version 25 (IBM, Chicago, IL). An a priori alpha level of 0.05 was used in all analysis. Effect sizes are presented as Cohen's *d* and interpreted using the criteria of trivial (0.0 – 0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0) and nearly perfect (4.0 or greater) as suggested by Hopkins (19).

RESULTS

All results are presented as mean ± *SD*. CMJ and SJ data for all variables are presented in, Table 2. No differences were seen between body mass in the three hydration conditions ($p > 0.05$) (Table 1). Significant differences were seen between USG levels in each of the testing sessions ($F_{2,48} = 158.55$, $p < 0.001$, $d = 5.15$) (Table 1).

In the CMJ significant differences were seen in peak force ($F_{2,48} = 3.32$, $p = 0.045$, $d = 0.74$). Post hoc results showed that the euhydrated state had a greater peak force than the hypohydrated condition ($p = 0.025$). (Table 2) Additionally, mean force measures obtained from the force platform revealed significant differences ($F_{2,48} = 4.74$, $p = 0.013$, $d = 0.89$). Post hoc results showed that the hypohydrated condition was significant lower than both the control ($p = 0.008$) and euhydrated ($p = 0.028$) conditions. No other differences were seen across hydration conditions (Table 2).

Table 1: Body mass and Urine Specific Gravity across conditions

	Control	Hypohydrated	Euhydrated
Body Mass (kg)	85.20 ± 12.76	84.61 ± 12.56	85.63 ± 12.66
Urine Specific Gravity	1.018 ± 0.004*	1.024 ± 0.002*	1.007 ± 0.004

* = significantly greater than euhydrated at p <0.001 level

Table 2. Hydration Status on Countermovement Jump Performance.

	Control	Hypohydrated	Euhydrated
JH (cm)	35.2 ± 0.06	34.8 ± 0.06	34.8 ± 0.06
PF (N)	2067.36 ± 303.36	2059.77 ± 318.81*	2107.73 ± 317.22
MF (N)	1183.24 ± 151.59	1152.54 ± 144.91*^	1171.29 ± 144.21
TTPF (s)	0.091 ± 0.08	0.101 ± 0.08	0.067 ± 0.08
PV (m/s)	2.77 ± 0.23	2.74 ± 0.19	2.74 ± 0.18
MV (m/s)	1.70 ± 0.17	1.68 ± 0.15	1.68 ± 0.14
TTPV (s)	0.270 ± 0.05	0.270 ± 0.05	0.278 ± 0.04
PP (W)	4586.68 ± 668.96	4557.18 ± 655.64	4563.70 ± 614.45
MP (W)	1687.77 ± 212.35	1649.85 ± 220.11	1678.05 ± 216.98
TTPP (s)	0.234 ± 0.05	0.234 ± 0.05	0.233 ± 0.05
Concentric Duration (s)	0.296 ± 0.05	0.296 ± 0.0	0.297 ± 0.05
Impulse (Nm)	121.56 ± 20.23	116.03 ± 19.36	119.54 ± 19.53
RSIm	0.74 ± 0.22	0.71 ± 0.20	0.72 ± 0.16

JH = jump height; PF = peak force; MF = mean force; TTPF = time to peak force; PV = peak velocity; MV = mean velocity; TTPV = time to peak velocity; PP = peak power; MP = mean power; TTPP = time to peak power

* = significantly different from euhydrated at $p < 0.05$ level

^ = significantly different from control at $p < 0.05$ level

Table 3. Hydration Status on Squat Jump Performance.

	Control	Hypohydrated	Euhydrated
JH (cm)	33.2 ± 0.03	31.3 ± 0.06**^	33.9 ± 0.06
PF (N)	2118.12 ± 382.88	2122.45 ± 419.59	2215.86 ± 532.59
MF (N)	1578.11 ± 214.56	1547.47 ± 229.56	1588.15 ± 217.26
TTPF (s)	0.246 ± 0.09	0.246 ± 0.09	0.244 ± 0.08
PV (m/s)	2.69 ± 0.22	2.61 ± 0.21**^^	2.72 ± 0.21
MV (m/s)	1.25 ± 0.11	1.19 ± 0.10**^^	1.26 ± 0.12
TTPV (s)	0.321 ± 0.09	0.362 ± 0.20	0.325 ± 0.07
PP (W)	4668.38 ± 648.02	4506.02 ± 697.11*	4756.81 ± 608.36
MP (W)	1984.66 ± 296.27	1870.88 ± 301.17**^	2023.45 ± 300.59
TTPP (s)	0.286 ± 0.08	0.283 ± 0.08	0.284 ± 0.07
Concentric Duration (s)	0.350 ± 0.08	0.351 ± 0.08	0.346 ± 0.06
Impulse (Nm)	228.41 ± 24.06	221.39 ± 26.42**^	234.55 ± 29.09
RSIm	0.72 ± 0.23	0.72 ± 0.26	0.78 ± 0.22

JH = jump height; PF = peak force; MF = mean force; TTPF = time to peak force; PV = peak velocity; MV = mean velocity; TTPV = time to peak velocity; PP = peak power; MP = mean power; TTPP = time to peak power

* = significantly different from euhydrated at p < 0.05 level

** = significantly different from euhydrated at p < 0.01 level

^ = significantly different from control at p < 0.05 level

^^ = significantly different from control at p < 0.01 level

SJ analysis showed that multiple variables were significantly different across conditions. Peak power was significantly different between conditions ($F_{2,45} = 3.99$, $p = 0.026$, $d = 0.85$) (Table 3). Hypohydration exhibited the lowest output and was different from the euhydration ($p = 0.012$). Mean power also showed difference between conditions ($F_{2,45} = 4.42$, $p = 0.018$, $d = 0.90$) with hypohydration being significantly lower than both the euhydration and control conditions ($p = 0.004$ and $p = 0.047$ respectively) (Table 3). Both peak and mean velocity were different between conditions ($F_{2,45} = 7.081$, $p = 0.002$, $d = 1.17$ and $F_{2,45} = 6.043$, $p = 0.005$, $d = 1.05$ respectively). In both the peak and mean hypohydration was significantly lower than euhydration ($p = 0.003$ and $p = 0.002$ respectively) and control ($p = 0.009$) conditions.

Additionally, in the SJ differences were seen in jump height ($F_{2,45} = 6.06$, $p = 0.005$, $d = 1.05$) with hypohydration having lower heights then both the euhydration ($p = 0.004$) and the control ($p = 0.015$) (Table 3). As well as differences were seen in impulse during the SJ ($F_{2,45} = 7.419$, $p = 0.002$, $d = 1.16$) with hypohydration being lower than both the euhydration ($p = 0.002$) and control ($p = 0.011$) conditions (Table 3).

DISCUSSION

This investigation sought to examine if hydration status influenced performance in both the CMJ and SJ. The main finding from this investigation was that differences were observed between variables based on hydration status. As assessments of neuromuscular fatigue continue to be used prior to training sessions and competition, it is important to identify factors that may impact the assessment.

The finding that jump height was not impacted by hydration status is consistent with previous investigations evaluating hypohydration on anaerobic performance using the CMJ (5, 7, 16, 17, 21). However, this is conflicting to the results of Cheuvront et al. (7) where a reduction in CMJ jump height was seen when holding mass constant with the use of a weight vest. Though not significantly different, mass was reduced during the hypohydrated condition by less than 1% to the control condition. Similarly, mass was increased by less than 1% in the euhydrated condition and similar jump heights were maintained (Table 1). While both study held mass constant from a statistical perspective differences in the distribution of mass with the additional weight vest used in the prior investigation could have impacted jump height. Differences in load positioning has been shown to impact jump height at lighter loads (28). This may explain the differences that were seen between the two studies.

The finding that jump height was significantly impacted in the SJ is conflicting to previous investigations that used the squat jump in the hypohydration literature (16,18). Gutierrez et al. (16) found that jump height was reduced by a nonsignificant 4.7 % in a sample of 6 men after a dehydration protocol. The findings in the present investigation can be explained by the significant differences seen in the peak velocity. As velocity is used in the calculation of jump height from the force platform a higher velocity in the euhydrated state would explain the greater jump height. It is also important to note that both Gutierriez et al (16) and Hoffman et al (18) used contact mats in determining jump heights. This is important to note for two specific reasons. The use of a contact mat while practical, limits the ability to detect if the squat jump had a preceding countermovement which would make it an invalid test. Additionally, the use of a contact mat has some restrictions as to the accuracy of the measurement of flight time and thus jump height (35). Thus, the methods used in the present study as it relates to squat jump performance using a force platform potentially could be conflicting to the results of the previous literature in this area. Furthermore, it should be noted that the sample size in the present investigation was considerably larger than both of the previous investigations using the SJ. This increase in statistical power may also explain the differences in the results seen in the present study and those previously reported.

It was important to this investigation as to assess how other variables outside of jump height that are commonly used by practitioners in their assessments of athletes. It has been suggested by some that the use of jump height as simple measure to indicate early overreaching (32–34), while others have suggested that jump height lacks the sensitivity needed to detect changes that would show signs of neuromuscular fatigue (10, 11). This has led to the use of both kinetic and kinematic variables in assessing jumping performance (9, 14) These include peak and mean force, velocity, and power as well as time to peak for the given variables. In addition other alternative variables used in the propulsive duration, impulse, and reactive strength index modified (14).

Conversely, to the findings of Cheuvront et al. (7) the present investigation found a reduction in both peak and mean force during the CMJ when hypohydrated (Table 2). While not significantly different it can be seen that euhydrated condition had lower time to peak force then the hypohydrated and control conditions with a moderate effect size (d = .79). Thus, a small change in the technique used may have been present to offset the difference in force to produce the same jump height. When time to peak is calculated as a percentage of the propulsive duration, the euhydrated condition reached its peak force 12% faster than the hypohydrated.

With regard to the impulse calculated in this investigation, a moderate effect (d = 0.66) was seen between conditions in the CMJ with the hypohydrated condition being the lowest of the three. This is similar to the previous findings that also assessed the CMJ impulse and hydration (7). In the present investigation, force was reduced where velocity was maintained, which is the direct contrast to the findings of Cheuvront et al (7), where a reduction in velocity was seen and no difference between force during the CMJ. The present investigation added a component for time that was not reported in previous investigations. This is important as impulse can be impacted by a change in force or a change in the duration or time component. We can see that the propulsive duration remained unchanged between conditions, thus the reduction in force seen in the hypohydrated would lead to the reduced impulse (Table 2). During the SJ however, impulse was significantly higher in the euhydrated and control conditions than that of the hypohydrated. With no differences in time and a small to moderate effect size seen with peak force (d = 0.46) (Table 3). The results of the previous study by Cheuvront et al. (7) are more similar to the findings of the SJ in the present study were jump height, peak velocity and impulse all showed differences by conditions.

In regards to the SJ, earlier examinations only used jump height as a dependent variable to hydration status. As stated above this can be problematic as there is some agrument as to the importance of jump height as a measure. Thus, it was critical to examine of differences were found outside of jump height. Both peak and mean velocity and power showed significant differences between conditions. While peak values are commonly sought as a variable of interest, the value is for only one instantaneous moment in time, consequently only representing a very small portion of the entire movement. The inclusion of mean values provides a more robust representation of the variable over the entire movement. As power was calculated as the product of force and velocity at each time point a reduction in either force or velocity would have an impact on power. As both peak and mean velocity was lower in the hypohydrated condition it would be expected that power would be reduced as well. Additionally, the small reductions in force that are seen would add to the reduced peak and mean power values Additionally, it should be noted that both the control and euhydrated conditions are different from the hypohydrated, but not different from one another for both velocity and power. This is relevant as the mean USG on the control day would be classified as euhydrated based on the critical values set forth in the literature (3).

There are limitations to this investigation, with special regard to the measurement of hydration. As mentioned previously, it was important to make sure that body mass was held near constant between sessions, thus using the methods such as the commonly referenced 3% reduction in body mass as a measure of hypohydration was not viable for this investigation (13,16). As such, USG was selected as the method of choice. While the reliablity of USG measure have been called into question, the criterion values that were used in this investigation provided a level of confidence, that individuals were indeed in the classification that was desired on the given day.

As strength and conditioning professionals continue to use the both the CMJ and SJ as assessment tools, it is important to have an understanding of how additional factors can play a role in the results of the assessment. As many athletes arrive to both training and competition hypohydrated, it is important to consider how this impacts the variables of interest and modifications to training programs based on the results of those evaluations. Additionally, it can be seen that while both the CMJ and the SJ are impacted by hydration status, the SJ seems to be influnenced to a greater extent.

REFERENCES

1. Argus CK, Gill N, Keogh J, Hopkins W. Assesing lower-body peak power in elite rugby-union players. J Strength Cond Res 25(6): 1616–21, 2011.

2. Bobbert MF, Mackay M, Schinkelshoek D, Huijing PA, van Ingen Schenau GJ. Biomechanical analysis of drop and countermovement jumps. Eur J Appl Physiol Occup Physiol 54(6): 566–73, 1986.

3. Casa DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff RV, Rich BSE, et al. National Athletic Trainers' Association position statement: fluid replacement for athletes. J Athl Train 35(2): 212–24, 2000.

4. Chavda S, Bromley T, Jarvis P, Williams S, Bishop C, Turner AN, et al. Force-time characteristics of the countermovement jump: analyzing the curve in Excel. Strength Cond J 20(2): 67–77, 2018.

5. Cheuvront SN, Carter R, Haynes E, Sawka M. No effect of moderate hypohydration or hyperthermia on anaerobic exercise performance. Med Sci Sport Exerc 38(6): 1093–7, 2006.

6. Cheuvront SN, Kenefick RW. Dehydration: physiology, assessment, and performance effects. Compr Physiol 4(1): 257–85, 2014.

7. Cheuvront SN, Kenefick RW, Ely BR, Harman EA, Castellani JW, Frykman PN, et al. Hypohydration reduces vertical ground reaction impulse but not jump height. Eur J Appl Physiol 109(6): 1163–70, 2010.

8. Claudino JG, Mezncio B, Soncin R, Ferreira JC, Couto BP, Szmuchrowski LA. Pre vertical jump performance to regulate the training volume. Int J Sports Med 33(2): 101–7, 2012.

9. Cormack SJ, Newton RU, McGuigan MR. Neuromuscular and endocrine responses of elite players to an Australian rules football match. Int J Sports Physiol Perform (3): 359–74, 2008.

10. Coutts A, Reaburn P, Piva TJ, Murphy A. Changes in selected biochemical, muscular strength, power, and endurance measures during deliberate overreaching and tapering in rugby league players. Int J Sports Med 28(2): 116–24, 2007.

11. Coutts AJ, Reaburn P, Piva TJ, Rowsell GJ. Monitoring for overreaching in rugby league players. Eur J Appl Physiol 99(3): 313–24, 2007.

12. Ebben WP, Petushek EJ. Using the reactive strength index modified to evaluate plyometric performance. J Strength Cond Res 24(8): 1983–7, 2010.

13. Gann JJ, Green JM, O'Neal EK, Renfroe LG, Andre TL, McBride C, et al. Effects of hypohydration on repeated 40 yard sprint performance. J Strength Cond Res 30(4): 901–9, 2016.

14. Gathercole R, Sporer B, Stellingwerff T, Sleivert G. Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. Int J Sports Physiol Perform 10(1): 84–92, 2015.

15. Gathercole RJ, Sporer BC, Stellingwerff T, Sleivert GG. Comparison of the capacity of different jump and sprint field tests to detect neuromuscular fatigue. J Strength Cond Res 29(9): 2522–31, 2015.

16. Gutiérrez A, Mesa JLM, Ruiz JR, Chirosa LJ, Castillo MJ. Sauna-induced rapid weight loss decreases explosive power in women but not in men. Int J Sports Med 24(7): 518–22, 2003.

17. Hayes LD, Morse CI. The effects of progressive dehydration on strength and power: is there a dose response? Eur J Appl Physiol 108(4): 701–7, 2010.

18. Hoffman JR, Stavsky H, Falk B. The effect of water restriction on anaerobic power and vertical jumping height in basketball players. Int J Sports Med 16(4): 214–8, 1995.

19. Hopkins WG. A scale of magnitudes for effect statistics [Internet]. Retrieved from: www.sportsci.org/resource/stats/effectmag.html; 2002.

20. Judelson DA, Maresh CM, Anderson JM, Armstrong LE, Casa DJ, Kraemer WJ, et al. Hydration and muscular performance: does fluid balance affect strength, power and high-intensity endurance? Sports Med 37(10): 907–21, 2007.

21. Judelson DA, Maresh CM, Farrell MJ, Yamamoto LM, Armstrong LE, Kraemer WJ, et al. Effect of hydration state on strength, power, and resistance exercise performance. Med Sci Sports Exerc 39(10): 1817–24, 2007.

22. McMahon JJ, Suchomel TJ, Lake JP, Comfort P. Understanding the key phases of the countermovement jump force-time curve. Strength Cond J 40(4): 96–106, 2018.

23. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1–8, 2019.

24. Osterberg KL, Horswill CA, Baker LB. Pregame urine specific gravity and fluid intake by National Basketball Association players during competition. J Athl Train 44(1): 53–7, 2009.

25. Peacock OJ, Stokes K, Thompson D. Initial hydration status, fluid balance, and psychological affect during recreational exercise in adults. J Sports Sci 29(9): 897–904, 2011.

26. Petronijevic MS, Ramos AG, Mirkov DM, Jaric S, Valdevit Z, Knezevic OM. Self-preferred initial position could be a viable alternative to the standard squat jump testing procedure. J Strength Cond Res 32(11): 3267–75, 2018.

27. Savoie F-A, Kenefick RW, Ely BR, Cheuvront SN, Goulet EDB. Effect of hypohydration on muscle endurance, strength, anaerobic power and capacity and vertical jumping ability: a meta-analysis. Sports Med 45(8): 1207–27, 2015.

28. Swinton PA, Stewart AD, Lloyd R, Agouris I, Keogh JWL. Effect of load positioning on the kinematics and kinetics of weighted vertical jumps. J Strength Cond Res 26(4): 906–13, 2012.

29. Taylor K-L, Chapman DW, Cronin JB, Newton MJ, Gill N. Fatigue monitoring in high performance sport: a survey of current trends. J Aust Strength Cond 20(1): 12–23, 2012.

30. Viitasalo JT, Kyrolainen H, Bosco C, Alen M. Effects of rapid weight reduction on force production and vertical jumping height. Int J Sports Med 8(4): 281–5, 1987.

31. Volpe SL, Poule KA, Bland EG. Estimation of prepractice hydration status of National Collegiate Athletic Association division I athletes. J Athl Train 44(6): 624–9, 2009.

32. Warren BJ, Stone MH, Kearney JT, Fleck SJ, Johnson RL, Wilson GD, et al. Performance measures, blood lactate, and plasma ammonia as indicators of overwork in elite junior weightlifters. Int J Sports Med 13(5): 372–6, 1992.

33. Watkins CM, Barillas SR, Wong MA, Archer DC, Dobbs IJ, Lockie RG, et al. Determination of vertical jump as a measure of neuromuscular readiness and fatigue. J Strength Cond Res 31(12): 3305-10, 2017.

34. Welsh TT, Alemany JA, Montain SJ, Frykman PN, Tuckow AP, Young AJ, et al. Effects of intensified military field training on jumping performance. Int J Sports Med 29(1): 45–52, 2008.

35. Whitmer TD, Fry AC, Forsythe CM, Andre MJ, Lane MT, Hudy A, et al. Accuracy of a vertical jump contact mat for determining jump height and flight time. J Strength Cond Res 29(4): 877–81, 2015.

36. Young WB, Pryor JF, Wilson GJ. Effect of instructions on characteristics of countermovement and drop jump performance. J Strength Cond Res 9(4): 232–6, 1995.