Title: Countermovement Jump Recovery in Professional Soccer Players Using an Inertial Sensor

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Authors: Malachy P. McHugh[1,5], Tom Clifford[2,5], Will Abbott[3,4], Susan Y. Kwiecien[1,5], Ian J. Kremenic[1], Joseph J. DeVita[1], Glyn Howatson[5,6]

[1]Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, New York, NY; [2]School of Biomedical Sciences, Newcastle University, United Kingdom;
[3]School of Sport and Service Management, Brighton University, UK;
[4]Brighton and Hove Albion F.C, American Express Elite Performance Centre, Lancing, UK;
[5]Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle, United Kingdom;
[6]Water Research Group, School of Environmental Sciences and Development, Northwest University, Potchefstroom, South Africa.

Corresponding Author:
Malachy P McHugh Nicholas Institute of Sports Medicine and Athletic Trauma, Manhattan Eye Ear and Throat Hospital, 210 East 64 Street, New York, NY 10065, USA
PH: +1 212 434 2714, email: mchugh@nismat.org

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ABSTRACT

Purpose

The purpose of this study was to assess the utility of an inertial sensor for assessing recovery in professional soccer players.

Methods

In a randomized, crossover design, 11 professional soccer players wore shorts fitted with phase change material (PCM) cooling packs or uncooled packs (control) for 3 h after a 90 minute match. Countermovement jump (CMJ) performance was assessed simultaneously with an inertial sensor and an optoelectric system, pre match, and 12, 36 and 60 h post match. Inertial sensor metrics were flight height, jump height, low force, countermovement distance, force at low point, rate of eccentric force development, peak propulsive force, maximum power, and peak landing force. The only optoelectric metric was flight height. CMJ decrements, and effect of PCM cooling were assessed with repeated measures ANOVA. Jump heights were also compared between devices.

Results

For the inertial sensor data there were decrements in CMJ height on the days after matches (88±10% of baseline at 36 h $P=0.012$, effect size 1.2, for control condition) and accelerated recovery with PCM cooling (105±15% of baseline at 36 h, $P=0.018$ vs. control, effect size 1.1). Flight heights were strongly correlated between devices ($r=0.905$, $P<0.001$) but inertial sensor values were 1.8±1.8 cm lower ($P=0.008$). Low force during countermovement was increased ($P=0.031$) and landing force was decreased ($P=0.043$) after matches, but neither were affected by the PCM cooling intervention. Other CMJ metrics were unchanged after matches.

Conclusions

This small portable inertial sensor provides a practical means of assessing recovery in soccer players.

Key Words: muscle function, accelerometer, cryotherapy, phase change material, power

INTRODUCTION

Counter movement jump (CMJ) tests are commonly used to assess recovery of muscle function following strenuous exercise. Impairments in CMJ have been demonstrated on the days following various forms of exercise including drop jump protocols,[1-3] repeated sprint and simulated field sport tests[4-9] and soccer matches. [10-11] Traditionally, CMJ performance has been measured using a vertical structure where athletes jump to touch incrementally separated pegs with their out stretched arm.[3,12] Since this test involves an asymmetric vertical reach with one arm, alternative tests have been adopted to better isolate the actual jump performance, and eliminate the reaching component. To this end, CMJ performance has been assessed using contact mats[4,8,11,13,14] or optoelectric systems[1,5-7,9,10] that can accurately measure flight time, and thereby calculate center of mass vertical displacement. These tests assume that the subjects land with the same body alignment with which they took off.

Performance during CMJ tests has also been assessed using inertial devices that measure vertical acceleration.[15-18] In addition to providing a measure of jump height, these devices can derive other biomechanical metrics describing the jump performance, such as force, power, velocity and center of mass position. Force data derived from inertial sensors has been shown to agree well with simultaneously recorded force plate data.[16] However, while jump heights derived from inertial sensors correlate strongly with heights calculated from force plates, inertial devices were shown to slightly underestimate jump height compared to force plate data.[18] Furthermore, inertial sensor derived CMJ heights were well correlated with optoelectric measurements but provided slightly higher jump heights.[18] Thus, practitioners are advised against using these systems interchangeably.

Tests of CMJ performance have been used to assess recovery in numerous studies examining interventions to accelerate exercise recovery; several studies used contact mats,[4,8,13] while other studies used an optoelectric system,[1] force plates,[2] or an inertial sensor.[15] In the one study using an inertial sensor, Bieuzen et al[15] examined recovery in professional soccer players in response to an exercise protocol involving a combination of countermovement jumps and rowing exercise. However, CMJ performance had recovered within one hour of the exercise intervention so it was not possible to assess the ability of the inertial sensor to detect differences in recovery over time or between intervention and control.

Standardized performance tests are important for monitoring athletes over the course of a season to assess training adaptations and recovery. To this end CMJ performance has become a common recovery metric in soccer across a range of playing abilities, including professional,[14,15] semi-professional,[4,9,10] college[6,12,19] and youth players.[11,18] The use of inertial sensors to assess CMJ recovery in soccer players offers several advantages over other methods; inertial sensors are small, portable, wearable devices that can provide metrics for different components of the CMJ in addition to jump height. Therefore, the purpose of this study was to assess the utility of an inertial sensor for examining recovery in professional soccer players. This dataset is part of a larger study examining the effectiveness of a cryotherapy intervention on recovery in soccer players.[20] The full data set has been published previously but the data from the inertial sensor was not included because the software for analysis was still under development. The specific goals of the present study were to determine: (1) if the inertial sensor was sufficiently sensitive to detect decrements in jump height on the days following a professional soccer match, (2) if the inertial sensor data agreed with the optoelectric data, (3) if the inertial sensor was able to detect accelerated recovery of jump height with the cryotherapy intervention, and (4) if the additional force, power, velocity, and position metrics from the inertial sensor provided useful information on the biomechanics of CMJ impairment and recovery. It was hypothesized that the inertial sensor would show impaired CMJ metrics following the soccer match, accelerated recovery with the cryotherapy intervention, and good agreement with the optoelectric measurements.

METHODS

Study Participants

The study participants were 11 professional soccer players (age 19±1 yrs, height 1.80±0.57 m, mass 75.9±7.2 kg, body fat 7.9±1.3%) from the under-23 squad of a team playing in the second tier of the English league. All participants gave written informed consent and the study was approved by institution review board.

Study Design

The full experimental protocol has been described in detail in the larger study[20] and is summarized here. This was a randomized crossover design examining the effectiveness of a novel cryotherapy intervention on recovery on the days after a soccer match. For the cryotherapy intervention, players wore shorts fitted with phase change material (PCM) cooling packs over the quadriceps muscles. The PCM cooling packs maintained a temperature of 15°C during a 3 h treatment. The control condition was room temperature PCM packs worn inside the same shorts. Each player was randomized to wear the PCM cooling packs or the room temperature packs after a match and received the opposite treatment after a subsequent match. Matches were selected where the team had longer than a 3 h coach ride back to their team facility after the match. Thus, compliance with the intervention could be confirmed by study personnel. The following tests were administrated on the days prior to the study matches and on each of the following three mornings after the matches: muscle soreness assessment, CMJ, maximal isometric voluntary contraction, and an adapted Brief Assessment of Mood (BAM+) questionnaire. The details of the CMJ test are described here. All other test results have been reported previously.[20]

CMJ Test

The CMJ performance was measured using two different instruments; an optoelectric system (Optojump system, Bolzano, Italy) and an inertial sensor (BTS G-Sensor 2, Brooklyn, NY). As described previously, participants started the movement standing upright with hands on their hips and after a verbal cue, descended into a squat (countermovement) prior to performing a maximal effort vertical jump. Participants performed three maximal efforts, separated by approximately 60 s of standing recovery; the mean of the 3 jumps was used for analysis. During testing the inertial sensor was placed in a pouch attached to a waistband strapped tightly to the participants. The inertial sensor was aligned with the middle of the lumbar spine. The 70x40x18 mm inertial sensor weighed 37 g and contained a triaxial accelerometer, gyroscope and magnetometer. The signals were collected at 100 Hz via Bluetooth® connection.

The metrics derived from the inertial sensor are described according to the phase in which they occurred, countermovement, propulsive, or landing phase (Fig. 1).
Countermovement Phase: The countermovement phase started with the initiation of the countermovement to the lowest point of the countermovement, with both points identified from the derived position data. The countermovement metrics that were examined were: (1) low point

(lowest position of center of mass during countermovement); (2) low force (lowest force during initiation of countermovement; (3) force at low point (the force at the lowest point of the countermovement); (4) rate of eccentric force development (the difference between low force and force at low point, divided by the time interval).
Propulsive Phase: The propulsive phase started from the point of initiation of the upward movement from low point, to the maximum height of the jump, with both points identified from the derived position data. The propulsive metrics that were examined were: (1) flight height (calculated from time in air based on the acceleration data); (2) jump height (flight height plus difference between standing height and takeoff height); (3) peak propulsive force (the peak force during the propulsive phase occurring prior to take off); (4) maximum power (calculated from the product of the force and velocity data).
Landing Phase: Only one metric from the landing phase was examined; peak landing force, defined as the peak force occurring after ground contact when landing from the jump. All inertial sensor data were processed using G-Studio software (BTS Bioengineering, Brooklyn NY).

Statistical Analyses

A single factor (time) repeated measures analysis of variance (ANOVA) was used to assess if the inertial sensor was sufficiently sensitive to detect impairments in jump height and other jump metrics on the days following the matches (baseline, 12 h, 36 h, and 60 h post match). Only the control data were included and analyses were performed on absolute numbers and on values expressed as a percentage of baseline. Low force during the countermovement was expressed as a percentage of body weight. Changes in low force were not assessed as a percentage of baseline since some baseline values were very low, creating a non-normal distribution for percent change. Bonferroni corrections were used for planned pairwise comparisons (baseline versus 12 h, 36 h and 60 h).

Pearson product-moment correlations were used to assess relative reliability between inertial sensor and optoelectric measurements with paired t-tests used to assess bias. These assessments were made on baseline flight height averaged between the PCM cooling and control conditions. Differences between devices in ability to detect decrements in CMJ flight height were assessed using 2x3 repeated measures ANOVA (device: inertial sensor vs. optoelectric measurement; time: 12 h, 36 h and 60 h post match). The primary statistic of interest was the effect of device comparing percent decrement in flight height between devices.

Treatment (PCM cooling vs. control) by time repeated measures ANOVA were used to assess if the inertial sensor was able to detect accelerated recovery of CMJ height, and other jump metrics, with the cryotherapy intervention. The treatment by time analysis of CMJ height from the optoelectric system has been reported previously and is also provided here for comparison to inertial sensor results. Bonferroni corrections were used for planned pairwise between treatment comparisons at each of the time intervals (baseline, 12 h, 36 h and 60 h for absolute values, and 12 h, 36 h and 60 h for values expressed as a percentage of baseline).

All variables were tested for normality of distribution using the Shapiro-Wilk test. Variables with non-normal distribution were analyzed with the Friedman test for time effects and the Wilcoxon signed ranks test for pairwise comparisons. Additionally, within ANOVAs, Greenhouse-Geisser corrections were applied for violations of sphericity. Effect sizes for time or treatment effects were computed using Cohen's d_Z statistic[21] with the magnitude of effects considered either small (0.20–0.49), medium (0.50–0.79) or large (>0.80). Statistical analyses were performed using SPSS (v21 IBM, Armonk, NY).

RESULTS

Match Details

There were no significant differences in playing demands between PCM cooling matches and control matches. Average playing time was 81±18 min for the matches after which players received PCM versus 83±11 min for control matches. Other match demand metrics did not differ between treatments (PCM vs.control: total distance ran 9414±2142 m vs. 9742±1365 m; sprint distance 330±129 m vs. 339±85 m).

Inertial Sensor CMJ Flight Height and Jump Height

Flight height (time effect P=0.018) and jump height (time effect P=0.007) were decreased on the days after the matches (Table 1). Similar effects were evident when heights were expressed as a percentage of baseline (Time effects: flight height P=0.028, jump height P=0.006, Table 1). Greatest decrements were evident 36 h post match for flight height (88% of baseline, P=0.012 for post hoc pairwise comparison) and 12 h post match for jump height (90% of baseline, P=0.006 for post hoc pairwise comparison).

Comparison Between Inertial Sensor and Optoelectric System

Inertial sensor and optoelectric CMJ flight heights were strongly positively correlated (r=0.905, P<0.001), but there was significant bias, with inertial sensor values 1.8±1.8 cm lower than optoelectric values (P=0.008).

Optoelectric measurement of CMJ flight height was decreased on the days after the match (time effect P=0.035 for absolute and relative values). Flight height was 93±8% of baseline at 36 h (P=0.027 for post hoc pairwise comparison, effect size 1.0). Decrements in CMJ flight height were greater with the inertial sensor compared with the optoelectric system (inertial sensor averaged 90±3% of baseline across measurements at 12, 36, and 60 h versus 95±2% for the optoelectric device, effect of device P=0.047, device by time P=0.22). This effect was most pronounced at 60 h (91±12% vs. 99±11%, P=0.045 for post hoc pairwise comparison).

Effect of PCM Cooling Intervention on CMJ Height

The inertial sensor showed accelerated recovery of absolute jump heights with PCM cooling versus control (treatment by time P=0.027, Fig. 2A) but there were no significant effects for absolute flight heights (treatment effect P=0.072, treatment by time P=0.054). When expressed as a percentage of baseline, flight heights and jump heights were both better for PCM cooling versus control (flight height: treatment effect P=0.007, treatment by time P=0.061, Table 2; jump height: treatment effect P=0.035, treatment by time P=0.013, Fig. 2B). With the optoelectric system the effect of PCM cooling on flight height was similar to that observed with the inertial sensor (absolute flight height: treatment effect P=0.037, treatment by time P=0.103; relative flight height: treatment effect P=0.064, treatment by time P=0.095, Table 2).

Countermovement, Propulsive and Landing Phase Metrics

Countermovement Phase: Low point (time effect P=0.427) and force at low point (time effect P=0.497) did not differ from baseline on the days after the match. However, low force was elevated on the days after the match (time effect P=0.031); at baseline, low force was 18% of body weight compared with 30% at 12 h (P=0.393 for post hoc pairwise comparison, effect size 0.5), 39% at 36 h (P=0.051 for post hoc pairwise comparison, effect size 0.9) and 32% (P=0.096 for post hoc pairwise comparison, effect size 0.8) at 60 h post match. Additionally, low force was negatively correlated with flight height at baseline (r=-0.81, P=0.003), 12 h (r=-0.96, P<0.001), 36 h (r=-0.64, P=0.04) and 60 h (r=-0.62, P=0.04) indicating that the magnitude of unweighting during the initiation of the countermovement improved jump height. Eccentric rate of force development was not normally distributed and there was no significant effect of time using the Friedman test (P=0.263).

Propulsive Phase: Peak propulsive force (time effect P=0.98) and maximum power (time effect P=0.199) were not different from baseline on the days after the match.

Landing Phase: Peak landing force was decreased on the days after the match (time effects: P=0.040 for absolute values, P=0.043 for values relative to baseline). Landing force was 99% of baseline at 12 h (P=0.999 for post hoc pairwise comparison), 89% of baseline at 36 h (P=0.039 for post hoc pairwise comparison) and 98% of baseline at 60 h (P=0.126 for post hoc pairwise comparison).

There was no effect of PCM treatment on these countermovement, propulsive or landing phase metrics (treatment by time effects: low point P=0.518; force at low point P=0.293; low force P=0.254; eccentric force development P=0.220; peak propulsive force P=0.781; maximum power P=0.388; peak landing force P=0.965).

DISCUSSION

With respect to the specific goals of the study: (1) the inertial sensor was sufficiently sensitive to detect decrements in jump height on the days following a professional soccer match; (2) the inertial sensor data correlated strongly with the optoelectric data but recorded significantly lower flight heights; (3) the inertial sensor was able to detect accelerated recovery of jump height with the cryotherapy intervention; and (4) the additional force, power, velocity, and position metrics from the inertial sensor provided limited information on the biomechanics of CMJ impairment and recovery. Each of these goals is discussed in detail in the following four sections.

Inertial Sensor Detection of Impairments in CMJ on the Days After a Soccer Match

Marked impairments in both flight height and jump height were apparent on the days after the soccer match. However, lowest flight height was apparent at 36 h (88% of baseline) but the lowest jump height occurred earlier (90% of baseline at 12 h). Additionally, by 60 h post game jump height had fully recovered (102% of baseline) while flight height was still impaired (91% of baseline). To put these results in context it is important to understand the difference between flight height and jump height. Flight height is the maximum vertical displacement of center of mass while the body is off the ground. Jump height is flight height plus the difference between standing height and take-off height. Differentiating the two using inertial sensor data is non-trivial. Biomechanically the difference between flight height and jump height represents the sequential thrust of hip extension, knee extension and plantarflexion prior to take off. The actual differences between flight height and jump height were 11.9±1.6 cm at baseline, 9.6±1.6 cm at 12 h, 12.9±1.0 cm at 36 h, and 16.1±1.5 cm at 60 h (time effect P=0.005). It is not clear whether these numbers represent actual changes in jump mechanics or are systematic errors in accelerometer data processing. Regardless, from a practical perspective the flight height data seems to be more sensitive than jump height for measuring performance impairment.

Inertial Sensor Versus Optoelectric System

Flight heights measured by inertial sensor were shown to be strongly correlated with opetoelectric values, but the inertial sensor heights were on average 1.8 cm lower. This represents a 5% underestimate of flight height compared with optoelectric values. Using a different inertial sensor than that used here, Lesinski et al[18] also showed that inertial sensor heights were strongly correlated with optoelectric values in measurements made on youth female soccer players. However, they found that the inertial sensor flight heights were on average 0.55 cm higher than optoelectric values. Importantly, CMJ height calculated from force plate data, was 1.21 cm higher than optoelectric values and 0.66 cm higher than inertial sensor values. Differences in hardware and software between inertial sensor devices likely means that absolute values cannot be compared directly. Furthermore, comparisons between CMJ heights derived from different technologies is not advised.

Both devices showed significant decrements in CMJ after the soccer matches, with similarly large effect sizes at 36 h (optoelectric 93±12%, effect size 1.0 vs. inertial sensor 88%±10%, effect size 1.1). However, overall, greater decrements were evident with the initial sensor versus the optoelectric system. Based on the effect sizes reported in Table 1 for the inertial sensor a 6-8% decline in flight or jump height represents a moderate effect and an impairment of more than 8% represents a large effect. The decrements in post-match optoelectric flight height (96% at 12 h, 93% at 36 h, 99% at 60 h) are comparable to other studies using the same optoelectric system; 96% at 24 h, 98% at 48 h, 100% at 72 h after a soccer match,[10] and 95% at 24 h, 95% at 48 h, 96% at 72 h after a simulated soccer match.[9] Higher values for post-match decrements in CMJ height were reported for elite under-21 soccer players when CMJ was assessed using contact mats (88% at 24 h, 95% at 48 h, 97% at 72 h).[11] Together these data indicate that the optoelectric system might be less sensitive to detecting decrements in CMJ compared with other techniques. However, these four studies differed in standard of play (professional – current study, semi-professional,[9,10] elite youth[11]) and may have differed in match intensity. Thus, it is not possible to definitively attribute differences in CMJ decrements to the different technologies used in the respective studies.

Effect of PCM Cooling Intervention of CMJ Recovery

We have previously reported that the PCM cooling intervention accelerated recovery of strength and soreness, but recovery of optoelectric CMJ height was not significantly accelerated.[21] The relative changes in optoelectric CMJ height that were reported in that study are also included here for the purposes of comparison to inertial sensor data (Table 2). The absolute changes in optoelectric CMJ height were not previously reported.

The benefits of PCM cooling on CMJ recovery were more apparent with the inertial sensor data than the optoelectric data (Table 2). The inertial sensor data showed a marked benefit of PCM cooling for relative flight height, with large effect sizes at 36 h and 60 h. A benefit of PCM cooling was demonstrated for both relative and absolute jump heights (Fig. 2). By comparison, the benefits of PCM cooling on CMJ recovery were less clear with the optoelectric data (Table 2). Since PCM cooling is a novel recovery intervention it is not possible to compare CMJ recovery metrics to other PCM cooling studies. The best comparison to PCM cooling would be cold water immersion. Two systematic reviews[22,23] concluded that, from limited data, cold water immersion may be beneficial in accelerating CMJ recovery. The current PCM cooling data are consistent with that conclusion.

Inertial Sensor Additional Biomechanical Metrics

In general, the additional CMJ biomechanical metrics generated from the inertial sensor did not show obvious changes on the days following the soccer matches, nor were there changes in recovery associated with the PCM cooling intervention. While one would assume that decrements in power, force, or rate of force development would be apparent when CMJ height is impaired, such studies have not been performed in soccer players during recovery from a match. It is noteworthy that low force and landing force differed from baseline on the days after the soccer matches.

The increase in low force on the days after the match indicates that the players did not unweight themselves as much during the initiation of the countermovement. In Figure 1 the nadir in acceleration at approximately 0.3 s shows this subject unweighting himself at the initiation of the countermovement. For this subject, the low force amounted to 11% of his body weight (force data not shown). The average low force for baseline jumps in the control condition was 18%, increasing to 30-39% on subsequent days. Importantly, low force was negatively correlated with flight height, indicating that the more a player unweighted himself at the initiation of the jump the better his vertical jump was. Thus, the higher values for low force on the days after the soccer matches may represent increased leg stiffness due to muscle damage. However, since there was no indication of improvement in low force with the PCM cooling intervention, it is unclear the extent to which this metric may have been a mechanism for the impaired performance.

In contrast to the increase in low force, landing force was decreased on the days after the soccer match. This could reflect decreased eccentric strength. It is noteworthy that peak changes in low force, landing force and flight height occurred at the same time, 36 h post match. However, the PCM cooling intervention did not impact landing force or low force, despite improving CMJ height. The acute effects of fatigue on jump landing forces have been examined in several studies but there is no consensus on whether muscle fatigue increases or decreases landing forces.[24] The effects of prior exercise, such as a soccer game on landing forces on subsequent days has not been examined previously.

Practical Applications, Limitations and Future Directions

Testing professional athletes during the rigors of a long competitive season may not be the best environment in which to assess the utility of a new CMJ testing device. A field study using professional athletes provides less control than one would have in a laboratory-based study using less high demand participants. This potential sacrifice of experimental control is offset by the greater ecological validity of the findings for practitioners working in high demand elite sports. Future studies should test CMJ metrics derived from this inertial sensor against kinetic and kinematic data from high speed cameras and force plates. Additionally, future studies should establish the day-to-day variability in jump metrics with this inertial sensor, in a controlled setting without an exercise intervention that systematically affects jump performance. Finally, since inertial sensor measurements of impairments in jump performance differed between flight height and jump height, future work, using high speed motion capture with ground reaction forces, is needed to examine whether this was due to a change in jumping mechanics or an error in inertial sensor data processing.

Conclusions

The inertial sensor was sensitive to detecting impairments in CMJ and in demonstrating accelerated recovery in CMJ in professional soccer players. This small portable device can provide a practical means of collecting objective recovery data in repeated sprint sports, like soccer. Finally, improvements in inertial sensor recorded CMJ performance with PCM cooling reaffirms the accelerated recovery provided by this novel cryotherapy intervention.

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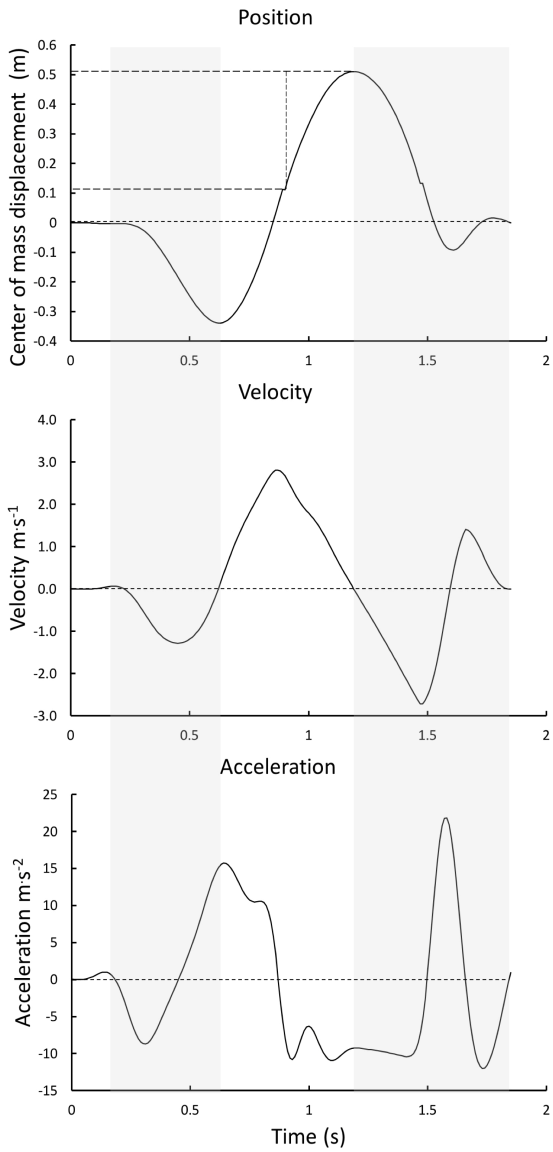

Figure 1: Position, velocity and acceleration recording during a baseline CMJ from a sample player. The inertial sensor measured acceleration, from which position and velocity were derived. The shaded area to the left indicates the countermovement phase, starting at the initiation of the countermovement and ending at the lowest position. The shaded area to the right indicates the landing phase, starting from the highest position (jump height) and ending when the subject returns to standing upright position. On the position graph, jump height is indicated by the horizontal line from the apex in position. Flight height is jump height minus position when the subject left the ground, indicated by the lower horizontal dashed line on the position graph. Acceleration equals 0 at peak velocity and equals -9.81 $m \cdot s^{-2}$ at the point of take-off. Baseline force (N) is body mass x 9.81 and thereafter was the product of acceleration. Power was the product of force and velocity force and power not shown in this figure).

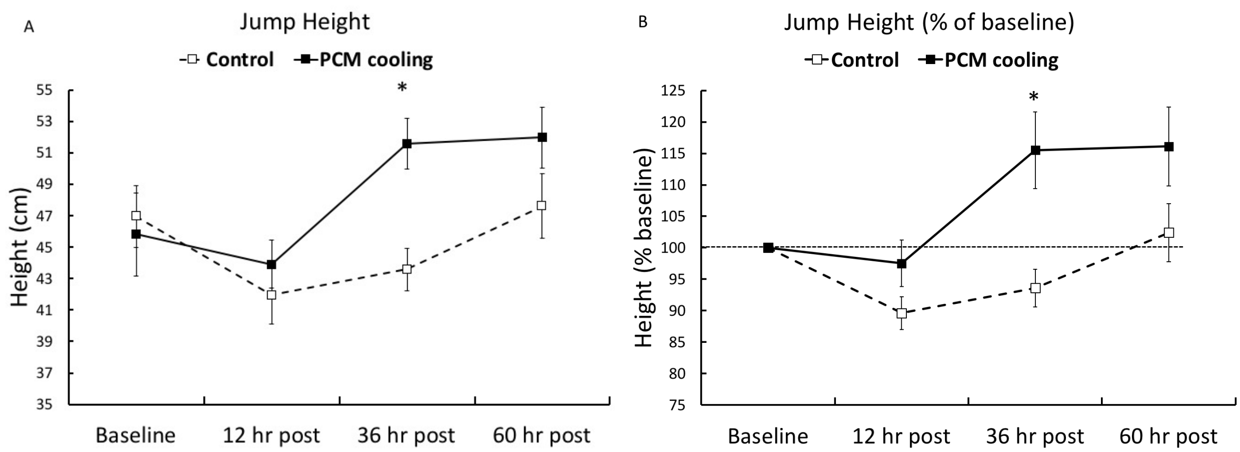

Figure 2: Effect of PCM cooling intervention on absolute (A) and relative (B) changes in jump height. Absolute jump height: treatment effect P=0.020, treatment by time P=0.027. Relative jump height: treatment effect P=0.035, treatment by time P=0.013. * higher jump height with PCM cooling treatment versus control P<0.05. Mean±SE displayed.

Table 1: Inertial sensor CMJ flight height and jump height before and after soccer match in control condition.

	Flight Height			Jump Height		
	cm	**% baseline**	**Effect Size vs. baseline**	**cm**	**% baseline**	**Effect Size vs. baseline**
Baseline	35.1±5.0	100%		47.0±6.6	100%	
12 h	32.4±6.7	92±13%	0.6	41.9±6.0*	90±9%*	1.1
36 h	30.7±3.7*	88±10%*	1.1	43.6±4.5	94±10%	0.7
60 h	31.5±4.2	91±12%	0.8	47.6±6.8	102±15%	0.1
Effect of Time	P=0.018	P=0.028		P=0.007	P=0.006	

Effect of time is P value for ANOVA; *P<0.05 different from baseline; effect size is Cohen's d_Z calculated from differences in absolute height from baseline. Mean±SD reported.

Table 2: Effects of PCM cooling on recovery of flight height for inertial sensor and optoelectric measurements.

	Inertial Sensor			Optoelectric System		
	PCM	**Control**	**Effect Size**	**PCM**	**Control**	**Effect Size**
Baseline	100%	100%		100%	100%	
12 h	102±13%	92±13%	0.4	99±5%	96±7%	0.3
36 h	105±15%*	88±10%	1.1	102±7%	93±8%	0.8
60 h	103±10%*	91±12%	0.9	107±14%	99±11%	0.4
Treatment Effect	P=0.007			P=0.064		
Treatment x Time	P=0.061			P=0.095		

*P<0.05 different from control; effect size is Cohen's d_Z calculated from differences in relative height between treatments. Mean±SD reported.