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# Recovery of kicking kinematics and performance following repeated high-intensity running bouts in the heat: Can a rapid local cooling intervention help young soccer players?

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**ABSTRACT**

The effects of a cooling strategy following repeated high-intensity running (RHIR) on soccer kicking performance in a hot environment (>30ºC) were investigated in youth soccer players. Fifteen academy under-17 players participated. In Experiment 1, players completed an all-out RHIR protocol (10×30 m, with 30s intervals). In Experiment 2 (cross-over design), participants performed this running protocol under two conditions: (1) following RHIR 5 minutes of cooling where ice packs were applied to the quadriceps/hamstrings, (2) a control condition involving passive resting. Perceptual measures [ratings of perceived exertion (RPE), pain and recovery], thigh temperature and kick-derived video three-dimensional kinematics (lower limb) and performance (ball speed and two-dimensional placement indices) were collected at baseline, post-exercise and intervention. In Experiment 1, RHIR led to small-to-large impairments ($p < 0.03$;$d = -0.42$–$-1.83$) across perceptual, kinematic and performance measures. In experiment 2, RPE ($p < 0.01$; Kendall's $W = 0.30$) and mean radial error ($p = 0.057$; $\eta^2 = 0.234$) increased only post-control. Significant small declines in ball speed were also observed post-control ($p < 0.05$; $d = 0.35$). Post-intervention foot centre-of-mass velocity was moderately faster in the cooling compared to control condition ($p = 0.04$; $d = 0.60$). In youth soccer players, a short cooling period was beneficial in counteracting declines in kicking performance, in particular ball placement, following intense running activity in the heat.

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## Introduction

In young soccer players, fatigue is manifestly observed over the course of match-play and is illustrated by an increase in players' ratings of perceived exertion (RPE) and a concomitant reduction in locomotor outputs in the second half (Aslan et al., 2012). Although the majority of in-game activities are performed in the "low intensity" domain (<13 km/h; Buchheit et al. (2010a)), players repeatedly execute very high-intensity (e.g., >19 km/h) running bouts (Buchheit et al., 2010b)). These are associated with substantial acute increases in both perceived effort (Brocherie et al., 2015; Sánchez-Sánchez et al., 2014) and sensations of pain (Monks et al., 2017) and are subsequently linked to impairments in neuromechanical responses owing to central or peripheral fatigue (Brocherie et al., 2015; Goodall et al., 2015; Perrey et al., 2010). Declines in kicking performance have also been observed using protocols to simulate running loads commonly observed in official soccer matches, including intermittent high-intensity activity (Palucci Vieira, Santinelli, et al., 2021; Russell et al., 2011; Sánchez-Sánchez et al., 2014), notably in senior players and in low environmental temperatures (18.2–21ºC). In contrast, only limited evidence exists in youth populations regarding the effects of repeated high-intensity running exercise on kicking performance as well as the consequences of heat (Palucci Vieira, Santinelli, et al., 2021). Lower muscle mass and force of lower limbs reported at younger compared to senior ages may be accompanied by less homoeostatic disturbance and muscle damage due to exercise (Buchheit et al., 2011). Furthermore, responses to imposed workload demands – and also kicking performance – are age dependent implying that the current body of knowledge regarding the effects of intense exercise efforts on kicking ability, derived predominantly from studies using adult players, cannot be easily extrapolated to youth soccer contexts [see review (Palucci Vieira, Santinelli, et al., 2021)].

In an attempt to accelerate recovery processes during and/or following exercise, cooling interventions are frequently utilised and their benefits are seemingly amplified in hot environments [temperature >30ºC (Bongers et al., 2015; Girard et al.,

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2015)]. Following exercise, cooling can have a transient analgesic effect aiding reduction of swelling and muscle pain while lowering RPE values (Bleakley et al., 2012; Duffield et al., 2013). These positive effects can subsequently facilitate the ensuing execution of physical efforts (Fischer et al., 2009). For example, studies have demonstrated short-to-long-term beneficial effects of cooling during the half-time interval and post-exercise on running outputs in soccer players (Buchheit et al., 2011; Duffield et al., 2013). However, research (Bleakley et al., 2012; Tyler et al., 2015; Wassinger et al., 2007) contrastingly shows that cooling techniques can exert acute adverse effects on motor performance immediately following such interventions. These include severe declines in both lower limb power-dependent activities such as jumping and maximal speed running and goal-directed technical skills using the upper limbs. The longer cooling treatment times utilised in the majority of intervention studies ranging up to 20 minutes are also considered to be an issue. This is particularly the case in team sports where time constraints exist. Prolonged cooling seems also linked with reductions in muscle temperature and consequent acute impairment in levels of preparedness (Bleakley et al., 2012). It is therefore noteworthy that preliminary evidence in both individual and team sport athletes shows that a substantially shorter period of cooling (≤5 minutes) can help attenuate the negative effects of exercise on power development post-exercise (Egaña et al., 2019; Peiffer et al., 2010) whilst not impairing peripheral blood flow, muscle temperature or motor responses (Fischer et al., 2009; Thorsson et al., 1985; Zemke et al., 1998). As such, additional testing of the impact of shorter cooling periods is warranted, which arguably could enable the development of more practical interventions (Egaña et al., 2019; Fischer et al., 2009; Peiffer et al., 2010).

Recovery strategies are necessary to help re-establish ballistic skill performance following intense physical exercise such as repeated high-intensity running. Yet, regardless of age, there is a lack of information related to the effects of specific recovery treatments such as cooling in relation to performing technical soccer skills. Indeed, a systematic review has recently identified a need for studies investigating the influence of cooling specifically in goal-directed skills and particularly in soccer kicking performance where both high standards of accuracy and velocity are required (Palucci Vieira, Santinelli, et al., 2021). Local application of ice packs has previously demonstrated positive effects in reducing perceived pain (Algafly et al., 2007), improving thermal and recovery sensations (Wiewelhove et al., 2020) and even assisting the power response of lower limbs in a heat stress experimental condition (Castle et al., 2006). Thus, the aims of the present study were to examine the effects of (i) intermittent high-intensity running efforts, and (ii) local cooling application on kicking movement kinematics and performance. The working hypothesis was that, in youth soccer players (i) all-out running exercise in the heat would generate acute reductions in ball kicking movement and performance outcomes, and notably velocity outputs. It was then expected that (ii) the subsequent application of an ice pack for a short period of 5 minutes in the recovery phase would favour youth soccer players' perceived well-being comprising sensations of recovery, pain and exertion while not negatively impacting kicking movement or performance recovery following intense exercise in the heat.

## Materials and methods

### Participants

Fifteen youth players participated [16.27 ± 0.86 years-old; 2.12 ± 0.71 (range: 0.95 to 2.97) years from peak height velocity (PHV); 64.14 ± 10.98 kg; 172 ± 9 cm]. All procedures were approved by the local Human Research Ethics Committee (protocol #2650204; CAAE85994318.3.0000.5398) and Brazilian Clinical Trials Registry ReBEC (http://www.ensaiosclinicos.gov.br/; included in the network of WHO primary registries) under number RBR-8prx2m. The players belonged to the under-17 age-group of a club competing at state standard in Brazil (1st place in São Paulo Interior League 2020 edition). The youth players and their legal guardians, respectively, signed approved assent and consent forms to allow participation.

In Experiment 1, possible exercise-induced changes in kicking performance parameters were investigated in a subsample of 13 players. This was considered to be the estimated required sample size owing to the expected declines in kicking performance following general intermittent high-intensity exercise mode (effect size = 0.92; power = 85% and α = 0.05) [data derived from a systematic review by Palucci Vieira, Santinelli, et al. (2021)]. In Experiment 2, which evaluated the effects of a recovery intervention, all 15 players were included to meet the a priori required sample size based on the assumption that the use of ice would affect motor skills precision (effect size = 0.86; power = 80% and α = 0.05) (Wassinger et al., 2007) and/or global performance in ensuing sports-related tasks (average effect size = 0.83; data from systematic review by Bleakley et al. (2012)). Sample size estimations for each experiment were obtained using G*Power© v.3.1.9.2 environment (Universität Düsseldorf, Germany).

### Experimental design

Two experiments were conducted to test the study hypothesis on the potential effects upon kicking performance of: (1) intense repeated high-intensity exercise in hot conditions and (2) the impact of a cooling intervention in the same conditions. In Experiment 1, a pre-post paired test design was used, in order to analyse the potential impact of the running exercise protocol on measures of kicking performance. Players were firstly asked to perform a standardised 15-minute warm-up composed of dynamic stretching, jogging and submaximal kicks. Thereafter, participants performed a running protocol involving repeated high-intensity exercise (10 × 30 m; see description below). Immediately prior to and at end of this exercise, players performed a kicking protocol (description in the next subsection) to assess lower limb movement mechanics and performance.

Following the assumption that exercising in the heat would have deleterious effects, a second experiment was conducted to evaluate the possible effectiveness of cooling as a recovery mode. In Experiment 2, a repeated measures, cross-over pre-post testing design was adopted, randomised and counterbalanced between data collection days where participants acted as their own controls. After completing the same warm-up and running protocol as in Experiment 1, each participant was assigned to one of the 2 experimental conditions [control or

5 minutes cooling (COOL)] on two separate days, 24–26 hours apart. All participants performed the kick testing protocol before commencing the running exercise in a rested state and immediately following the post-exercise intervention with COOL or control (5 minutes of passive recovery). Reliability estimates were computed for the specific RHIR protocol used (10 × 30 m) since (at the time of writing) there are no previous studies reporting such reference values for this exercise protocol generally or when performed in heat conditions (Lopes-Silva et al., 2019; Paul & Nassis, 2015).

Both experiments were performed on an official FIFA-standard natural grass soccer pitch in the presence of sunlight during afternoon period (between ~14:30–17:30 h). A request was made by the present authors to the club participant to standardised pre-test diet in an attempt to maintain consistency across testing days. Players were also asked to avoid consumption of stimulant/inhibitory medication or carbohydrate-rich drinks during experiments. The historical data provided by an automatic meteorological station near to the location where the data collection took place (Centro de Meteorologia de Bauru, Local Meteorological Research Institute IPMet – UNESP–Bauru – Brazil; https://www.ipmetradar.com.br/) was used to obtain environmental temperature and relative humidity.

### Kick testing data collection and processing

The present kick testing protocol was based on that employed in a previous study (Palucci Vieira, Lastella, et al., 2022). In brief, the participants were asked to perform instep kicks, 18 m from the midpoint goal line, using FIFA-approved stationary balls (PENALTY® brand, 5-sized, 70 cm diameter, 430 g weight, and air pressure maintained at 0.7 atm). Kicks were performed at maximal velocity and aimed at the centre of a 1 × 1 m target fixated in the contralateral goalpost upper corner. The approach run was constrained to 3.5 m and 45 degrees, with a 40 s passive rest interval between repeated attempts within the same block. Differences to the original protocol included: trying to increase standardisation as much as possible between the two proposed intervention conditions as well across the time-moments, goalkeeper omission, and three kick attempts allowed per block (time-moment).

Body motion and ball displacement immediately after kicking were recorded using two digital video cameras fixed on tripods (GoPro Hero 7 Black Edition, GoPro GmbH, München – Germany), sampling at 240 frames/s [wide field-of-view (FOV) mode; 1280 × 960 pixel; 1/480 s shutter speed], both of which were turned on and synchronised via remote control (Smart Remote GoPro). The cameras were positioned laterally around the kick mark (2.5 m) so their focus was ~ 90 degrees between them. Afterwards, video files from data collections were downloaded onto a laptop computer (DELL INSPIRON 5590; Dell Inc., Texas – USA). The OpenPose markerless motion detector method in addition to a tracking algorithm previously validated to evaluate ball kicking action (Palucci Vieira, Santiago, et al., 2022) were used to automatically extract two-dimensional screen coordinates of seven keypoints derived from the hip (preferred and non-preferred), knee, ankle and foot regions (measurement error = 3.49 cm and 1.29 m/s; Palucci Vieira, Santiago, et al. (2022)). A calibration frame was defined using 49 reference points with absolute three-dimensional coordinates known (4.11 × 4.05 × 1.30 m). Following tracking and appropriate correction of the radial distortion (Rossi et al., 2015), screen coordinates of both cameras were inputted in a specific Python 3.8.3 algorithm (Python Software Foundation, Delaware – USA) to run three-dimensional Direct Linear Transformation (DLT) reconstruction. Time-series positional data was then extrapolated following impact (20%) and smoothed (dual filter 4th-order Butterworth/rloess) in MATLAB software (R2019a MathWorks Inc., Natick – USA). Residual analysis helped define filtering parameters (cut-off frequency = 25 Hz and span = 0.1, respectively). After treatment, extrapolation was then removed. Custom-built routines were written to obtain linear velocities [non-preferred hip, foot centre-of-mass ($CM_{foot}$) and $CM_{foot}$ to knee relative], angular (i) joint displacement (ankle plantarflexion/dorsiflexion and eversion/inversion at impact) (ii) range-of-motion (hip and knee flexion/extension) and (ii) peak knee extension velocity. These were computed using local reference frames of joints and segments as described elsewhere (Palucci Vieira, Barbieri, et al., 2021; Palucci Vieira, Carling, et al., 2022).

The ball centroid was manually tracked in the DVIDEOW kinematic system (Rossi et al., 2015) to compute ball speed metrics, using image sequences from both cameras, considering 10 available airborne frames after the foot contacted the stationary ball. To determine resultant post-impact ball speed, its horizontal and vertical components were calculated from the first derivative of linear and quadratic (second derivative = $-9.81$ m/s$^2$) regression lines, respectively (Nunome et al., 2006). Mean and maximal values for ball speed across each block of three kicks were retained for further analysis.

To obtain indices related to ball placement, two cameras sampling at 60 frames/s (GoPro Hero 7 Black Edition, GoPro GmbH; 1920 × 1080 pixel, linear FOV) were placed one in front of the goal (~23 m apart) and another above the goal line. A calibration frame was defined considering all goalpost upper/lower extremities (four reference points; 7.35 × 2.32 m). The two-dimensional coordinates of the ball centre at the moment it crossed the goal line were obtained using the same software and similar procedures as for ball speed digitisation. The Euclidean distance between the ball and target centre coordinates was calculated for each kick attempt. Taking the three repeated kick attempts within the same given block, the mean radial error (average ball-target distance), bivariate variable error (square root of the sum of standard deviation squared derived from x- and y-coordinates of the ball) and overall accuracy (a compound of the two previous measures) were computed using specific equations described elsewhere (Vieira et al., 2018) where Euclidean distances and two-dimensional coordinates of ball and target centre were adopted as input parameters.

### Running protocol

To simulate the repeated high-intensity running efforts that players frequently perform during soccer training and testing, a protocol including 10 "all-out" running bouts x 30 m distance each, interspersed by a recovery period of 30 s was conducted.

The player ran for 25 s at low intensity back to the starting line, ensuring 4–5 s of passive resting before performing the next sprint (Buchheit & Mendez-Villanueva, 2014). In young soccer players across various ages, this RHIR model has previously demonstrated good construct validity for predicting in-game running performance (Buchheit et al., 2010a). Standardised ("go, go, go . . . "), constant and strong verbal encouragement was provided during each effort. The time to complete each sprint was recorded by a single experienced examiner using a digital manual stopwatch (LIVEUP® SPORTS, Paraná–Brazil; 1/100 s sensitivity). Mean time (MT), worst time (WT), best time (BT), total time (TT) and percentage of velocity decay (DEC) were the variables retained for further analysis.

### Ice application

At the end of the running exercise, the participants performed the cooling protocol (COOL condition). They were asked to sit on the substitute's bench pitch-side near where the kicking and running protocols took place. A licenced physical therapist tightly covered the anterior and posterior portions of the thigh of the participant's preferred lower limb using plastic wrapping paper, respectively, with two thin plastic bags (20 × 40 cm), approximately 1/3 filled with cubed ice; these were maintained constantly over the quadriceps and hamstrings muscle sites for 5 minutes (Algafly et al., 2007; Fischer et al., 2009). To standardise across players, the centre of the bags were aligned with thigh midpoint. During the ice application, participants kept their treatment leg comfortably extended on an auxiliary chair at a height slightly lower than the bench on which they were sitting.

### Perceptual measures

Before the beginning (Pre), immediately following the running cessation (post-RHIR) and intervention or control conditions (Post), measures referring to general ratings of perceived exertion (RPE) were collected using the 0–10 Borg scale (Foster, 1998); subjective perception of pain, using a 10-point Likert scale (0 = no soreness and 10 = very, very sore) (Pointon et al., 2011) and perception of recovery, based on another 10-point Likert scale (0 = very poorly recovered/extremely tired and 10 = very well recovered/highly energetic) (Paul et al., 2019). Each participant was asked individually to provide their RPE using printed A4 size sheets containing the scales, with no other teammates around. The skin surface temperature at the mid-point of the thigh – between the anterior superior iliac spine and base of patella; ink demarked – was also determined at the same time by a single examiner using an infrared manual thermometer (precision = ± 0.2ºC; capture range = 0–60ºC; model YRK-002A – HC260, Multilaser Industrial S.A., São Paulo – Brazil). The thermometer device was previously calibrated and kept ~1 cm apart and perpendicular to the skin surface for recordings as per procedures described elsewhere (Buono et al., 2007).

### Statistical analysis

Statistical tests were performed in IBM Statistical Package for the Social Sciences v.25 (IBM Corp. ©, Armonk – USA) with an alpha level set at $p \leq 0.05$ for determining significance unless otherwise stated. Data normality was first assessed using Shapiro-Wilk's test. If data was flagged as non-normal (i.e., when $p < 0.05$ in the normality test), then kurtosis, skewness and frequency plots were checked. If log-transformation was not efficient, non-parametric versions of tests were employed. In Experiment 1, Student's t-test for dependent samples was used to compare measures pre- and post-RHIR. Effect size for paired comparisons was obtained using Cohen's $d$ where $d >$ 0.20 (small), > 0.50 (medium), and > 0.80 (large). In Experiment 2, the Student's t-test or Wilcoxon signed-rank test was used to obtain estimates of reliability of the responses to the running protocol between testing days/conditions. In the case where the latter was necessary, r effect size ($r = z/\sqrt{N}$) was calculated and interpreted as $r > 0.10$ (small), > 0.30 (moderate) and ≥ 0.50 (large). Intraclass correlation coefficients (ICC), typical error (TE) and coefficient of variation (CV) were also computed using a specific Microsoft Excel (Microsoft Corp., Redmond – USA) spreadsheet (x.rely.xls, available on https://sportsci.org/). ICC values were considered poor (<0.50), moderate (0.50–0.75), good (0.75–0.90) or excellent (>0.90). Finally, to compare the two distinct experimental conditions, 2 (time: pre, post) x 2 (condition: Control, COOL) repeated measures ANOVAs were run with Bonferroni adjustment to the alpha level in post-hoc comparisons. Partial eta-squared ($\eta^2$) was taken as effect size for main effects and deemed as $\eta^2$ >0.01 (small), > 0.06 (moderate), and > 0.15 (large). When necessary, Friedman's two-way ANOVA by ranks was utilised, also with post-hoc significance adjusted by dividing alpha level by the number of multiple comparisons performed. Kendall's $W$ effect size for main effect was determined and considered as $W > 0.10$ (small), > 0.30 (moderate) and ≥ 0.50 (large).

## Results

The environmental temperature and relative humidity recorded in Experiment 1 were, respectively, 36.67 ± 3.3ºC [32–41ºC] and 26.70 ± 8.78% [15.10–35.90%]; in Experiment 2, 35.5 ± 2.8ºC [33.37–38.67ºC] and 20.2 ± 7.5% [15.12–28.8%] (control condition) and 33.8 ± 4.6ºC [30.59–39.09ºC] and 21.0 ± 7% [14.82–28.55%] (COOL condition).

### Experiment 1

#### Intense running exercise, perceptual measures and kicking outputs

Table 1 reports the perceptual indices, kicking kinematics and performance pre- and post-RHIR exercise. The repeated high-intensity running protocol led to a significantly *large* increase in ratings of perceived exertion (percentage difference, mean/median absolute difference [CI lower; upper] = +659.74%, 4 a.u. [3; 9]; $p < 0.01$) and a *large* decrease in perception of recovery (−40.47%, 3.62 a.u. [1.66; 5.57]; $p < 0.01$). Perception of pain (+17.56%, 0.23 a.u. [0.27; 0.73]) and thigh temperature (+0.95%, 0.34 ºC [0.02; 0.71]) did not statistically change post-RHIR [$p \geq 0.7$, $d < 0.5$ (small)].

A *large* significant increase in mean radial error was observed following the exercise protocol (+34.90%, 0.67 m [0.10; 1.25]; $p =$ 0.03). There was also a *large* non-significant increase in accuracy

Table 1. Effects of repeated high-intensity running bouts (RHIR) on perceptual measures and kicking performance indices ($n = 13$).

| | Pre-RHIR | Post-RHIR | *p*-value | ES [90% CL] – rating |
|---|---|---|---|---|
| RPE (a.u.) | .77 ± 1.17* | 5.85 ± 2.54 | .006 | 4.08 [2.96; 5.19] – large |
| Pain (a.u.) | 1.31±.48 | 1.54±.78 | .337 | 0.45 [−0.35; 1.25] – small |
| Recovery (a.u.) | 8.92 ± 1.85* | 5.31 ± 1.89 | .002 | −1.83 [−2.64; −1.02] – large |
| Thigh temperature (ºC) | 35.88±.73 | 36.22±.34 | .066 | 0.49 [0.08; 0.90] – small |
| Mean radial error (m) | 1.92±.42* | 2.59±.67 | .025 | 1.50 [0.46; 2.54] – large |
| Bivariate variable error (m) | 1.86±.59 | 1.79±.95 | .764 | 0.12 [−0.82; 0.58] – trivial |
| Accuracy (m) | 2.76±.51 | 3.26 ± 1.10 | .113 | 0.93 [−0.04; 1.90] – large |
| Average ball speed (m/s) | 28.70 ± 2.30* | 27.80 ± 1.19 | .038 | −0.36 [−0.64; −0.09] – small |
| Peak ball speed (m/s) | 29.68 ± 2.64* | 28.51 ± 2.05 | .029 | −0.42 [−0.72; −0.12] – small |
| $CM_{foot}$ velocity (m/s) | 23.88 ± 6.55 | 24.39 ± 8.27 | .224 | 0.07 [−0.21; 0.36] – trivial |
| $CM_{foot}$ to knee relative velocity (m/s) | 17.59 ± 3.42 | 18.49 ± 3.89 | .274 | 0.24 [−0.14; 0.63] – small |
| Non-preferred hip velocity (m/s) | 1.51 ± 3.19 | 11.41 ± 4.65 | .244 | 0.27 [−0.12; 0.65] – small |
| Peak knee angular velocity (rad/s) | .53±.18 | .57±.22 | .497 | 0.17 [−0.27; 0.61] – small |
| ROM hip (rad) | 1.30±.47 | 1.37±.49 | .161 | 0.13 [−0.05; 0.30] – trivial |
| ROM knee (rad) | 1.54±.46 | 1.57±.46 | .229 | 0.06 [−0.03; 0.14] – trivial |
| Plantarflexion/dorsiflexion at impact (rad) | −.54±.47 | −.54±.43 | .968 | 0.00 [−0.13; 0.14] – trivial |
| Eversion/inversion angle at impact (rad) | −.07±.22* | .11±.15 | .019 | 0.78 [0.27; 1.30] – moderate |

RPE, ratings of perceived exertion; ROM, range-of-motion; ES, effect size (Cohen's *d*); CL, confidence limits. *significant difference when comparing Pre- vs Post-RHIR at $p \le 0.05$ level.

after RHIR (+18.12%, 0.50 m [0.14; 1.14]; $p = 0.11$). *Small* significant declines occurred in average (–3.14%, 0.89 m/s [0.06; 1.73]; $p = 0.04$) and peak ball speed values (–3.94%, 1.18 m/s [0.15; 2.21]; $p = 0.03$). Ankle eversion/inversion angle of the kicking limb at impact *moderately* increased after the running protocol (+257.14%, 0.18 rad [0.04; 0.33]; $p < 0.02$). Other kicking outputs (Table 1) showed no statistically significant differences pre- vs. post-RHIR [$p \ge 0.16$; $d \le 0.27$ (trivial to small)].

## Experiment 2

### Running protocol reliability

Table 2 presents performance indices observed in the running protocol, statistical outcomes from comparisons of these indicators between distinct intervention conditions as well as their concordance. No significant differences were identified for any of the parameters (i.e., MT, WT, BT, TT and DEC) when players performed Control or COOL conditions ($p \ge 0.17$, *small* effect sizes, $d = –0.34–0.38$). Running outputs exhibited *moderate*-to-*good* reliability (ICCs = 0.50–0.88; $p \le 0.04$) between the two conditions with the exception of DEC (ICC = –0.43; $p = 0.95$). CVs ranged between 2.93% (TT) to 5.87% (BT) while a substantially higher value was observed for DEC (CV = 40.66%). Results are indicative of low systematic and random bias of the RHIR model, respectively.

### Recovery treatment effects

Perceptual measures and skin temperature are presented in Figure 1. Responses were similar at baseline (Pre) between the two experimental conditions ($p = 1.00$; $r = 0.02–0.38$). Friedman's test showed a significant *moderate* main effect for RPE ($X^2_{(3)} = 13.408$; $p = 0.004$; Kendall's $W = 0.30$; Figure 1(a)). Pairwise comparisons revealed a *large* increase in RPE in the Post- as compared to Pre-Control (+484.85%, 1 a.u. [0; 3]; $p = 0.02$; $r = 0.69$) whilst RPE was similar across moments in the COOL condition (+75.00%, 0 a.u. [0; 2]; $p = 1.00$; $r = 0.35$ [*moderate*]). Friedman's test also detected a *large* main effect for thigh temperature ($X^2_{(3)} = 25.711$; $p < 0.001$; Kendall's $W = 0.57$; Figure 1(d)). Pairwise comparisons indicated a *large* decline following COOL as compared to pre-COOL (–8.59%, 3.3 ºC [2.4; 4]; $p < 0.001$; $r = 0.88$). Thigh temperature was *largely* lower in COOL as compared to Control at Post moment (–9.09%, 3.2 ºC [2.0; 3.7]; $p = 0.002$; $r = 0.88$). A main possible effect for condition favouring COOL in Friedman's test also occurred regarding the perceived Recovery ($X^2_{(3)} = 11.057$; $p = 0.011$; Kendall's $W = 0.25$ [*small*]; Figure 1(c)); however, pairwise comparisons lacked statistical significance (e.g., Pre- vs. Post-Control; –23.85%, 1 a.u. [0; 4]; $p = 0.08$; $r = –0.65$ [*large*]). No main effect for condition regarding pain was observed ($p > 0.83$; Kendall's $W = 0.02$).

Kicking ball placement-derived indices (mean radial error, bivariate variable error and overall accuracy) and ball speed (average and peak) across the experiment are shown, respectively, in Figures 2 and 3. These parameters did not differ at baseline when comparing Control and COOL conditions ($p = 0.39–0.78$; $d = 0.11–0.36$ and $p = 0.47–0.78$; $d = 0.10–0.29$, respectively). There was a *large* main Time × Condition interactive effect of borderline significance concerning mean radial error ($F_{(1, 14)} = 4.286$; $p = 0.057$; $\eta^2 = 0.234$). Pairwise comparisons

Table 2. Characterisation of performance indices in the repeated high-intensity running bouts for each condition with reliability measures for responses computed between conditions ($n = 15$).

| | Mean ± SD | Comparison statistics | ICC (90% CI) | TE (90% CI) | CV (%) |
|---|---|---|---|---|---|
| MT (s) | Control: 5.02 ± 0.41 COOL: 4.94 ± 0.38 | t(14) = 1.458; *p* = .17; d = .20 | 0.88*** (0.73–0.95) | 0.15 (0.11–0.21) | 3.01 |
| WT (s) | Control: 5.35 ± 0.45 COOL: 5.28 ± 0.42 | Z = –.796; *p* = .43; *r* = –.15 | 0.74** (0.46–0.89) | 0.24 (0.18–0.34) | 4.51 |
| BT (s) | Control: 4.67 ± 0.35 COOL: 4.53 ± 0.38 | t(14) = 1.410; *p* = .18; d = .38 | 0.50* (0.09–0.76) | 0.27 (0.20–0.39) | 5.87 |
| TT (s) | Control: 50.17 ± 4.06 COOL: 49.39 ± 3.82 | t(14) = 1.458; *p* = .17; d = .20 | 0.88*** (0.73–0.95) | 1.46 (1.12–2.13) | 2.93 |
| DEC (%) | Control: 12.53 ± 4.64 COOL: 14.09 ± 4.48 | t(14) = –.887; *p* = .39; d = –.34 | –0.43 (–0.72–0.01) | 5.41 (4.16–7.89) | 40.66 |

MT, mean time; WT, worst time; BT, best time; TT, total time; DEC, percentage of velocity decay in the RSA protocol; SD, standard deviation; CI, confidence interval; intraclass correlation coefficient (ICC), typical error (TE) and coefficient of variation (CV). Statistical significance: * $p \le 0.05$; ** $p < 0.01$; *** $p < 0.001$.

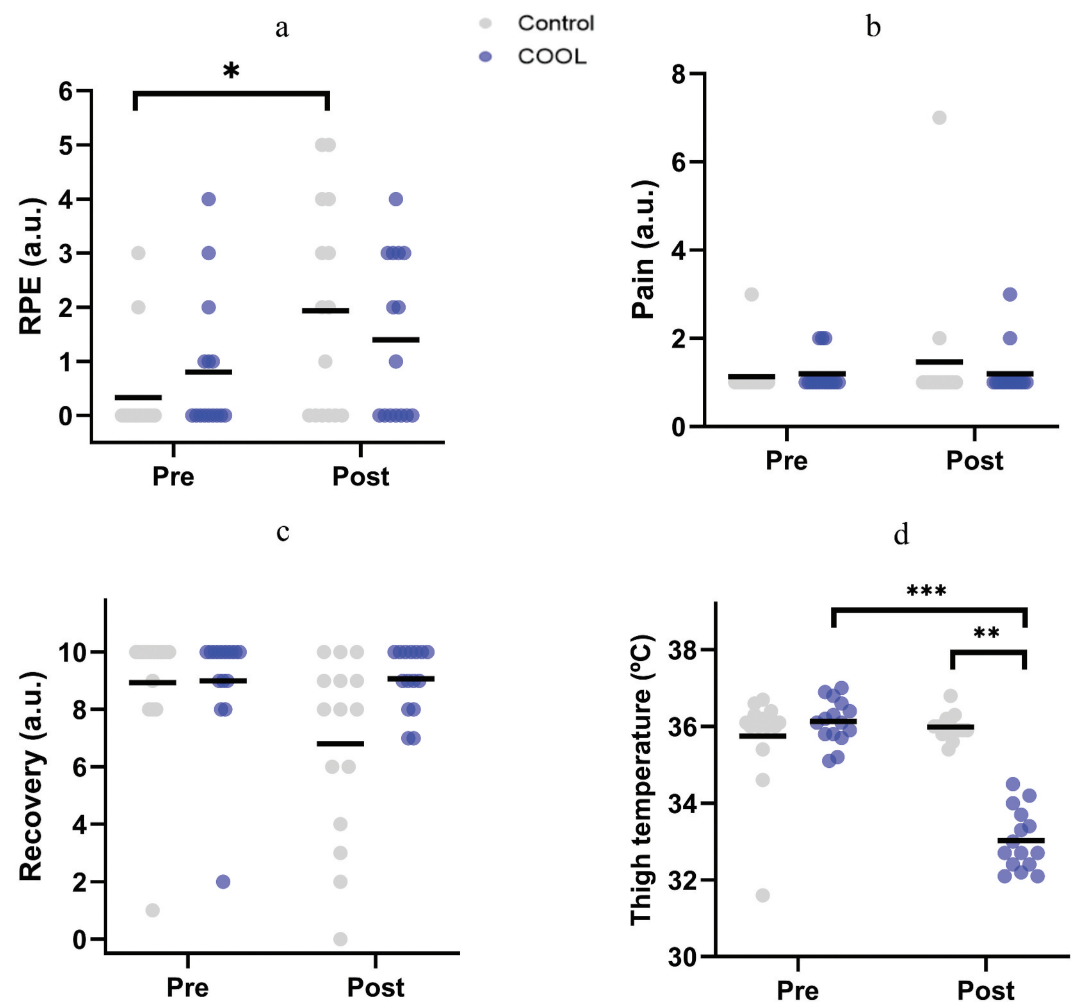


Figure 1. Perceptual measures and skin temperature according to time-moments and conditions. * $p \leq 0.05$; ** $p < 0.01$; *** $p < 0.001$.

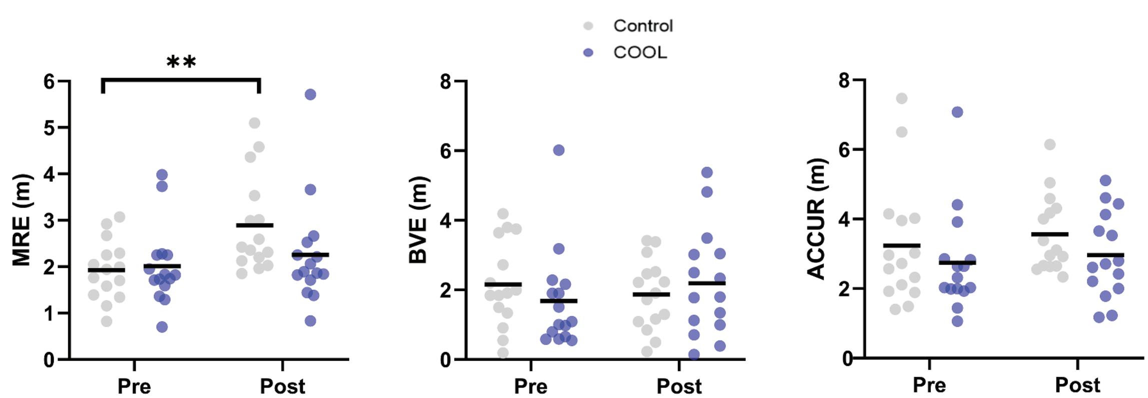


Figure 2. Ball placement-derived indices according to time-moments and conditions. ** $p < 0.01$.

indicated a *large* significant increase in mean radial error after Control condition as compared to baseline (+50.26%, 0.97 m [0.40; 1.54]; $p = 0.003$; $d = -1.12$; Figure 2) while no significant pre-post variations existed in COOL intervention (+12.44%, 0.24 m [–0.43; 0.91]; $p = 0.45$; $d = -0.25$ [*small*]). Bivariate variable error and accuracy presented no significant Time × Condition interactive effects ($p \geq 0.16$; $\eta^2 \leq 0.05$).

No significant *small* Time × Condition effects were found for ball speed (average: $F_{(1,\ 14)} = 0.126$; $p = 0.73$; $\eta^2 = 0.009$; peak: $F_{(1,\ 14)} = 0.394$; $p = 0.54$; $\eta^2 = 0.027$). Separate *large* Time effects were significant for both average ($F_{(1,\ 14)} = 6.649$; $p = 0.02$; $\eta^2 = 0.322$) and peak ball speed ($F_{(1,\ 14)} = 6.580$; $p = 0.02$; $\eta^2 = 0.322$). Pairwise comparisons revealed significant *small* declines (both $d = 0.35$) in ball speed following the Control condition (average:

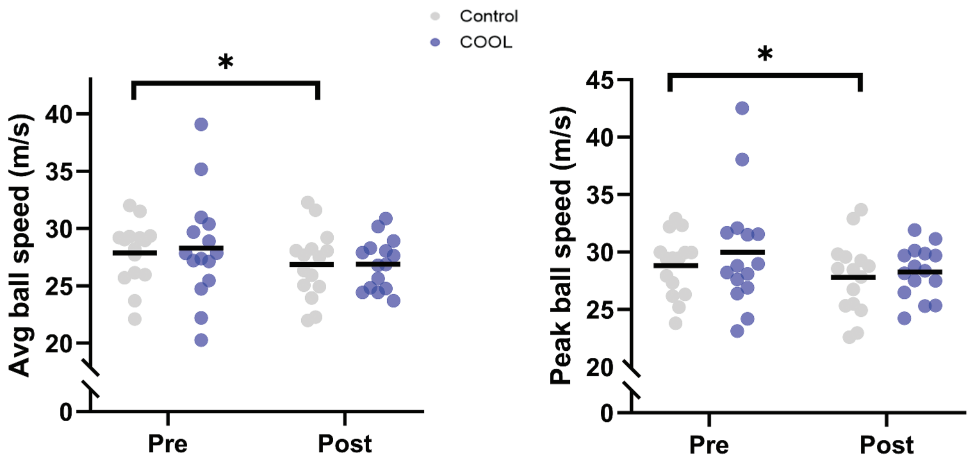


Figure 3. Ball speed indices [average (Avg) and maximal (peak)] according to time-moments and conditions. * $p \leq 0.05$; ** $p < 0.01$.

−3.62%, −1.01 m/s [−1.95; −0.06]; $p = 0.04$ and peak: −3.57%, −1.04 m/s [−1.89; −0.18]; $p = 0.02$; Figure 3) but not in COOL condition (average: −4.92%, −1.40 m/s [−3.38; 0.59]; $p = 0.15$; $d = 0.38$ and peak: −5.67%, −1.70 m/s [−3.83; 0.42]; $p = 0.11$; $d = 0.44$).

Regarding the movement kinematics (Figure 4), in general, the measures also showed no between-condition differences at baseline ($p = 0.14$–$0.84$; $d = 0.02$–$0.42$). One exception occurred for the value of ankle eversion angle at impact (main Time × Condition effect: $F_{(1,\ 14)} = 5.339$; $p = 0.04$; $\eta^2 = 0.276$ [*large*]), which had a significant pairwise difference among conditions in the Pre (355.56%, −0.32 rad [−0.58; −0.06]; $p = 0.02$; $d = 1.02$ [*large*]) but this was not the case in the Post-intervention (33.33%, 0.01 rad [−0.26; 0.29]; $p = 0.91$; $d = -0.06$ [*trivial*]; Figure 4(h)). Finally, there was a *large* main Time × Condition interactive effect in reference to $CM_{foot}$ velocity ($F_{(1,\ 14)} = 6.538$; $p = 0.02$; $\eta^2 = 0.318$). In particular $CM_{foot}$ velocity was *moderately* faster in the COOL as compared to Control in the Post-intervention moment (+21.85%, 4.61 m/s [0.14; 9.08]; $p = 0.04$; $d = 0.60$; Figure 4(a)). The remaining movement kinematic parameters exhibited non-significant Time × Condition effects [$p \geq 0.15$; $\eta^2 \leq 0.14$ (small to moderate)].

## Discussion

The main objectives of the present investigation in youth soccer players were to investigate under an environmental stressor condition (hot temperature) (i) whether repeated high-intensity running (RHIR) efforts immediately modify kinematics and performance (ball placement and velocity) outputs in kick attempts subsequently performed from the edge of penalty area and (ii) to evaluate the effectiveness of applying a brief local cooling pack (COOL) on the thigh as a potential recovery intervention following RHIR exercise and its consequences on measures of kicking performance. The working hypothesis was that declines in kicking performance would occur following

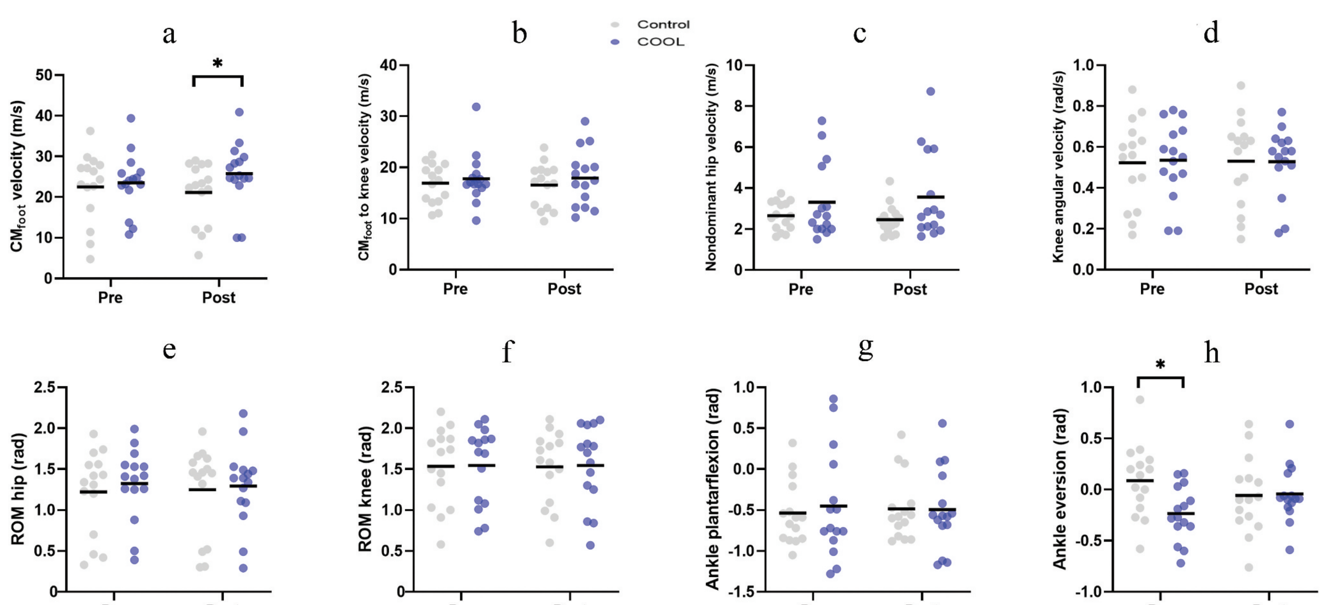


Figure 4. Kinematics of the lower contact limb according to time-moments and conditions. * $p \leq 0.05$.

RHIR and a rapid application of ice packs would aid recovery. The first hypothesis was rejected in part since RHIR exercise provoked negative changes notably regarding ball placement (inducing kicks generally farther from the target in goalpost upper corners) while ball speed was affected to a small extent. Conversely and partly in line with the second hypothesis, five minutes of COOL following RHIR bouts promoted benefits in perceptual measures (internal load), kinematics ($CM_{foot}$) and performance (both ball placement and velocity indicators) for kick attempts in comparison to the control condition. Hereinafter, the transient negative impact of RHIR exercise and the ergogenic effects provided by COOL during the acute recovery phase are discussed.

In the present under-17 youth players, RHIR impaired both kinematics and different performance components of soccer kicking. These included distal mechanics of the contact limb as illustrated by modification of the ankle eversion to inversion pattern at the moment of foot to ball impact. In addition, mean radial error substantially increased following the running protocol. Recent related research has notably shown that greater ankle inversion is associated with higher mean radial error in kick attempts from entrance of penalty area (Palucci Vieira, Carling, et al., 2022). Importantly, performing RHIR in the heat is recognised to cause central neurotransmission and muscle activity declines (Goodall et al., 2015; Meeusen et al., 2006; Perrey et al., 2010), both of which are determinant aspects of kicking accuracy (Palucci Vieira, Carling, et al., 2022; Palucci Vieira, Santinelli, et al., 2021). Ball speed verified in the present experiment was within the range (22–32 m/s) of other age-matched players (Nunome et al., 2006; Vieira et al., 2018), while the mean radial error was slightly greater than in penalty trials or 15-m kicks (0.90–1.50 m (Russell et al., 2011; Vieira et al., 2018)). Findings are also in accordance with those of Rampinini et al. (2008) who reported impaired short passing performance in youth players following a RHIR protocol that attempted to reproduce most demanding phase of matches (10 × 40 m runs with one change-of-direction). According to a recent review on the topic (Palucci Vieira, Santinelli, et al., 2021), only two studies assessing the acute impact of RHIR mode of exercise on subsequent kicking aspects of youth soccer currently exist. Non-significant (trivial-to-large) exercise effects on kicking accuracy were previously observed but no concomitant information on velocity was provided (Gharbi et al., 2017; Masmoudi et al., 2016). It is also of note that these studies were conducted in players with a mean age of 14.6 years meaning that they certainly fell in the circum-PHV stage (Buchheit & Mendez-Villanueva, 2013) while the present players were all post-PHV. More mature players are shown to perform faster bouts than developing pre/circum-PHV peers in repeated sprint activity (Selmi et al., 2020). Consequently, the impaired ball placement ability following RHIR efforts reported in the current investigation in youth players aged under-17 but not in other under-15s in the literature could potentially be attributed to a greater disturbance in homoeostasis experienced in the former. In addition, kick task constraints used in previous studies included attempts performed 6.1 m apart from a small-dimension (2.44 × 1.22 m) goal/target aiming only at its centre (Gharbi et al., 2017; Masmoudi et al., 2016). As such, one could question whether prior evidence of no changes on ball placement ability in youth soccer following RHIR can be linked to the low-challenging technical demands of the protocol.

It is important to highlight that kicking velocity and ball placement responded in different ways to the demands of the intense exercise protocol. Indeed, the central and peripheral signalling paths and measures responsible for kick accuracy and velocity are not identical (Palucci Vieira, Carling, et al., 2022; Palucci Vieira, Zagatto, et al., 2022), which a priori can explain the differences in results. However, exercise-related fatigue affects the functioning of brain regions/waves determinants for ball speed (frontal theta) and placement (occipital alpha) (Baumeister et al., 2012) to a similar extent implying that the problem could be observed more at limb level. Evidence that vastus lateralis RMS may be unchanged after repeated sprint activity and recovers rapidly has been provided (Billaut & Basset, 2007). Data from another investigation demonstrates that EMG amplitude indices such as quadriceps RMS/integral is related to ball kicking speed in teenage athletes (Palucci Vieira, Zagatto, et al., 2022). In contrast, biceps femoris activity, which is related to ball kicking placement in youth soccer, seems to be more consistently altered by repeated intense bouts (Hautier et al., 2000; Timmins et al., 2014; Zarrouk et al., 2012) possibly owing to the high strain placed upon the hamstrings during the deceleration phase separating RHIR efforts. Notwithstanding, a strong linear negative relation exists between kicking ball speed and the chance of a goal attempt being blocked (Hunter et al., 2018) in other words, it is possible that players attempted to maintain velocity output when fatigued, and with impaired motor control (e.g., ankle joint), this may have resulted in worser ball placement following RHIR.

A key finding of the present analysis was that a cooling intervention using the application of an ice pack on the quadriceps/hamstrings (COOL) following RHIR performed in the heat reduced players' perception of effort. It also helped reduce deleterious effects on performance-related indices including ball placement, $CM_{foot}$ and ball speed declines as observed in the passive resting condition. There was also a trend represented by a non-significant ($p = 0.08$) large-sized decrease in perceived recovery during post-control while this was not the case in the COOL condition. Aside from the substantial impairment in kicking ball placement induced by RHIR, reductions in ball speed owing to this mode of exercise were also significant, albeit small, and did not surpass the minimal difference (~1.27 m/s; Palucci Vieira, Lastella, et al. (2022)). These small reductions differ to previous results on kicking performance following official competition where moderate-to-large declines in post-match ball speed in youth players across all playing positions were observed (Izquierdo et al., 2020). This discrepancy across results might be due to the longer duration of exercise and the likely greater frequency of repeated high-intensity of actions observed in match-play settings as compared to the RHIR model adopted in the present experiment.

As such, these results highlight the potential role of COOL in match-play given the ergogenic effects it had on foot and ball kinematics in the present study. Among the possible mechanisms at play, the forceful reduction in local temperature could have counteracted the declines in neuromuscular output observed under heat conditions (Matsuura et al., 2015). A further aspect to account for is that a 5-min COOL, despite promoting substantial decreases in skin (Figure 1) and subcutaneous temperatures (Myrer et al., 1997), can help induce limited declines in intramuscular temperature compared to during the rested state (e.g., ~0.64ºC; Zemke et al. (1998)). This is important especially owing to the strong relationship between declines in muscle temperature and lower limb power performance in soccer (Mohr et al., 2004). In a previous meta-analysis, the effectiveness of a commonly used COOL intervention (cold-water immersion) was reported to similarly alleviate RPE but had no meaningful effects on power performance in adolescent athletes (Murray & Cardinale, 2015). In addition, long periods (e.g., 2 × 15 min) of ice pack maintenance following interval sprints session are recognised to cause bionegative adaptations such as decreased anabolic response in youth team sport athletes (Nemet et al., 2009). Taken together, the premise that COOL has a time-dependent effect on ensuing performance (Bleakley et al., 2012; Fischer et al., 2009; Peiffer et al., 2009) seems well supported as a brief cooling intervention was effective here in some instances – especially concerning ball placement – or at least not deleteriously affecting kicking outputs whilst attenuating exercise effort and recovery perceptions. From a practical viewpoint, we can suggest that cooling breaks similar to those adopted in senior soccer should be encouraged in youth match-play particularly when exercise is performed in high environmental temperatures. In addition, the rolling substitute policy used in youth soccer tournaments played in hot climatic conditions could arguably benefit from the ice pack mode of cooling by helping alleviate the immediate effects of loading in substitute players on pitch entry.

There are various caveats that should be made that collectively may limit the generalisability of the current findings. For example, evidence derived from non-parametric data should be interpreted with caution. Also, it might have expected that RHIR would promote an acute increase in pain sensation while COOL could reverse this. However, this was not confirmed since the players' post-exercise perceptions of pain were similar to baseline levels. The lack of an extended familiarisation period for the players with this subjective rating monitoring tool might be a reasonable explanation. This was due to logistical constraints to access the players since this work was conducted across a sensitive period during the COVID-19 pandemic. The perception of pain scale used here reflects only a general state of pain and scales to assess local muscle soreness are recommended. Advanced measures of body temperature such as infrared thermography imaging were unavailable rendering unclear the actual physiological impact of COOL treatment over the whole working muscle group. A lack of fine control on the pre-test diet may have also potentially interfered in the results. While the design of Experiment 2 likely minimised the risk of confounders, we were unable to determine whether any residual fatigue existed during the second testing session which may have partly masked some of the potential beneficial effects of the cooling intervention. Finally, when designing the ball kicking task, a choice was made to omit opposition players contesting kicks in an attempt to reduce any potential undesirable inter-trial/condition variability interfering with the treatment effects. Despite increasing experimental control, this approach arguably reduced experimental external validity.

## Conclusions

Intense and consecutive running bouts can impair soccer kicking performance and specifically the ability of players to successfully pass or shoot. The present investigation is the first to show in youth soccer players that a short period of local cooling can be beneficial in reducing losses in kicking performance following intense exercise in hot conditions. Indeed, a five-minute application of two ice packs applied, respectively, to the quadriceps and hamstrings muscles of the kicking limb helped favour recovery represented by players' perception of effort and notably ball placement and to a lesser extent velocity. As such, the major practical implication of this work is that a short period of cryotherapy could play an important role in counteracting potential in-game fatigue-related declines in kicking outputs experienced by youth players following repeated high-intensity running efforts in the heat.

## List of abbreviations

| | |
|---|---|
| a.u. | Arbitrary units |
| BT | Best time |
| CI | Confidence interval |
| CMfoot | Foot centre-of-mass |
| COOL | Cooling |
| CV | Coefficient of variation |
| DEC | Percentage of velocity decay |
| DLT | Direct Linear Transformation |
| EMG | Electromyography |
| FIFA | Fédération Internationale de Football Association |
| FOV | Field-of-view |
| ICC | Intraclass correlation coefficient |
| OSF | Open Science Framework |
| PHV | Peak height velocity |
| RHIR | Repeated high-intensity running |
| RPE | Ratings of perceived exertion |
| TE | Typical error |
| TM | Mean time |
| TT | Total time |
| WHO | World Health Organisation |
| WT | Worst time |

## Data availability statement

The raw data supporting the conclusions of the current manuscript has been made publicly available at https://doi.org/https://doi.org/ (Open Science Framework – OSF).

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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