# Post-drop jumps kick potentiation in youth trained soccer players: temporal changes in EMG, kinematics and performance components

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## ABSTRACT

Scientific studies testing warm-up routines and their effects on subsequent soccer kicking features are restricted to only-stretching based or unloaded resistance, with no information to date on the possible consequences of priming plyometric efforts as the main conditioning activity (CA). Therefore, this study addressed the possible effects of a warm-up intended to cause postactivation performance enhancement (PAPE) based on traditional prescription (low intensity running and dynamic stretching) followed by conditioning repeated drop-jumps. Also, time-course of PAPE expression in kicking indices was determined over five blocks, before (Pre) and after (immediately, 5, 10 and 15 minutes) CA cessation. Fifteen under-17 soccer players (16 ± 1 years; 2 ± 1 year from peak height velocity) kicked stationary

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balls from the entrance of the penalty area aiming at square target positioned in their contralateral goalpost upper corner, in each of the five blocks of assessment. All procedures were conducted on-field in habitual training/match time. Kick attempts were monitored using wireless EMG and concomitant video kinematics to obtain limb motion and performance parameters (ball velocity and placement). Some increases in EMG indices were observed between 5 (rectus femoris activation and median frequency) and 10 minutes (biceps femoris median frequency) after CA. Angular velocity of knee extension in 5 minutes was greater than immediately post. Frequency of missed kicks increased immediately and post-15 minutes. Ball speed and other placement-derived indices remained stable from pre to all post-measures. Kicking ball velocity was correlated with vastus lateralis and rectus femoris EMG (integral and RMS). Ball placement was associated with approach run velocity and biceps femoris activation. To conclude, following a traditional warm-up plus conditioning drop-jumps, PAPE effect was observed only in a restricted number of neuromuscular parameters in under-17 players that are not generally converted into acute harm or benefits to movement mechanics and performance responses. Distinct muscle activity indicators may act as determinants to ball velocity and placement in youth soccer.

## INTRODUCTION

Postactivation performance enhancement (PAPE)-based techniques have been extensively used among strength and conditioning professionals in applied settings via prescription of conditioning activity (CA) generally ranging from separate or combined submaximal running, stretching, resistance and plyometric exercises (9, 10). The PAPE has been defined as a phenomenon by which acute improvements are observed in muscle performance characteristics (e.g. voluntary force production) or athletic outcomes itself as a result of the musculoskeletal system contractile history (9, 11, 45). Mechanisms contributing to PAPE includes muscle temperature, water content and activation while inhibition aspects comprise fatigue, motion pattern and perseveration (9). Inducing PAPE through plyometric CAs prior to explosive criterion tasks can shows superior positive effects or at least similar to traditional warm-up methods (33, 56, 57). In the context of youth soccer, plyometric exercises have been recognised to induce important chronic functional adaptations, including gains in muscle strength and power, endurance capacity, balance and coordination (7, 48, 49) essentials to overall performance in soccer as well as various of these aspects are in particular determinants to technical outputs such as required in ball kicking (28, 58, 70).

Ball kicking movement requires ballistic contractions of the lower limbs (5). As a consequence, adding some load in CAs to attempt induce PAPE in kicks seems reasonable owing to the fact that it favored acute neuromuscular responses and performance in activities of similar etiology, in both professional senior and young players (e.g. jump and running; (51, 64, 72)). In this sense, previous studies in university and professional players (aged ~19–23 years-old) reported that dynamic stretching/resistance CAs using only bodyweight (BW) (1-5, 22, 43) were sufficient to increase kicking performance in soccer (e.g. hip flexion-extension range-of-motion, knee extension angular velocity and ball velocity). Additional work in children revealed benefits to kicking accuracy (21). These results suggest the manifestation of post-stretching kick potentiation mainly due to priming dynamic stretch-based CAs in boys or senior players. However, warm-up routines in soccer are not restricted only to isolated stretching exercises, there is no information to date in youth (teenager) population and of great importance assessment of neuromuscular activity has been also overlooked in kick attempts (51). This indicates that

PAPE mechanisms related to soccer kicking skill lacks scientific support. Furthermore, the experimental studies evaluating PAPE in soccer kicking involved only trials with initial ball position ≤ 11 m from the goalposts, characterised as events with low frequency in real match-play and targets were only centered in the goal plane, which collectively represents kick testing approaches with low external validity (43). To the extent of our knowledge, while long-term training effects of plyometric exercises have been known to be positive (velocity or horizontal distance attained by the ball (12, 49, 53)), the possible acute influence of this mode of CA upon kicking characteristics was never addressed (see for a review in (43)). Notwithstanding, warm-up routines applied to developing players increasingly adopt high-intensity CAs in addition to stretching, based on the assumption that the former can facilitate a PAPE state to a greater degree than traditional methods (62, 64, 72). Yet heavy-loaded CAs generally requires additional load and installations outside the pitch environment, likely implying some associated financial costs and logistic constraints. In addition, they can generate higher immediate fatigue thereby potentially delaying PAPE expression (71). Conversely, those low-intensity ballistic/explosive CAs are possibly preferable in team sports as they are equally capable of causing subsequent recruitment of high-order muscle fibers, evoked force and performance enhancements (16, 33, 37) without the need for specialized external (load) apparatus.

Available studies on PAPE effects in youth still shows conflicting evidence, with acute increases (38), no changes (61) or decreases (18) in motor performance (i.e. running at high-intensity and jumping) have been simultaneously reported. A possible explanation for this discrepancy across studies fell again on the use of an unstandardized intensity across papers (e.g. BW–5RM). Given that youth do not seem to sustain benefits of PAPE to the same magnitude as observed in senior players (32), it is still necessary to clarify whether low-intensity ballistic CAs using own BW (e.g. plyometrics) would be effective to increase kicking performance preparedness in this population, since this mode of exercise originates less muscle by-products which favoured ensuing power performance as compared to heavy-resistance on teenagers soccer players in a preliminary study (57). Most important, to date and regardless of age and CA type no studies determined the temporal expression in terms of kicking performance measures integrating velocity and ball placement analysis given PAPE protocols according to a recent systematic review (43). Determining the time-evolution of criterion task performance following cessation of CA is important to offer knowledge on whether an “optimal” time-moment exist (i.e. when potentiation effects overcome fatigue expression) and how much time intended benefits can persist. Based on such assumptions, the present study aimed to analyse, in youth soccer players, the post-drop jumps kick (unknown) potentiation/depression effects. The time-course of possible changes in neuromuscular, movement kinematics and outcome in soccer kicking after drop-jumps cessation was also determined. Finally, relationships between kicking EMG, kinematics and performance were also examined. The hypothesis was that plyometric-based PAPE protocol would promote positive effects on various kicking components - aiming at a far target - in youth soccer players, by notably enhance muscular readiness and consequent faster movement and ball velocities following 5 minutes of CA termination (33, 56).

# METHOD

## Participants

Sample size calculation was done a priori (software G*Power© 3.1.9.2, Universität Düsseldorf, Germany) based on results of previous experimental studies from Amiri-Khorasani and collaborators (4, 5), considering positive responses in neuromuscular, mechanics and performance of soccer kicking after dynamic conditioning exercises (i.e. increases in RMS of vastus lateralis and rectus femoris, knee angular and ball velocities; effect size ≥ 0.8). Fifteen under-17 trained soccer players (16.3 ± 0.9 years-old; 64.1 ± 11 kg; 172 ± 9 cm; 2.1 ± 0.7 years from peak height velocity), competing at regional/state level composed the sample (statistical power = 80%; $\alpha = 0.05$). Training background of the players consisted in three to four practice sessions per week (including separate resistance tasks for at least 1 year) and one competition game on weekends. The study followed a cross-sectional design with repeated measures of kicking variables (EMG, kinematics and performance) being collected before and after the execution of the selected warm-up PAPE-based intervention. All procedures were approved by the Institutional Ethics Board (approval number CAAE85994318.3.0000.5398). Players and respective guardians were informed of the benefits and risks of the study prior to signing respectively assent and consent forms, confirming participation as a volunteer.

## PAPE protocol

The overall warm-up process lasted approximately 17 minutes across subjects and included three distinct phases: 1) initiation consisting in low-intensity running bout (4 minutes at a 5 km/h pacing) followed by 2) dynamic stretching to the lower limbs (2, 5) and ended with 3) drop-jumps as the main CA prior to performing kicks (14, 16, 37). Velocity of running was controlled using beeps through a pre-defined linear/curvilinear route demarked by cones in the pitch. A dynamic stretching routine was implemented as per previous studies (1-3, 5) and included exercises to stimulate the gastrocnemius, hamstrings, hip extensors, hip flexors, quadriceps and hip adductors. These were performed by the participants in the order stated and alternating between legs within each series. A total of 3 series x 30 s exercising (approximately 15 s in each leg) x 1 cycle of stretch-shortening per second was completed [full description of stretching method available elsewhere (2, 5)]. After finishing stretches, players undertook 5 repetitions of drop jumps with 15 s passive resting intervals between then. In each repetition, the athletes started on top of a box (30 cm height) (47) and were instructed to keep their hands on the waist, step down to the ground and in sequence perform a jump as explosively as possible to attain maximal individual height; notable brake between the descending and ascending phases of drop-jump was not allowed (14, 16, 47).

## Kick testing

To determine kick-derived indices, a field testing protocol adapted from (41) was used here. In short, players were asked to kick stationary balls (PENALTY® company – FIFA-stamped, 5 sized, 430 g, 0.7 atm controlled across the experiment) positioned 18 m apart from the midpoint goal line, using the instep portion of the preferred limb with maximal velocity and aiming at the centre of a hollow iron square (1 m²) target allocated in the contralateral goalpost upper corner. Further details on task constraints (e.g. approach run, justifications and day-to-day reliability) are available elsewhere (41). Three kick attempts (8) interspersed by 40 s rest were given to the players at each of the 5 time-moments they were evaluated. All procedures (warm-up and kick testing) were performed outdoors in an official pitch with natural emerald grass, during the mid-afternoon period of which the participant club generally train/compete.

**Dependent measures**

*EMG*. Monitoring of muscular activity was done using a wireless eletromyographic system (Mini Wave Infinity – COMETA© srl, Bareggio, Italy) with bipolar surface electrodes (Ag/AgCl, circled – 2 cm centre-to-centre) attached to the muscles vastus lateralis, rectus femoris and biceps femoris of the preferred limb (4, 28, 34), in accordance with SENIAM guidelines (http://www.seniam.org). Before electrodes fixation, the skin was shaved, sanded and cleaned with alcohol (70%). The EMG signals were collected with an acquisition frequency set at 1000 Hz, gain of 400 times and a 8–500 Hz bandpass filter (28). Subsequently, the data were treated by a 4th-order Butterworth high-pass filter (cut-off frequency = 20 Hz). Kicking attempts were then cropped considering a time-window of interest lasting from -450 ms to ~impact instant based on the identification of vastus lateralis peak activity recorded (13). Thus, for each attempt/muscle the following dependent measures were extracted: (a) median frequency, being defined as the frequency in which the spectral power is divided into two equal parts after the EMG signal passed through the FFT (Fast Fourier Transform) (65); (b) percentage activation, taking the average normalised time-window values by dividing it to the maximal EMG observed for each muscle in each specific attempt (34); (c) root mean square (RMS) and (d) integral (area under the curve) indexes (4, 6).

*Movement kinematics*. Two digital video cameras (GoPro® model Hero 7, GoPro GmbH, München–Germany) tripod-mounted operating at 240 Hz (1280 x 960 pixel resolution; 1/480 s shutter speed; NTSC and wide field-of-view modes) and synchronized via proprietary remote control were allocated laterally to the initial ball position in order to capture lower limb behaviour and initial ball flight across kick testing. The kick zone was calibrated (3.47 x 3.08 x 1.30 m) using a rigid object resulting in 49 control points. Image sequences were transferred into a laptop computer (Dell Inc., Intel(R) Core™ i7-10510U, Texas–USA) and to automatically obtain time-series position of lower limb keypoints of interest (all derived from the hip, knee, ankle and foot were used), it was applied an updated version of the OpenPose algorithm (42) that showed overall error lower than 35 mm in determining kinematics of soccer kicking of youth-aged players. Combined data from both cameras allowed three-dimensional DLT (Direct Linear Transformation) reconstruction through a custom-built Python 3.8.3 code (Python Software Foundation, Delaware–USA) after radial distortion correction (52). Matrices of position as a function of time were then exported to MATLAB R2019a environment (MathWorks Inc., Natick–USA), linearly extrapolated in 20% after foot-ball impact, treated by a dual filter [Butterworth (cut-off frequency=25 Hz) and rloess (span=0.1)] and then such estimated data following impact was removed from further analysis. Approach run velocity, joint angles in the sagittal plane [and consequent range-of-motion (ROM)], peak knee angular velocity, foot centre-of-mass (CMfoot; obtained from the centroid of ankle, heel and small toe coordinates) linear velocity and leg relative velocity (formally described as CMfoot to knee relative velocity at impact) were computed as described elsewhere in (40, 41).

*Performance parameters*. Ball velocity was taken from its centroid trajectory across the 10 frames following impact with the foot (40), using the image sequences and calibration files as for movement kinematics. The peak ball speed reached among the three trials was then conserved for further analysis. Two additional video cameras having the same model as those above stated, adjusted at 60 Hz sampling frequency (1920 x 1080 pixel resolution and linear field-of-view mode), were tripod-mounted (i) above the goal line in its intersection with penalty area line, to detect the exact moment when the ball entered the goal and (ii) frontally to the goalposts in order to obtain the 2-dimensional position of ball centroid in the DVIDEOW software (52). To provide a calibration frame, goalpost dimensions (7.35 x 2.32 m) and its four extremities were considered as the control points. Thus, for each kick attempt the Euclidean distance between the manually digitised ball centroid and target centre was calculated. This allowed for each time-windows of assessment the subsequent determination of various ball placement measures: mean radial error, bivariate variable error, global accuracy (41, 66, 67), percentage of kicks on-target and the absolute frequency of missed kicks.

## Independent variable

Time of data collection was considered as the independent variable in the present study and included kicking measures taken at baseline (Pre) and immediately, 5, 10 and 15 minutes following the cessation of the drop-jump conditioning activity. These 5-minute epochs were chosen considering that three repeated kick attempts of a same block were interspersed with 40 s intervals and to allow at least 3 minutes for passive resting (41) between the execution of the last kick attempt of a given block and the first one pertaining to the subsequent block, a total of 5 minutes were thereby required.

## Statistical analysis

Normality of the data distribution was checked by the Shapiro-Wilk's test, kurtosis, skewness and visual inspection. To obtain reliability estimates, Pearson product-moment (r) and intraclass correlation coefficients (ICC), typical error (TE) and coefficient of variation (CV) were calculated (https://sportsci.org/resource/stats/xrely.xls). For those variables normally distributed, values are presented as mean ± standard deviation. One-way ANOVA with repeated-measures was ran to evaluate the time-course expression (Pre, Post, 5, 10 and 15 minutes) of kicking-derived variables. Fisher's LSD post-hoc was applied for pairwise comparisons. Effect sizes were calculated as the $\eta^2$ ($\eta^2 > 0.01$, small; $\eta^2 > 0.06$, moderate; and $\eta^2 > 0.14$, large) and Cohen's d ($d > 0.20$, small; $d > 0.50$, moderate; and $d > 0.80$, large) respectively for main effects and pairwise analysis. When normality assumption was violated and logarithmic transformation did not resolved, variables are described as median and interquartile range; Friedman's test was used to evaluate possible time-course changes, accompanied with Dunn's post-hoc test. In this case, effect size for testing main effect was obtained by the Kendall's W value ($W > 0.10$, small; $W > 0.30$, moderate and $W \geq 0.50$, large). Spearman's rank-order correlation coefficients (rho) were computed between EMG, kinematics and performance variables derived from soccer kick attempts. GraphPad Prism version 8.2.1 was used (GraphPad Software Inc., San Diego–USA) and the level of statistical significance was pre-set at $p \leq 0.05$.

## Results

### Overview and reliability

Table 1 shows overall mean and standard deviation values for all collected parameters. Reliability measures computed between repeated kick attempts for EMG, kinematics and performance metrics are also displayed. In general, apart from RMS of the biceps femoris having poor reliability (ICC = 0.49 [0.26; 0.72]; p = 0.04), EMG parameters showed moderate (biceps femoris percentage activation; ICC = 0.50 [0.28; 0.72]; p < 0.001) to good (median frequency of the vastus lateralis; ICC = 0.82 [0.69; 0.91]; p < 0.001) reliability. CVs ranged from 5.45% (percentage activation of the biceps femoris) to 110.69% (integral of the rectus femoris). Lower limb kinematics demonstrated moderate (ROM ankle; ICC = 0.54 [0.33; 0.75]; p < 0.001) to excellent reliability (CMfoot velocity; ICC = 0.97 [0.94; 0.99]; p < 0.001). There was only one exception of approach run velocity that showed poor reliability (ICC = 0.20 [0.01; 0.47]; p = 0.003). CMfoot velocity showed the lowest CV (4.78%) whilst ROM ankle presented the highest (36.24%). All performance measures related to ball placement in the goal also showed poor reliability with high CVs (e.g. bivariate variable error; ICC = -0.05 [-0.17; 0.16]; p = 0.19; CV = 35.79%) while peak ball speed had a good reliability (ICC = 0.88 [0.79; 0.94]; p < 0.001; CV = 3.12%).

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### Time-course of changes in kicking characteristics

*EMG*. Temporal dynamics of muscle activation-derived indices are presented in the Figure 1. RM ANOVA indicated a large main time effect for the median frequency of the biceps femoris (F(4, 56) = 3.675; p = 0.01; $\eta^2 = 0.208$; Figure 1(C)). Post hoc analysis indicated that biceps femoris median frequency values peaked at 10 minutes as compared to Pre (percentage, mean absolute difference [CI lower; upper] = +21.18%, 12.87 Hz [0.74; 24.99]; p = 0.04; d = 0.41 [moderate]), Post (+35.78%, 21.74 Hz [9.62; 33.86]; p < 0.001; d = 0.73 [large]) and 5 minutes (+29.28%, 17.79 Hz [5.67; 29.91]; p < 0.01; d = 0.60 [moderate]) time-windows. No main time effects were observed, for any muscle, concerning integral (Figure 1 (D)–(F)) and RMS parameters (Supplementary online Figure 1). RM ANOVAs also revealed moderate non-significant main time effects concerning the rectus femoris median frequency (F(4, 56) = 1.669; p = 0.17; $\eta^2 = 0.107$), percentage activation of rectus femoris (F(4, 56) = 1.813; p = 0.14; $\eta^2 = 0.115$) and biceps femoris (F(4, 56) = 1.833; p = 0.14; $\eta^2 = 0.116$) despite some significant pairwise differences were noted for such three latter indicators. In particular, percentage activation of rectus femoris (Figure 1(H)) at 5 minutes period significantly demonstrated moderately superior levels as compared to both Pre (+5.05% [0.75; 9.35]; p = 0.02; d = 0.51) and 15 minutes (+4.87% [0.57; 9.16]; p = 0.03; d = 0.51) time-windows. Rectus femoris median frequency moderately declined in the 15 minutes instant compared to the 5 minutes time-moment (-28.91%, -10.60 Hz [-20.56; -0.63]; p = 0.04; d = 0.53; Figure 1(B)). Finally, percentage activation of biceps femoris were moderately higher in the 10 minutes (+4.19% [0.68; 7.69]; p = 0.02; d = 0.34) and 15 minutes (+3.93% [0.43; 7.43]; p = 0.03; d = 0.53) as compared with the Pre moment (Figure 1(I)).

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*Lower limb kinematics*. Figure 2 contains the results of the lower kicking limb kinematics parameters considered across the various time-windows. ANOVAs or Friedman's test revealed small-to-moderate non-significant main time effects for all variables in this category ($p = 0.16–0.94$; $\eta^2 = 0.014–0.111$). For example CMfoot velocity ($F(4, 56) = 0.8742$; $p = 0.49$; $\eta^2 = 0.059$ [small]; Figure 2(A)), CMfoot to knee relative velocity ($F(4, 56) = 0.1965$; $p = 0.94$; $\eta^2 = 0.014$ [small]; Figure 2(C)) and ROM ankle ($F(4, 56) = 0.445$; $p = 0.78$; $\eta^2 = 0.030$ [small]; Figure 2(G)) remained stable over time, from Pre to 15 minutes instant. Knee angular velocity also had moderate non-significant main time effects in the ANOVA ($F(4, 56) = 1.293$ $p = 0.28$; $\eta^2 = 0.085$; Figure 2(E)) accompanied by one post-hoc difference. Specifically, knee angular velocity at 5 minutes was moderately faster as compared to the Post moment (+13.79%, 0.07 rad/s [0.01; 0.14]; $p = 0.03$; $d = 0.36$).

**<<< Please insert Figure 2 near here >>>**

*Performance measures*. Kicking performance indices according to each temporal moment of assessment, before and after the PAPE protocol, are reported in the Figure 3. Friedman's test detected a small significant main time effect for the frequency of missed kicks ($X^2(4) = 12.40$; $p = 0.01$; $W = 0.207$; Figure 3(E)). Pairwise comparisons indicated that there were largely more missed kicks immediately Post (+62.14%, 0.87 a.u. [0.32; 1.42]; $p = 0.01$; $d = 1.07$) and at 15 minutes time-windows (+47.86%, 0.67 a.u. [0.12; 1.21]; $p = 0.01$; $d = 0.83$) when compared to Pre values. No other significant main time effects were found ($p = 0.41–0.76$), generally accompanied with small effect sizes (e.g. ball placement-derived indices excepting missed kicks; $W = 0.031–0.066$). Examples include the stability across the time regarding the peak ball speed ($F(4, 55) = 0.689$; $p = 0.60$; $\eta^2 = 0.101$ [moderate]; Figure 3(F)) and mean radial error ($X^2(4) = 1.867$; $p = 0.76$; $W = 0.031$ [small]; Figure 3(A)).

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## Associations between EMG, kinematics and performance

Figure 4 is an overview of the magnitudes of relationships tested between all kicking-derived measures (EMG, kinematics and performance) computed in the present study. In particular, approach run velocity was related to mean radial error (rho = 0.23 [0.01; 0.44]; $p = 0.053$) and accuracy (rho = 0.28 [0.05; 0.49]; $p = 0.01$). Frequency of missed kicks was significantly correlated with both ROM hip (rho = 0.26 [0.03; 0.47]; $p = 0.02$) and percentage activation of biceps femoris (rho = 0.27 [0.04; 0.48]; $p = 0.02$). Significant relationships were also observed between peak ball velocity and integral (rho = 0.25 [0.01; 0.47]; $p = 0.049$ and rho = 0.40 [0.15; 0.60]; $p < 0.01$) and RMS (rho = 0.27 [0.02; 0.48]; $p = 0.03$ and rho = 0.43 [0.18; 0.62]; $p = 0.001$) of the vastus lateralis and rectus femoris muscles, respectively. Finally, both median frequency (rho = 0.39–0.51; $p \leq 0.01$ and rho = 0.28–0.49; $p \leq 0.02$) and percentage of activation (rho = 0.28–0.40; $p \leq 0.01$ and rho = 0.39–0.60; $p \leq 0.001$, respectively) of the vastus lateralis and rectus femoris muscles were significantly related to all kinematics parameters computed.

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# Discussion

The objective of the current investigation was to verify the consequences, in youth academy players, the post-drop jumps kick (unknown) potentiation/depression effects. Also, the time-course of possible changes induced by this pre-kick exercise was assessed in reference to neuromuscular, movement and performance (ball placement and velocity) characteristics, immediately after CA cessation until 15 minutes of relative resting. A secondary goal was to explore the possible associations between EMG, kinematics and performance outputs concomitantly collected in kick attempts made from the entrance of penalty area. According to our results, the PAPE protocol based on low-intensity running followed by dynamic stretching plus five drop jumps induced some increases in muscle activity parameters. In particular, these notably occurred 5 minutes (rectus femoris percentage activation and median frequency) up to 10 minutes (biceps femoris median frequency) following CA termination. On the other hand, evidence of post-drop jumps benefits in mechanical features and performance of soccer kicking were both limited. There was only a transient increase in angular velocity of knee extension in 5 minutes while no significant changes happened in ball speed from pre to post-15 minutes. Of note, frequency of missed kicks increased immediately following PAPE and in the last window of assessment. Significant associations were observed amongst kicking movement and ball velocity with distinct EMG parameters derived from the vastus lateralis/rectus femoris (median frequency/percentage activation and integral/RMS, respectively) while ball placement was influenced by the approach run velocity/biceps femoris percentage activation. Below we will discuss the post-drop jumps effects on neuromuscular, kinematics and performance aspects of kicking in the youth sample, that are more evident in the former than in the latter. Explanations to neuro-mechanics-outcome relationships found are also provided.

Including plyometric exercise as drop jumps following a traditional dynamic warm-up routine demonstrated a few benefits to neuromuscular responses during kick actions in youth soccer players. These were observed in rectus femoris and biceps femoris muscles (e.g. median frequencies for both cases and percentage activation in the former). In addition, the peaks in these parameters occurred roughly 5–10 minutes after performing the selected CA. Comparing our results to literature, EMG was slightly lower than college/amateur young adults [RMS of the vastus lateralis: 0.28–0.36 mV (4); rectus femoris percentage activation: 50.9–85.4% (34)] while performance is compatible to data in high-level youth under-16-17s [ball velocity: ~18.41–28.74 m/s (8); successful kicks: 9.52–10.48% (44)]. In reference to neuromuscular responses after protocol intended into potentiate performance, if increases in arousal levels of players and/or in net motoneuron output occurred after warming-up, these may have reflected in increased muscle excitability detected (9). Drop-jumps indeed were shown previously to improve muscle electrical activity responses in explosive (sprint) activities (37, 71). In particular, we observed most frequent increase in median frequency components of EMG signal than in the other parameters computed. It is something that can provide evidence indicating the present PAPE plyometrics protocol caused modifications in quadriceps/hamstrings muscles during kick attempts mainly in the firing rate of motor units (65). As regarding the duration of neuromuscular (limited) effects observed, which lasted here from 5 up to 10 minutes following drop jumps, despite partly in agreement to ranges supported in existing meta-analyses (19, 59, 69), this time-frame is shorter than the typical interval separating the end of a warm-up and performance in the real-world (63) thereby implying that a post/re-warm-up practice (24, 59, 68) could be necessary when plyometric mode of pre-pitch entry exercise are prescribed in youth soccer. Thus, the effectiveness of performing drop jumps aiming at acutely improve subsequent kicking skill in developing players is not warranted given the scanty/transient task-related muscle activity improvements found.

Aside from the enhancements encountered in some EMG features as above mentioned, kick mechanics and performance such as ball velocity was almost unchanged post-drop jumps. There are three possible explanations to these unexpected findings; two based on previous work and one supported by our experiment data (i.e. EMG-performance relationships). Firstly, drop jumps were not always beneficial in scientific publications to subsequent performance as some demonstrated that its effects in explosive actions can be very short (≤ 2 min) (14) or adding no additional benefits as compared to using only dynamic warm-up exercises in youth engaged in after-school soccer practice (20). Despite in adult athletes drop-jumps was probed to induce both PAP/PAPE (16), recently in the context of female youth soccer, contractile responses indicative of PAP following CAs were also not translated to players lower limb power performance (46). Here only one exception existed in reference to a faster knee extension angular velocity at 5 minutes time-window and this may be attributed in part to increases in muscle (i.e. rectus femoris) electrical activity. Second, under-17 players are recognised to have not yet a mature kick movement pattern. By this age, players are still developing kinematics features associated to a proficient kick motion. This is evidenced in comparisons with the nearest older age-group under-20, which in turn presents skilled behaviour compatible to senior players (40, 66). Thus, in addition to the notion that teenagers appear not able to sustain PAPE effects as concerning power-dependent tasks given the reduced number/training status of type-II muscle fibers (23, 32, 36), their possible ongoing kick technique refinements may have influenced on the utilization of a few benefits (e.g. those neuromuscular) provided by traditional warm-up plus conditioning drop jumps.

To appraise the temporally unchanged ball velocity output, there is a third and most plausible reason considering solely the data gathered in the current investigation. According to the correlation analysis, movement characteristics were related to EMG median frequency. Ball velocity showed no significant correlations with this parameter, instead demonstrated associations to RMS and integral recorded in the two selected quadriceps muscles (Figure 4). In fact, weak correlations were also observed between high-density EMG median frequency of tibialis anterior muscle and associated force output (17). While median frequency of EMG signal notably reflects the velocity of electrical input transmission (60), RMS and integral components prominently represents mainly the amplitude of neural discharges (6). As a consequence, we provide preliminary evidence that kicking ball velocity in youth soccer players is more dependent upon the intensity rather than velocity of the electric signal propagation. Even owing to the fact that CMfoot velocity was also directly influence here by the median frequencies of quadriceps contraction during kick attempts, and distal end-point kinematics has been demonstrated as the most important parameter to subsequent ball flight characteristics (e.g. strong foot-ball velocity relationships regardless of age) (27, 39, 70) our data illustrate that it seems necessary an optimal magnitude of muscle activation levels (kinetics) to sustain transmission of momentum from foot to ball at impact instant and thus assist development of high ball velocity instead of solely movement velocity (kinematics). Hence, post-drop jump soccer kicking potentiation was purely neuromuscular in the present youth population, being little translated into mechanical and performance enhancements in developing under-17 players. This is due to the drop-jumps likely improved motor unit firing rates but not the amplitude of muscle activity, and this is an emergent aspect determinant to obtain faster ball velocity in youth soccer.

It is noteworthy that the absolute frequency of missed kicks (i.e. outside goalposts) significantly raised immediately after the cessation of CA as well as following 15 minutes. This indicates that drop jumps possibly induced youth players into a temporary state of fatigue right after the CA repetitions, then the number of missed kicks decreased (5 to 10 minutes) and worsened latter again. Indeed, simultaneous expression of potentiation and fatigue can coexist at a certain time-windows following CA (10, 25, 50), and this relation is time-dependent but not in a linear form (roughly U-shaped); PAPE effects are generally depressed right after CAs (i.e. augmented transient fatigue; (30)) and could dissipate following long lasting rest intervals (55). Notwithstanding, soccer kick is also often difficult to be fully predicted given its highly variable nature either in official competition matches or even using controlled testing conditions (8, 31, 67) that would render analysis of 'true' intervention effects uncertain, i.e. casting doubts on whether an observed kicking output across time-moments is result of PAPE protocol or undesired/involuntary adjustments in players motor behaviour occur across kick attempts even with standardised instructions. It is illustrated by various components of kicking including EMG (integral in all muscles, biceps and rectus femoris RMS), kinematics (approach run velocity and ROM ankle) and performance (all ball placement-derived indices) showing large CVs exceeding 30% (15).

Several additional limitations are recognised to the present findings. This includes the fact that, due to logistics, a fixed drop jump height was used while individualised drop box based on highest player reactive strength index maximize performance gains in youth soccer players (47). Despite well documented practical limitations to compute advanced kick features under match conditions (43), environmental constraints such as distance to the nearest opposition player, sight of goal and offensive pitch zone influences on kicking effectiveness (54) thus potentially limiting transference of our findings to actual game-play. Furthermore, even that influence of playing position on kicking performance observed in senior is less evident in youth soccer (29, 35), future analysis of PAPE effects according to positional role are warranted. To increase external validity, including specific ubiquitous exercises into the warm-up routine prior to measuring performance (e.g. small-sided games) are also recommended to future research (43). Finally, using other sampling windows (e.g. assessments interspaced by 2 minutes) could be pertinent to fully depict temporal changes in kicking performance while reduces the time that players keep resting passively.

## Conclusion

In youth under-17 players, a traditional warm-up routine consisting in low-intensity running followed dynamic stretching exercises in addition to five repetition drop jumps may immediately impair targeting ability in kick attempts made from the entrance of penalty area whilst a long period of relative inactive (15 minutes) also had similar effect. The best window at which neuromuscular functioning (firing rate or electric signal propagation velocity but not amplitude) improves slightly falls into 5 until 10 minutes after conditioning activity termination. Considering the limited transference of such transient gains in muscle activity to mechanical and performance outputs related to kicking ability, prescription of dynamic stretches plus drop-jumps with primary intention to cause PAPE in this skill is therefore questionable in developing teenagers. Kicking velocity in youth soccer players was demonstrated at first time to be dependent upon amplitude of intrinsic muscle contractions parameters rather than being strictly related to firing rate/velocity of electrical discharge. A robust inverse linear relationship exists between ball velocity and chance of a goalkeeper block the shot (26). Thus, while this was not the case in the protocol analysed here, priming exercises that promote substantial increases in amplitude characteristics of quadriceps EMG signal are of particular interest to obtain faster kicks which in turn are linked to a greater likelihood of success.

## Contributions

Contributed to conception and design: LHPV, AMZ, CAKF, FAB
Contributed to acquisition of data: LHPV, CAKF, VCM, FBS, JPS
Contributed to analysis and interpretation of data: LHPV, AMZ, CAKF, JPS, PRPS, STR, FAB
Drafted and/or revised the article: LHPV, AMZ, CAKF, VCM, FBS, JPS, PRPS, STR, FAB
Approved the submitted version for publication: LHPV, AMZ, CAKF, VCM, FBS, JPS, PRPS, STR, FAB

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## Data and Supplementary Material Accessibility

The raw data spreadsheets underlying the findings presented in the current manuscript can be found in https://osf.io/aqvy7/ .

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**Table 1.** Reliability measures across repeated attempts for muscle activity, kinematics and performance parameters all obtained from kicking (n = 15).

| | **Overall mean ± SD** | **r (90% CI)** | **ICC (90% CI)** | **TE (90% CI)** | **CV (%)** |
|---|---|---|---|---|---|
| *EMG* | | | | | |
| Fmed – VL (Hz) | 45.49 ± 30.74 | 0.81 (0.53 – 0.91) | 0.82*** (0.69 – 0.91) | 14.21 (12.19 – 17.45) | 22.67 |
| Fmed – RF (Hz) | 30.89 ± 19.19 | 0.59 (0.20 – 0.82) | 0.56*** (0.35 – 0.76) | 13.25 (11.37 – 16.27) | 21.32 |
| Fmed – BF (Hz) | 47.87 ± 28.47 | 0.66 (0.33 – 0.86) | 0.65*** (0.45 – 0.82) | 17.55 (15.07 – 21.56) | 23.30 |
| Integral – VL (µV/s) | 189.00 ± 202.46 | 0.76 (0.41 – 0.91) | 0.76*** (0.59 – 0.89) | 104.62 (87.41 – 133.52) | 55.36 |
| Integral – RF (µV/s) | 48.72 ± 51.00 | 0.63 (0.25 – 0.89) | 0.68* (0.46 – 0.84) | 30.33 (25.36 – 39.02) | 110.69 |
| Integral – BF (µV/s) | 37.36 ± 27.78 | 0.69 (0.20 – 0.75) | 0.60** (0.39 – 0.79) | 18.78 (16.03 – 23.37) | 57.80 |
| RMS – VL (mV) | 0.21 ± 0.17 | 0.75 (0.41 – 0.90) | 0.64*** (0.42 – 0.82) | 0.11 (0.09 – 0.14) | 30.48 |
| RMS – RF (mV) | 0.19 ± 0.20 | 0.76 (0.41 – 0.91) | 0.76* (0.59 – 0.89) | 0.10 (0.09 – 0.13) | 104.64 |
| RMS – BF (mV) | 0.14 ± 0.12 | 0.49 (-0.10 – 0.72) | 0.49* (0.26 – 0.72) | 0.09 (0.08 – 0.11) | 81.85 |
| Activation – VL (%) | 84.92 ± 9.95 | 0.83 (0.64 – 0.94) | 0.80*** (0.66 – 0.90) | 4.83 (4.14 – 5.93) | 5.45 |
| Activation – RF (%) | 79.20 ± 9.97 | 0.70 (0.31 – 0.85) | 0.70*** (0.53 – 0.85) | 5.77 (4.95 – 7.08) | 6.63 |
| Activation – BF (%) | 83.12 ± 6.90 | 0.47 (0.08 – 0.76) | 0.50*** (0.28 – 0.72) | 5.06 (4.34 – 6.22) | 5.90 |
| *Kinematics* | | | | | |
| $CM_{foot}$ vel (m/s) | 18.81 ± 6.13 | 0.97 (0.91 – 0.99) | 0.97*** (0.94 – 0.99) | 1.20 (1.03 – 1.48) | 4.78 |
| Foot/ball speed ratio (a.u.) | 1.36 ± 0.23 | 0.89 (0.70 – 0.96) | 0.83*** (0.68 – 0.93) | 0.11 (0.09 – 0.14) | 8.68 |
| Leg relative vel (m/s) | 16.63 ± 3.68 | 0.77 (0.49 – 0.90) | 0.78*** (0.63 – 0.89) | 1.88 (1.61 – 2.31) | 8.77 |
| Approach run vel (m/s) | 2.69 ± 1.13 | 0.60 (0.22 – 0.82) | 0.20** (0.01 – 0.47) | 1.03 (0.88 – 1.26) | 31.93 |
| Peak knee ang vel (rad/s) | 0.54 ± 0.21 | 0.87 (0.73 – 0.95) | 0.85*** (0.73 – 0.93) | 0.09 (0.08 – 0.11) | 11.67 |
| ROM hip (rad) | 1.26 ± 0.52 | 0.97 (0.93 – 0.99) | 0.97*** (0.95 – 0.99) | 0.10 (0.09 – 0.12) | 6.39 |
| ROM knee (rad) | 1.54 ± 0.45 | 0.96 (0.90 – 0.98) | 0.96*** (0.92 – 0.98) | 0.10 (0.09 – 0.13) | 5.46 |
| ROM ankle (rad) | 1.07 ± 0.47 | 0.55 (0.10 – 0.78) | 0.54*** (0.33 – 0.75) | 0.34 (0.29 – 0.42) | 36.24 |
| *Performance* | | | | | |
| MRE (m) | 1.93 ± 1.03 | 0.24 (-0.27 – 0.60) | 0.13** (-0.04 – 0.40) | 0.98 (0.84 – 1.21) | 50.64 |
| BVE (m) | 2.04 ± 1.25 | -0.12 (-0.45 – 0.42) | -0.05 (-0.17 – 0.16) | 1.30 (1.11 – 1.60) | 35.79 |
| ACCUR (m) | 2.90 ± 1.44 | 0.12 (-0.31 – 0.56) | 0.15** (-0.03 – 0.42) | 1.37 (1.16 – 1.67) | 33.09 |
| Kicks on-target (%) | 10.59 ± 18.62 | -0.04 (-0.43 – 0.44) | -0.08 (-0.18 – 0.13) | 19.19 (16.35 – 23.72) | 57.58 |

| | | | | | |
|---|---|---|---|---|---|
| Missed kicks (a.u.) | 1.83 ± 0.83 | -0.05 (-0.46 – 0.37) | -0.03 (-0.15 – 0.20) | 0.79 (0.68 – 0.97) | 79.28 |
| Peak ball speed (m/s) | 28.75 ± 2.72 | 0.89 (0.67 – 0.94) | 0.88*** (0.79 – 0.94) | 1.03 (0.88 – 1.26) | 3.12 |

Note: VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; Fmed, median frequency; RMS, root-mean-square; vel, velocity; ang, angular; MRE, mean radial error; BE, bivariate variable error; ACCUR, accuracy; CI, confidence interval; Pearson product-moment correlation (r), intraclass correlation coefficient (ICC), coefficient of variation (CV) and typical error (TE). Overall data is representative of all blocks of assessment while reliability measures were calculated using data from the first block of kick attempts. * $p \leq 0.05$; ** $p < 0.01$; *** $p < 0.001$.

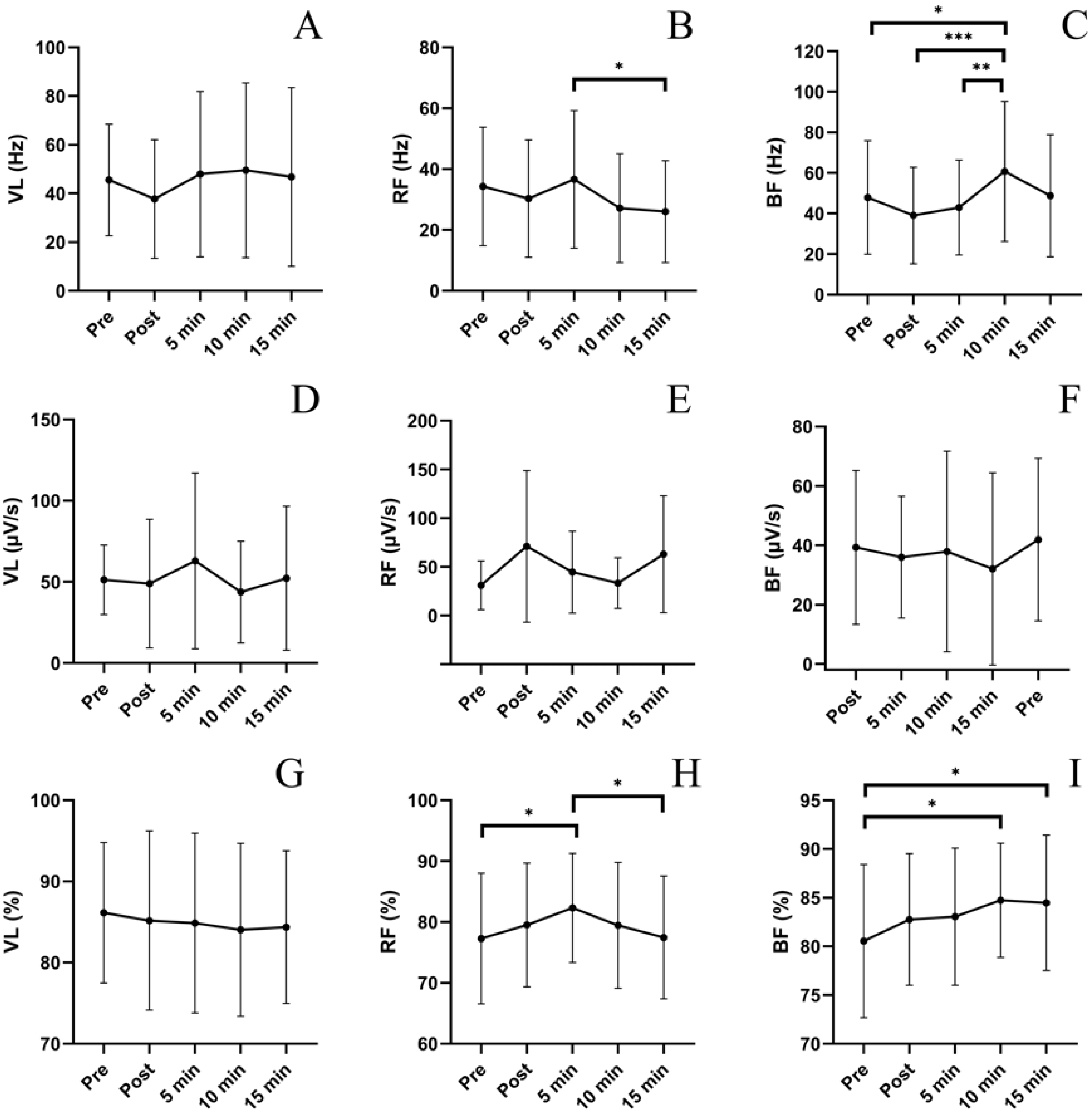


**Figure 1.** EMG indices observed at each time-window of data collection, containing median frequency (top row), integral (middle row) and percentage activation (bottom row) for the vastus lateralis (VL, left column), rectus femoris (RF, middle column) and biceps femoris (BF, right column) muscles of the lower kicking limb. Statistical significance level denoted as: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

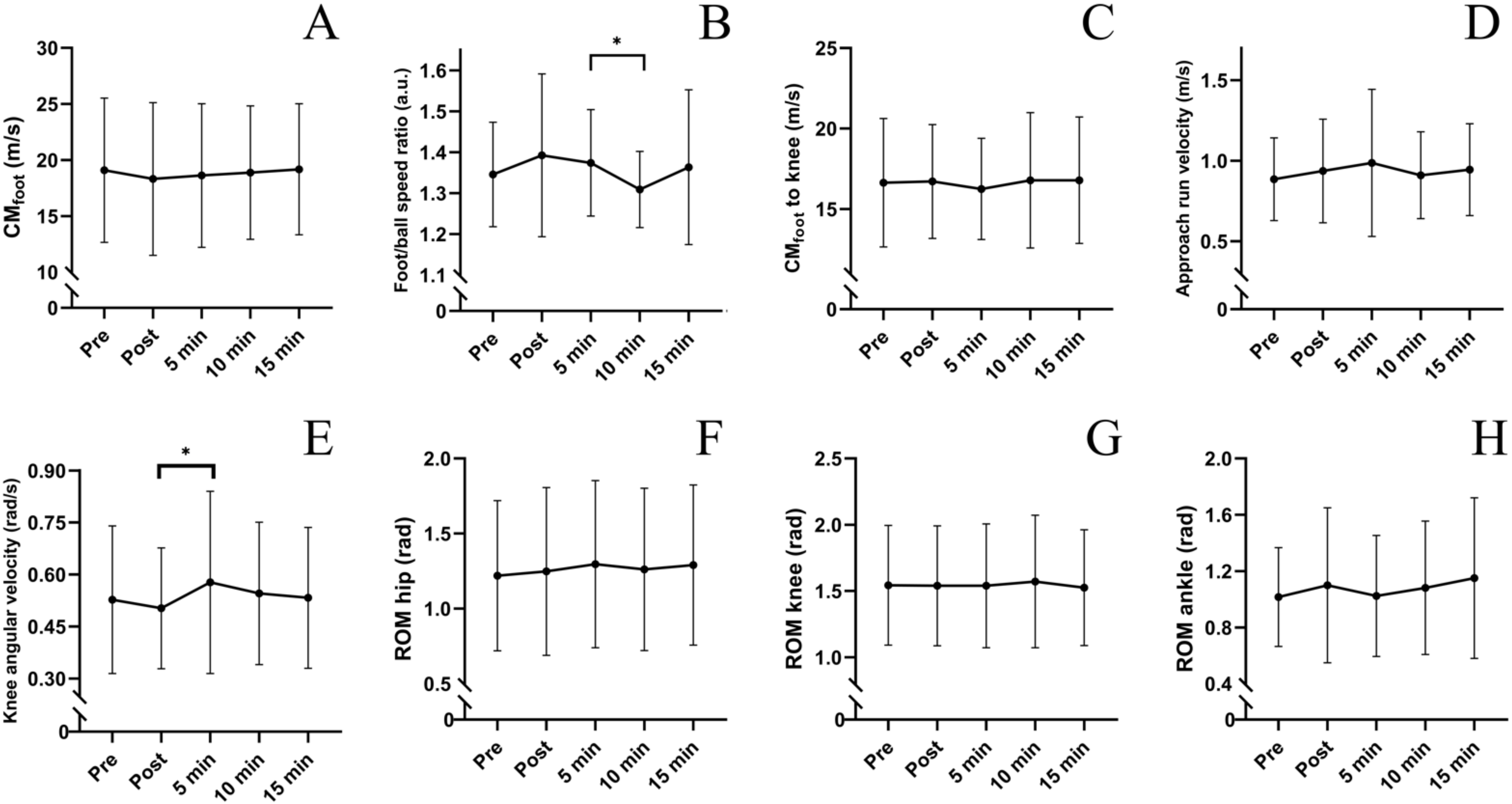


**Figure 2.** Kinematics of the lower kicking limb observed at each time-window of data collection. Statistical significance level denoted as: * $p < 0.05$.

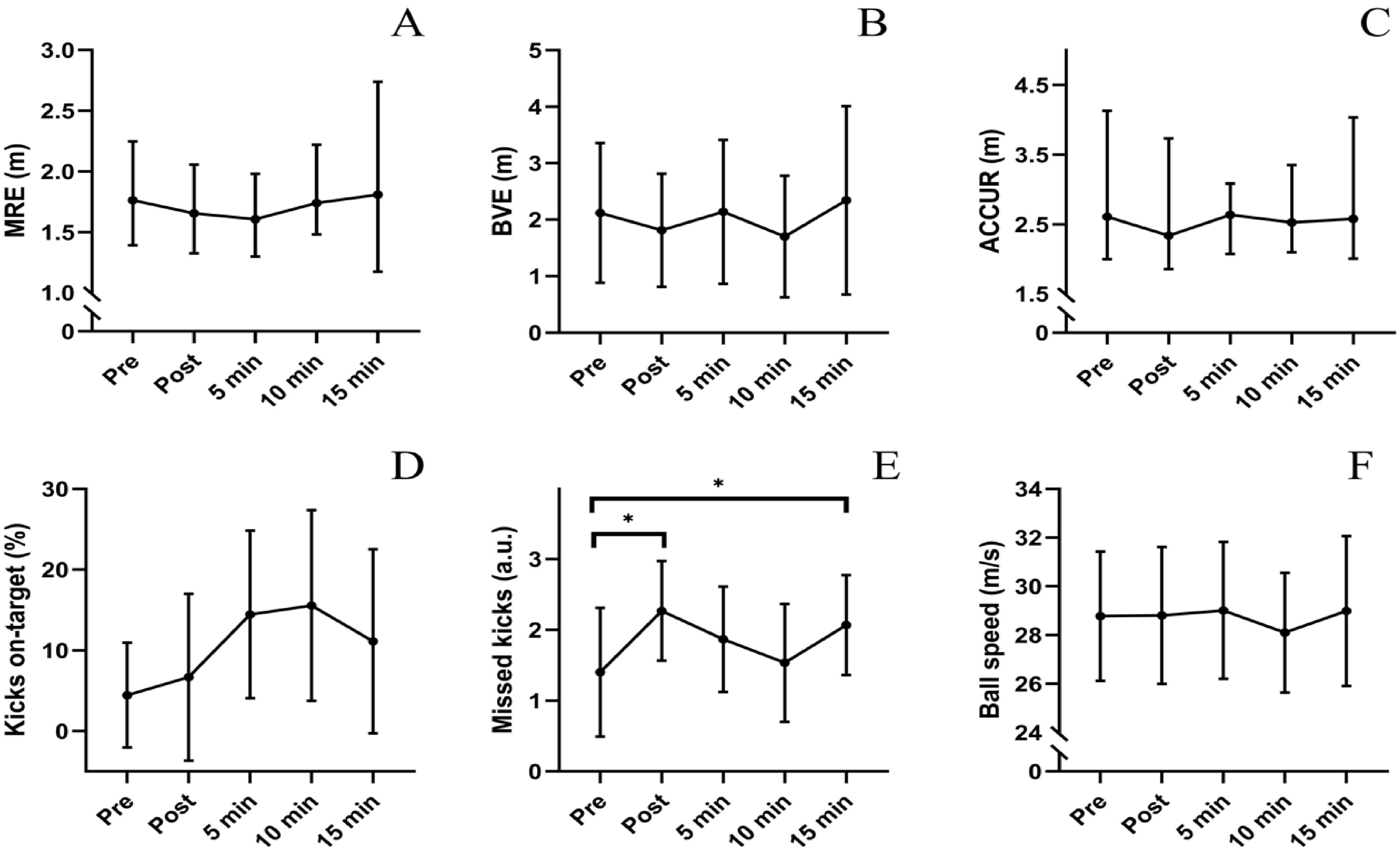


**Figure 3.** Kicking performance components observed at each time-window of data collection. Statistical significance level denoted as: * $p < 0.05$.

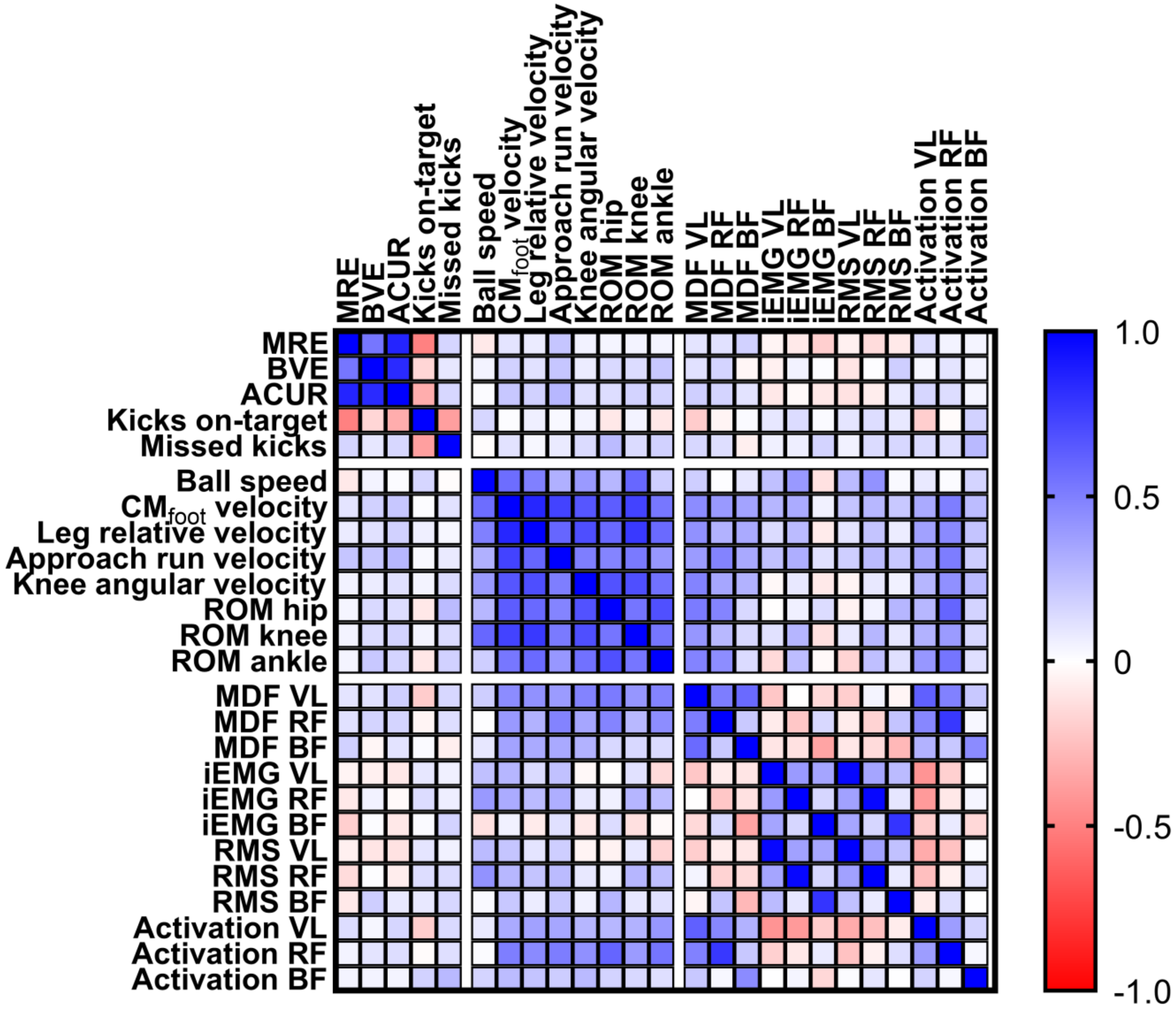
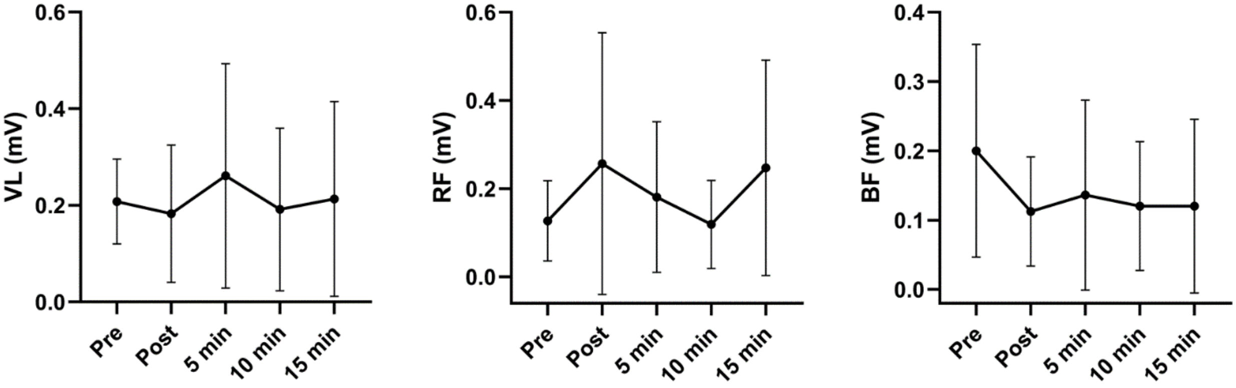


**Figure 4.** Spearman's rank-order correlations observed among EMG, kinematics and performance indices all concomitantly obtained from kicking. Note: MRE, mean radial error; BVE, bivariate variable error; ACUR, accuracy; $CM_{foot}$, foot centre of mass; ROM, range-of-motion; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; MDF, median frequency; iEMG, integral; RMS, root-mean-square.



**Supplementary online Figure 1.** EMG RMS for the vastus lateralis (VL, left), rectus femoris (RF, middle) and biceps femoris (BF, right) muscles of the lower kicking limb.