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Penalty feet positioning rule modification and laterality effect on soccer goalkeepers' diving kinematics

Rafael Luiz Martins Monteiro[1,2], Bruno Luiz Souza Bedo[2], Pedro Henrique Martins Monteiro[3], Felipe dos Santos Pinto de Andrade[1], Felipe Arruda Moura[4], Sergio Augusto Cunha[5], Ricardo da Silva Torres[6], and Paulo Roberto Pereira Santiago[1,2,*]

[1]Biomechanics and Motor Control Laboratory, School of Physical Education and Sport of Ribeirão Preto, University of São Paulo (USP), Ribeirão Preto, 14040-907, Brazil
[2]Program in Rehabilitation and Functional Performance, Ribeirão Preto Medical School, University of São Paulo (USP), Ribeirão Preto, 14049-900, Brazil
[3]Human Motor Systems Laboratory, School of Physical Education and Sport, University of São Paulo (USP), São Paulo, 05508-030, Brazil
[4]Laboratory of Applied Biomechanics, Department of Sport Sciences, Centre of Physical Education and Sport, State University of Londrina, Londrina, 86057-970, Brazil.
[5]Department of Sport Sciences, University of Campinas, Campinas, Brazil.
[6]Department of ICT and Natural Sciences, NTNU – Norwegian University of Science and Technology, Aalesund, Norway
[*]paulosantiago@usp.br

ABSTRACT

In 2019, a new rule was applied in soccer. It allows the goalkeeper to have only one foot or part of it on the goal line when the kicker hits the ball, unlike the previous rule that the goalkeeper should have both feet on the line. The purpose of the present study was to analyze how the change in the rule and the lower limbs laterality influences the dive performance. Six specialized goalkeepers participated in the research. They performed a total of 20 dives in the laboratory and had their force and impulse manifested by the lower limb and displacement/velocity data from the center of body mass collected through kinematic analysis. The side preference was collected through an inventory. The results showed that goalkeepers dive further ($p < 0.001$) and faster ($p < 0.001$) with the change of the rule. The lateral preference influenced only the mediolateral ($p = 0.02$) and resultant ($p = 0.03$) displacements, the highest values were found for the non-dominant lower limb side. Concluding, the goalkeepers performed better with the new rule in the analyzed variables and the lower limb preference has influenced only the mediolateral and resultant displacement.

Introduction

About 26% of the goals scored result from set play (corner kick, direct free kick, free kick assist, penalty kick, and throw- in assist) representing a little more than one-quarter of the total[1,2]. Other studies found that 32.6% of the goals in the 2006 World Cup came from set play, reaching near a third of the total scored in the championship[3]. The penalty represents 25 to 40% of the set play goals[1,4], not being the one that changes the scoreboard the most. However, it is the one with the highest conversion rate, reaching about 73%[5], which shows how it is decisive in determining the winner of matches and championships.

On March 13, 2019, the International Football Association Board (IFAB) officialized a series of changes in soccer rules, with the application starting on June 1, 2019. Among the changes, a new goalkeeper's feet positioning rule was determined in the penalty. In the old rule (OR), the goalkeeper must keep the feet on the goal line until the kicker hits the ball. In contrast, in the new rule (law 14 of the document "Laws of the game 2019/20 changes and clarifications"[6]) (NR), the goalkeeper may keep only part of one foot on the goal line at the moment the kicker hits the ball. This rule change demands research to verify its impact on the goalkeeper's diving kinematics in defense of the goal in penalty kicks.

Different studies have investigated the goalkeeper's position, among them physiological and neurophysiological ones, which explored the specificity of the goalkeeper's training[7], their training load and subjective perception[8], the use of neurofeedback to improve performance[9], besides the necessity of specific training for each athlete[10]. Also, an association between ball's and goalkeeper's velocity on the penalty concluded that goalkeepers must anticipate to reach the majority of balls in the corners of the goal[11].

Studies of the goalkeeper's visual dynamics have attested that for successful anticipation, a kick direction prediction is necessary[12]. In the biomechanics area, the subject has already been explored as well. A study investigated six elite goalkeepers' penalty diving save and concluded that the thorax and pelvis movements caused the asymmetries between the diving sides[13]. The relation between laterality and performance in the goalkeeper's dive has already been investigated, too, attesting that the non-preferred side had a bigger variability on the consecutive dives compared to the preferred side[14]. Other studies with goalkeeper's kinematic analysis concluded that the contralateral lower limb has a more significant contribution to mediolateral velocity, and the preparatory position is important for determining the dive performance[15,16].

In summary, several studies have investigated the goalkeeper's training for the defender to succeed in their function on decisive moments as the penalty. Due to the change of rule and considering the current literature state, researchers must understand how this change will affect the kinematics of the goalkeeper's dive in the penalty, which can help coaches and athletes in the training process, knowing if it is worth exploring the new rule diving movement. Therefore, the present study aimed to analyze the goalkeeper's dive in soccer penalties, comparing the goalkeeper's feet positioning rules and laterality effect in the performance. Our initial hypotheses were that (1) the NR trials would present greater values in most variables; (2) there would be no laterality effects on the dive variables.

Methods

Participants

Six soccer goalkeepers (23.68 ± 3.81 years; 81.6 ± 13.02 kg; 1.85 ± 0.05 m) with 15 ± 4.32 years of experience as a goalkeeper, besides training 4.17 ± 2.24 times a week participated in this study. Among the volunteers, only one was left-footed at the lateral preference of the lower limbs. The selected athletes did not present any sports injuries in the past two months which resulted in the absence of training for a period equal to or greater than fifteen days. The COVID-19 pandemic influenced the number of participants, as few teams were having their regular training practices. The experiments were performed within the ethical standards set out in Resolution 466/12 of the National Health Council of 12/12/2012 (BRASIL, 2012) and the Resolution of Helsinki (2001). The School of Physical Education and Sport of Ribeirão Preto ethics committee (5659) approved all the experimental procedures (CAAE: 24268719.0.0000.5659). Written consent was obtained from the participants or their legal guardian(s).

Instruments

The participants realized the collection with 39 reflexive circular markers of 24 mm attached to the body. A standard Vicon's protocol, the full-body modeling with plug-in gait[17], was utilized for the markers' locations. For three-dimensional motion data collection, a system of ten infrared cameras was used, adjusted in an acquisition frequency of 400 Hz (Vicon, Oxford, UK). A stick marked with known distances was used to calibrate the system. The errors and lens distortions were adjusted using the software Nexus.

Two force plates (40×60 cm, Bertec, Columbus, USA), adjusted in an acquisition frequency of 2000 Hz, were used to collect the force and impulse manifested by the lower limb ipsilateral to the side of the dive. The Global Lateral Preference Inventory (IPLAG)[18] was used to identify the volunteer's lower limbs' lateral preference.

Experimental procedures

Initially, the volunteers received instructions about how the collection procedures. Then, they filled out the IPLAG for the lower limbs lateral preference identification. Before starting the execution of the dives, each participant realized a warm-up conducted by the researchers following some principles proposed by the literature[19]. They completed a sequence of exercises with 5-10 minutes of duration at a lower intensity. The final part of the warm-up was the execution of four dives to the right (two with the OR and two with the NR) and four to the left (the same number with each rule) for the familiarization of the goalkeeper to the movement that would be executed in the collect.

The goalkeeper was positioned in a previously demarcated location for the test performance. If the goalkeeper would perform the diving save according to the OR, he was instructed to position his foot ipsilateral to the dive side on the force plate. When the volunteer was going to execute the dive according to the NR, he was instructed to position himself in a way that the ipsilateral foot hits the force plate during the diving movement.

The goalkeeper was warned previously regarding the side he would dive and if it would be according to the OR or NR. The collection started when the researchers executed a soccer penalty kick video seen by the goalkeeper's vision. The videos contained only kicks in which the ball trajectory passed a lateral distance of 3.5 meters of the center of the goal and a height of 1.6 meters. The goalkeeper was guided to initiate the movement according to the penalty kick of the video. Two balls were hung in the laboratory in the distance that the balls would have crossed the goal line to serve as a target to the defense simulated in the dive (Figure 1 and Figure 2). Mattresses were placed in the laboratory to cushion the impact of the fall.

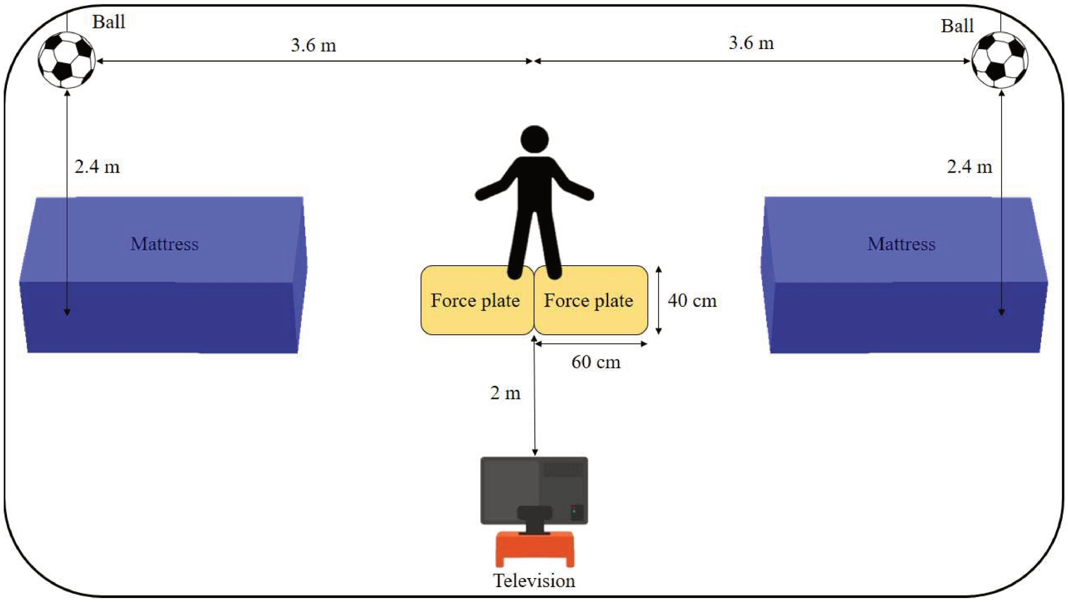

Figure 1. Experimental setup of the laboratory at the moment of the collection.

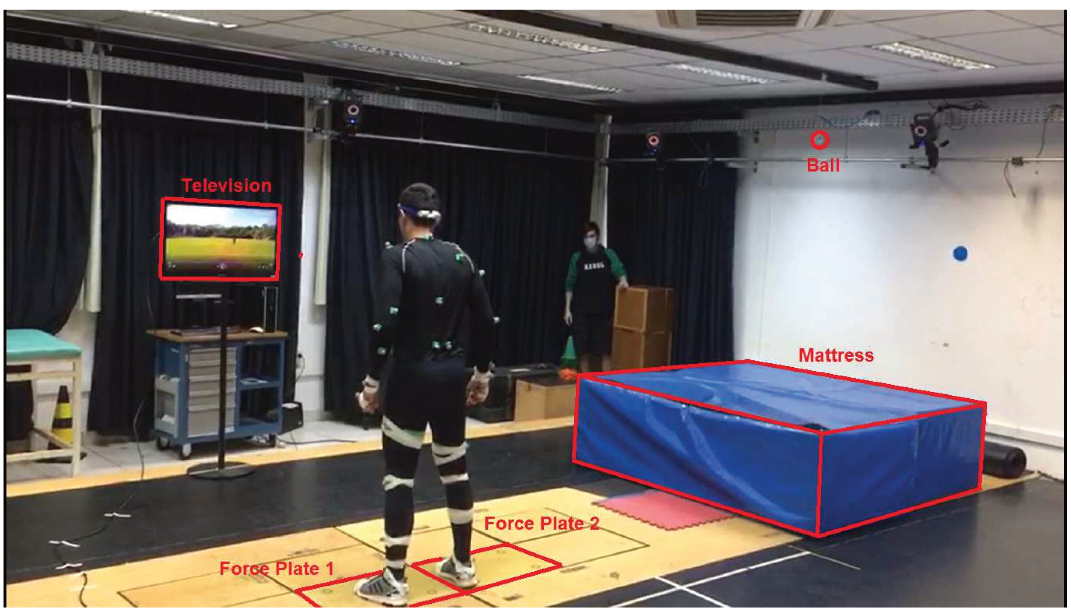

Figure 2. Image of the laboratory at the moment of the collection.

The volunteers performed a total of 20 dives, being 10 with each feet positioning rule and an equal number of dives for each side. There were 10 dives to the right, 5 with the OR and NR, and 10 to the left with the same number of trials with each rule. The order of the dive executions was random so this factor does not influence the final result. The recovery time between the trials was equal to or greater than 90 seconds. The collection was realized with three researchers, the social distancing was respected, and all security measures against COVID-19 were taken.

Data analyses

To determine laterality, the results of the IPLAG were observed. The lateral preference of the lower limbs was extracted. The IPLAG provides a numeric scale, in which: 1 = strongly left-footed; 2 = moderate left-footed; 3 = ambidextrous or without preference; 4 = moderate right-footed; 5 = strongly right-footed. However, to separate the diving saves between the dominant lower limb side (DLL) and non-dominant lower limb side (NDLL), the volunteers classified as 1 and 2 were aggrouped in left-footed and the ones classified as 4 and 5 formed the right-handed group. No one was classified in category 3.

The data processing was similar to the one utilized in other study[20]. For performance variables analysis of the dives, three-dimensional center of body mass (CM) data and the values collected by the force plate were used:

- Three-dimensional diving displacement: was given by the root of the sum of squares of the displacement in each of the three axes concerning the goalkeeper (X is the transversal, the Y represents the sagittal and the Z the longitudinal), having as the beginning of the displacement the minor point of the Z-axis and the end of the displacement the greater point of the Z-axis.

- The dive average velocity: was determined through the resultant displacement of the dive divided by the time spent on the dislocation.

- Peak velocity: was calculated by the greater value of displacement over the time between the lower and greater height of the CM in the rising phase of the dive.

- Peak force manifested by the lower limb ipsilateral to the dive side normalized by the weight: was obtained by identifying the greater value of force divided by the weight.

- Impulse manifested by the lower limb ipsilateral to the dive side normalized by the weight: it was determined through the trapezoidal integral of the force x time graph only at the moment of the impulse divided by the weight.

The CM three-dimensional coordinates were calculated using the software Nexus since we used a standard protocol of the markers' location. In cases where the cameras did not capture the essential markers to the CM calculation in the final frames, the anatomical point was transferred to a non-essential marker of the same corporal segment. When this procedure was not possible, the trial was discarded.

It was developed a custom routine on Python 3 to process and obtain the variables of interest. The raw data was filtered with the digital filter Butterworth of fourth-order, with the cut-off frequency obtained by the residue analysis (WINTER, 2009)[21].

Statistical analyses

For presenting the descriptive results, average ± standard deviation (SD) was used. . The normality of the data was confirmed using the Shapiro-Wilk test. The Student's paired t-test indicated the performance differences between the rules and between the sides of the dive lateral preference. The Cohen's d was used to report the effect size of the presented variables (0.2-0.3 small, 0.5-0.8 medium, > 0.8 large)[22]. In all cases, the significance level was $p \geq 0.05$. The analyses were conducted in the software SPSS (v.21.0, IBM Statistics).

Results

A total of 120 dives were processed, 16 were discarded due to data capture problems. Therefore, 104 dives were considered in the analysis. In the first analysis, the dives were divided according to the rules and laterality of the lower limbs (Figure 3). The dives with the NR to the side of the DLL (NRD) presented greater values in relation with the OR to this same side (ORD) in the following variables of the CM, normalized force and impulse of the DLL: mediolateral displacement (MLD) (1.492±0.257 m, $p < 0.001$, d = 0.87), anteroposterior displacement (APD) (0.485±0.181 m, $p < 0.001$, d = 1.78), resultant displacement (RD) (1.63±0.288 m, $p < 0.001$, d = 1.07), average velocity (AV) (3.17±0.2 $m.s^{-1}$, $p < 0.001$, d = 1.42), peak velocity (PV) (3.919±0.144 $m.s^{-1}$, $p < 0.001$, d = 1.48), vertical peak force (VPF) (2.302±0.492 times body weight (xBW), $p < 0.001$, d = 1.47), mediolateral peak force (MLPF) (0.541±0.07 xBW, p = 0.03, d = 0.69), anteroposterior peak force (APPF) (0.237±0.116 xBW, p = 0.005, d = 0.86), resultant peak force (RPF) (2.345±0.503 xBW, $p < 0.001$, d = 0.90), vertical impulse (VI) (2.581±0.381 xBW.s, p = 0.002, d = 0.76), anteroposterior impulse (API) (0.189 ± 0.085 xBW.s, p = 0.002, d = 0.93) and resultant impulse (RI) (2.652 ± 0.388 xBW.s, p = 0.002, d = 0.74).

The dives with the NR to the side of the NDLL (NRND) presented greater values in comparison to the dives with the OR to this same side (ODND) in the following variables: vertical displacement (VD) (0.433±0.703 m, p = 0.02, d = 0.53), MLD (1.58±0.324 m, p = 0.02, d = 0.63), APD (0.52±0.213 m, $p < 0.001$, d = 1.81), RD (1.727±0.355 m, p = 0.003, d = 0.79), AV (3.189±0.208 $m.s^{-1}$, $p < 0.001$, d = 1.99), PV (3.987±0.202 $m.s^{-1}$, $p < 0.001$, d = 1.27), VPF (2.22±0.364 xBW, $p< 0.001$, d = 1.65), RPF (2.261±0.361 xBW, $p < 0.001$, d = 1.65), VI (2.594±0.454 xBW.s, p = 0.02, d = 0.66), API (0.238±0.16xBW.s, p = 0.001, d = 0.99) and RI (2.67 ± 0.468 xBW.s, p = 0.03, d = 0.85).

In the second analysis, the dives were divided in relation to the rules (Figure 4). The trials with the NR presented greater values in relation to the ones with the OR in the following variables: VD (0.425±0.077 m, p = 0.03, d = 0.28), MLD (1.536±0.293 m, $p < 0.001$, d = 0.56), APD (0.503±0.197 m, $p < 0.001$, d = 1.84), RD (1.679±0.324 m, $p < 0.001$, d = 0.87), AV(3.179±0.203 $m.s^{-1}$, $p < 0.001$, d = 1.74), PV (3.953±0.177 $m.s^{-1}$, $p < 0.001$, d = 1.37), VPF (2.261±0.431 xBW, $p < 0.001$, d = 1.55), APPF (0.225±0.142 xBW, p = 0.04, d= 0.45), RPF (2.303±0.435 xBW, $p < 0.001$, d = 1.53), VI (2.588±0.415xBW.s, p

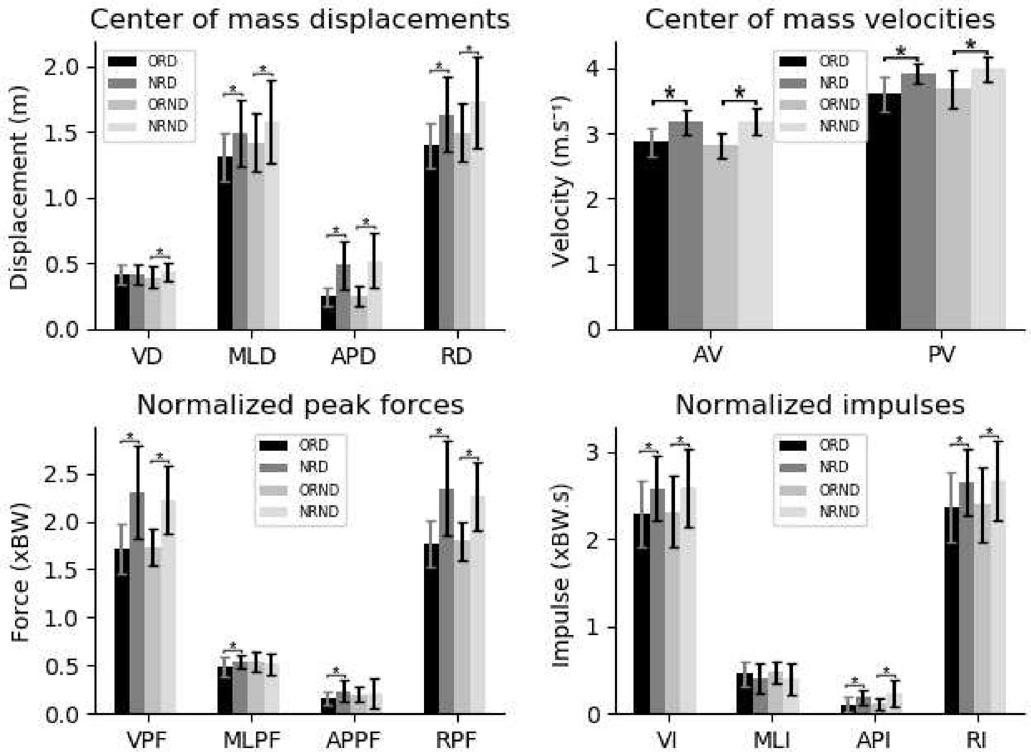

Figure 3. Average and standard deviation of the dive variables with the trials divided according to the rules and laterality of the lower limbs. * = $p < 0.05$. ORD = trials with the old rule to the side of the dominant lower limb; NRD = trials with the new rule to the side of the dominant lower limb; ORND = trials with the old rule to the side of the non-dominant lower limb; NRND = trials with the new rule to the side of the non-dominant lower limb; VD = vertical displacement; MLD = mediolateral displacement; APD = anteroposterior displacement; RD = resultant displacement; AV = average velocity; PV = peak velocity; VPF = vertical peak force; MLPF = mediolateral peak force; APPF = anteroposterior peak force; RPF = resultant peak force; VI = vertical impulse; MLI = mediolateral impulse; API = anteroposterior impulse; RI = resultant impulse; m = meters; s = seconds; xBW = times body weight.

< 0.001, d = 0.70), API (0.213±0.129 xBW.s, $p < 0.001$, d = 1.01) and RI (2.661±0.426 xBW.s, $p < 0.001$, d = 0.68). However, the OR trials presented only one variable with greater values compared with the NR trials, the mediolateral impulse(MLI) (0.464 ± 0.136 xBW.s, p = 0.02, d = 0.46).

In the last analysis, the dives were divided according to the lateral dominance of the lower limbs (Figure 5). The trials to the side of the NDLL presented greater values in comparison to the trials to the side of the DLL in only the following variables: MLD (1.497 ± 0.282 m, p = 0.02, d = 0.38) and RD (1.609 ± 0.312 m, p = 0.03, d = 0.31).

Discussion

This study aimed to compare the goalkeeper's performance in the dives with the OR and NR in the penalty and describe the effect of laterality on this phenomenon. About the performance, this research demonstrated that the variables of displacement and velocity were all greater when the dive was realized with the NR. In other words, the goalkeeper dives farther and faster when he can project a foot forward. This allied to the goalkeeper's anticipation technics to guess the side of the kick contribute to the defensor arriving faster to the corners of the goal, which increases his chance to defend the penalty[23–26].

When analyzing the peak force and impulse of the lower limb ipsilateral to the diving side, it is evident that these variables are greater for the vertical, anteroposterior and resultant direction. These findings demonstrate that dive dynamics with the NR interferes and benefits the force and impulse applied with the ipsilateral lower limb. However, in the mediolateral direction, it is observed that there was no difference in the peak force and the dives with the OR presented greater values of impulse. These results show a greater ipsilateral lower limb dependence on the MLI production in this rule, which was ineffective due to the lower MLD presented.

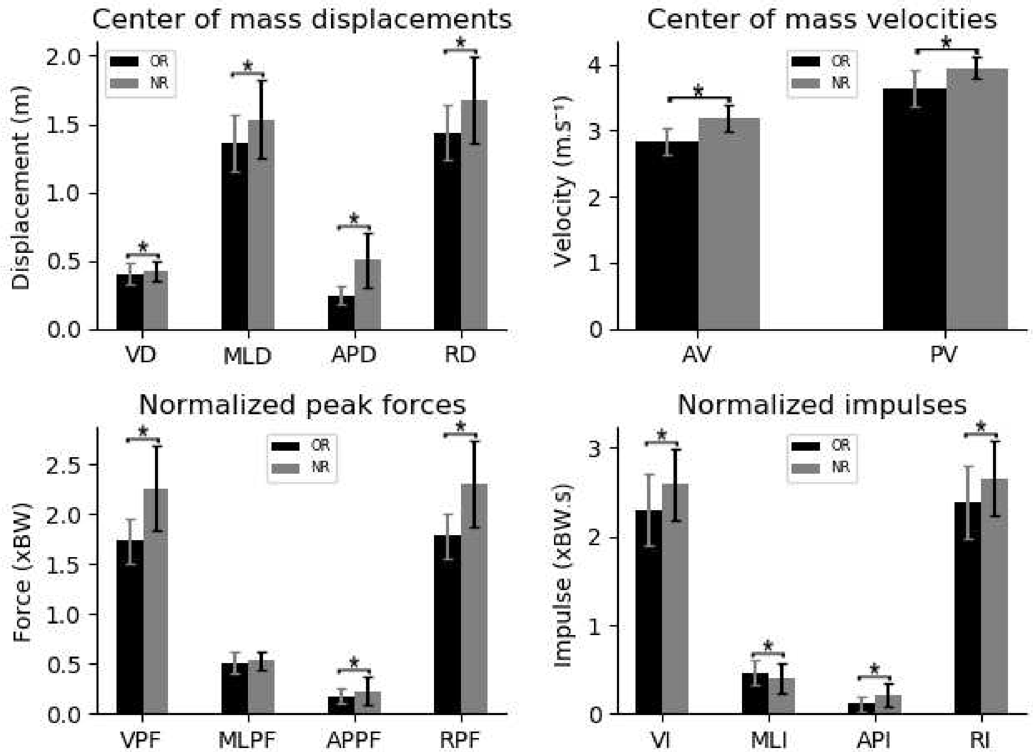

Figure 4. Average and standard deviation of the dive variables with the trials divided according to the rules. * = $p < 0.05$. OR = trials with the old rule; NR = trials with the new rule; VD = vertical displacement; MLD = mediolateral displacement; APD = anteroposterior displacement; RD = resultant displacement; AV = average velocity; PV = peak velocity; VPF = vertical peak force; MLPF = mediolateral peak force; APPF = anteroposterior peak force; RPF = resultant peak force; VI = vertical impulse; MLI = mediolateral impulse; API = anteroposterior impulse; RI = resultant impulse; m = meters; s = seconds; xBW = times body weight.

These results related to the MLI and MLPF demonstrate that the force and impulse in the mediolateral direction are generated mainly by the contralateral lower limb, while the ipsilateral has a more significant contribution to produce the vertical and anteroposterior force and impulse. This is even more evident when it is observed that in the NR trials, even though the MLI is lower and the MLPF does not show any difference in comparison to the OR, MLD is higher, which allows the conclusion that the impulse to this greater displacement can only have come from the contralateral lower limb, which corroborates with other's findings[15].

When observing the results regarding the lateral dominance of the lower limbs, it can be noted that most of the variables do not show a difference between the trials to the DLL and NDLL sides. The bilateral goalkeeper training can justify these findings due to the requirement of low asymmetry in the position, which makes the effects of lateral dominance lower, even more in professional or specialized athletes in the position, which is the case of this research.

However, it was still possible to observe the effects of the lateral dominance, although presenting a small effect size, the MLD and consequently the RD had greater values when the trial was made to the side of the NDLL in comparison to the DLL. This corroborates with what was found in this study that the contralateral lower limb is mainly responsible for the mediolateral force and impulse generation because when they dive to the side of the NDLL, the main responsible for the MLD generation is the DLL, which tends to be stronger in soccer goalkeepers[27].

Other researches had been made to investigate the laterality effect on soccer goalkeeper dives in the penalty. Differently from our results, they found that the CM had greater velocity in the contact with the ball when diving to the side of the DLL and reached the highest height to the side of the NDLL[13]. While a previous study did not find differences in the MLD between the diving sides, it reported similar results to the present study regarding the VD. It is essential to highlight that the study evaluated only one goalkeeper, and no training level was reported[14]. Another research used specialized goalkeepers and found similar results regarding laterality, i.e., it did not find differences in the CM velocity between the dives to both sides[15].

The limitations of this study were the ball being static at the moment of the dive; the collection having been carried out

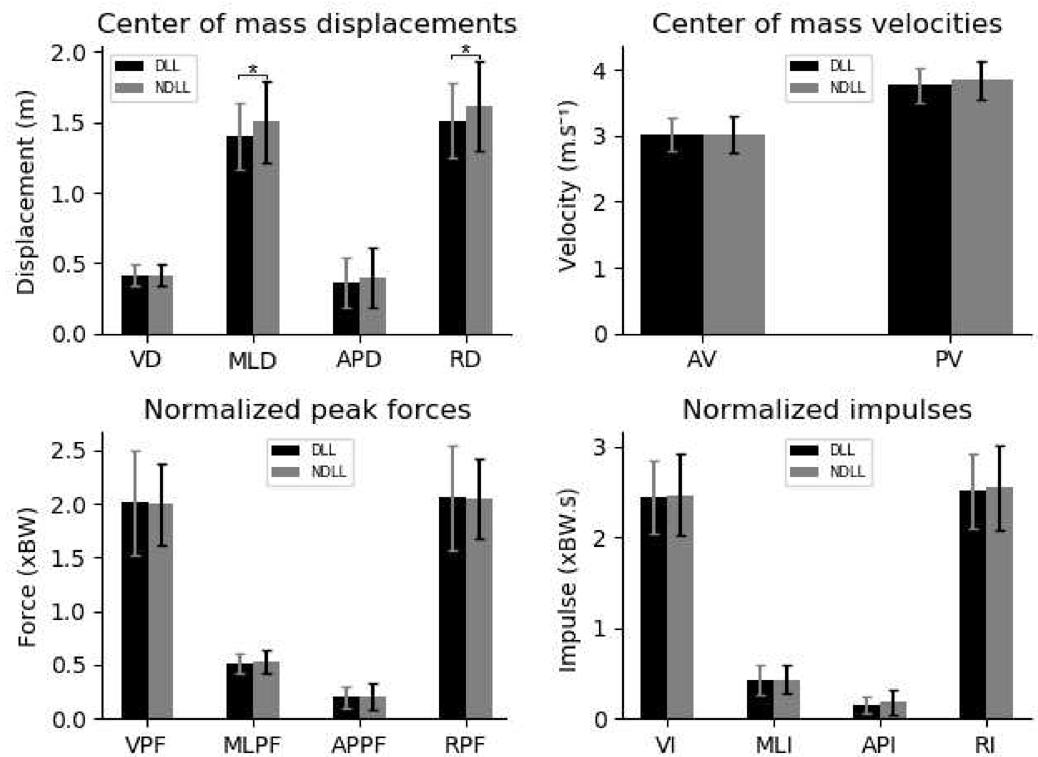

Figure 5. Average and standard deviation of the dive variables with the trials divided according to the laterality of the lower limbs. * = $p < 0.05$. DLL = trials to the side of the dominant lower limb; NDLL = trials to the side of the non-dominant lower limb; VD = vertical displacement; MLD = mediolateral displacement; APD = anteroposterior displacement; RD = resultant displacement; AV = average velocity; PV = peak velocity; VPF = vertical peak force; MLPF = mediolateral peak force; APPF = anteroposterior peak force; RPF = resultant peak force; VI = vertical impulse; MLI = mediolateral impulse; API = anteroposterior impulse; RI = resultant impulse; m = meters; s = seconds; xBW = times body weight.

inside a laboratory setting; the necessity of the goalkeeper to step on the force plate to realize the dive; the low number of participants due to the COVID-19 pandemic; and the difficulty to find people that fit our participation requirements. These factors may have taken the collection away from what happens in real penalty situations. The authors suggest that future studies should be carried out in the field and with balls in motion. This will provide greater ecological validity. We also emphasize that the literature lacks biomechanical studies analyzing the dynamics of soccer goalkeeper's dives and the relationship between the goalkeeper and lateral dominance.

Despite the limitations of this study, biomechanical analyses can establish themselves as important ways of soccer goalkeeper dive evaluation. It permits precise inferences in the analyzed variables. Besides that, they are an important tool for understanding the diving process, indicating the athletes' deficiencies and limitations concerning laterality, force, and impulse generation. All of this can contribute to improving the soccer goalkeepers training.

Concluding, this study demonstrated that soccer goalkeepers dived farther and faster with the feet positioning rule changing in penalty. Another found was that the lateral dominance in specialized goalkeepers influenced only the mediolateral displacement and resultant displacement in penalty dives, presenting greater values to the side of the non-dominant lower limb. Also, it was possible to identify that the contralateral lower limb has major participation in the mediolateral impulse generation.

Data and Code availability

The datasets generated and analyzed during the current study and the code for the data analysis pipeline performed are available on figshare[28] and `https://github.com/rafaellmmonteiro/DataDivingGoalkeepers` (As of Jan. 2021).

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Author contributions statement

R.L.M.M. and P.R.P.S. conceived the methodology, analyzed the data, and wrote the manuscript. R.L.M.M., P.H.M.M., and P.R.P.S. collected the data. R.L.M.M., B.L.S.B., P.H.M.M., F.S.P.A, F.A.M., S.A.C., R.S.T., and P.R.P.S. participated in the study idea, discussed the results, and revised the original manuscript text.