

# Progression of Mechanical Properties during On-field Sprint Running after Returning to Sports from a Hamstring Muscle Injury in Soccer Players

## Authors

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## Key words

- hamstring strain
- injury
- sprinting
- soccer

## Abstract

The objectives of this study were to examine the consequences of an acute hamstring injury on performance and mechanical properties of sprint-running at the time of returning to sports and after the subsequent ~2 months of regular soccer training after return. 28 semi-professional male soccer players, 14 with a recent history of unilateral hamstring injury and 14 without prior injury, participated in the study. All players performed two 50-m maximal sprints when cleared to return to play (Test 1), and 11 injured players performed the same sprint test about 2 months after returning to play (Test 2). Sprint performance (i.e., speed) was measured via a radar

gun and used to derive linear horizontal force-velocity relationships from which the following variables obtained: theoretical maximal velocity ( $V_0$ ), horizontal force ( $F_{H0}$ ) and horizontal power (Pmax). Upon returning to sports the injured players were moderately slower compared to the uninjured players.  $F_{H0}$  and Pmax were also substantially lower in the injured players. At Test 2, the injured players showed a very likely increase in  $F_{H0}$  and Pmax concomitant with improvements in early acceleration performance. Practitioners should consider assessing and training horizontal force production during sprint running after acute hamstring injuries in soccer players before they return to sports.

## Introduction

Hamstring muscle injuries are the most prevalent injuries in soccer, accounting for 12–16% of all injuries [7, 10, 13, 14, 19, 20, 45]. In addition to the high incidence, a common problem concerning this injury is the high risk of recurrence (12–31%) [7, 14, 45]. Most hamstring injuries in soccer occur during high-speed and power actions such as sprinting [2, 37, 45]. Whether the injury occurs during swing or stance phase of the sprint still remains controversial [9, 33, 38]. In soccer, rapid acceleration and sprinting movements are common in many match-winning actions such as winning possession of the ball, passing defending players or gaining position to score a goal [12, 15]. Therefore, from this basic standpoint it seems logical to expect sprinting to be a key parameter in soccer both from a performance and injury prevention perspective.

During the acceleration phase of sprinting, forward orientation of ground reaction force (GRF) has been shown to be a stronger determinant of field sprint performance than the overall magnitude of vertical or resultant GRF [29, 34, 35]. It

has been suggested that the bi-articular posterior thigh muscles have a major influence on controlling the direction of external forces producing a force that is directed horizontally but backwards, causing the body to propel forwards during the support phase [4, 27]. In addition, the biarticular hamstring muscles have been shown to contribute to a net transfer of power from proximal to distal joints during explosive leg extensions. This transfer of power allows for an efficient conversion of body segment rotations (during the first half of stance phase) into the translation of the center of mass (CM) in the horizontal direction [25, 26]. The significant increase in the electromyography activity of the biceps femoris muscle with increasing running speed at foot-strike could indicate that hamstring muscles are responsible for generating additional force production and pulling the body over the stance leg with minimal loss of horizontal speed and, therefore, make a significant contribution to propulsion [4, 30, 33]. In this regard, previously injured hamstrings have been shown to exhibit substantial weakness in eccentric strength despite athletes returning to full training and competition

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**Fig. 1** Performing an on-field single sprint trial using the novel method.

[31,41]. Thus, it is possible that athletes with a previous hamstring injury can have a reduced ability to generate forward propulsion, and hence impaired performance, during sprinting. However, no research has to date examined the mechanical properties during sprint running at the time of return to sports following a hamstring injury.

The ability to specifically produce and apply high amounts of force onto the ground in the horizontal direction as a function of running velocity is well described by linear force-velocity ( $F$ - $v$ ) and parabolic power-velocity relationships [28,35]. In particular, since mechanical power is the product of force and velocity, the slope of the linear  $F$ - $v$  relationship [28,35] may indicate the relative importance of force and velocity qualities in determining the maximal horizontal power output ( $P_{max}$ ), and the individual  $F$ - $v$  profile of each subject. These individual  $F$ - $v$  relationships describe the changes in external horizontal force generation with increasing running velocity. They may be summarized by 2 theoretical extrema: the theoretical maximal horizontal force the legs could produce over one contact phase at null velocity ( $F_{H0}$ ), and the theoretical maximal velocity the legs could produce during the same phase under zero load ( $V_0$ ). These integrative parameters characterize the mechanical limits of the entire neuromuscular system to produce horizontal force during sprint running, and encompass numerous individual muscle mechanical properties as well as other morphological, neural and technical factors [6]. Therefore, they provide an integrative view of the  $F$ - $v$  mechanical profile of a runner during his or her specific sprint running task. Recently, a simple field method has been proposed to quantify these parameters from a biomechanical model. The model requires only time and velocity measurements during a single sprint (◉ **Fig. 1**), which can be considered an economical and valid alternative to biomechanical lab testing [40]. Following our hypothesis that athletes with a recent hamstring injury can have a reduced ability to generate forward propulsion upon returning to sports, the 2 mechanical entities composing power output (i.e., force and velocity) analyzed through the linear  $F$ - $v$ , could also be affected. Therefore, the aim of the present study was to characterize sprinting performance and mechanical properties of sprint running (i.e.,  $V_0$  and  $F_{H0}$  and  $P_{max}$ ) at the time of returning to sports after the rehabilitation phase for a hamstring injury in soccer players. In addition, the assessment was then repeated after about 2 months of regular soccer training following the return to sports to provide additional insights into the recovery process over time.

## Material and Methods



### Subjects

28 semi-professional male soccer players recruited telephonically from 13 Spanish teams participated voluntarily in the study. 14 players ( $21.9 \pm 2.5$  years;  $174.6 \pm 4.7$  cm;  $69.3 \pm 5.9$  kg) had no history of hamstring injury (i.e., uninjured group). Another 14 players ( $21.6 \pm 2.5$  years;  $173.5 \pm 4.7$  cm;  $72.4 \pm 7.1$  kg) had experienced an acute recent hamstring injury (i.e., injured group) with a recovery time ranging between 1.5 and 6 weeks ( $3.5 \pm 1.5$  weeks). All hamstring injuries were diagnosed by the doctors or physiotherapists for each team; moreover, these were always checked by the same clinician (E.M.R.) during the first personal contact. At that time, each subject (injured and uninjured players) also completed a questionnaire in order to establish injury history, particularly in relation to hamstring injuries. Inclusion criteria for the injured group included: 1) sudden onset of posterior thigh pain of non-contact etiology during a match or training which forced the player to leave that training or match; 2) injury severe enough to have caused the player to miss at least one official match or week of regular training [42]; 3) tenderness triggered by palpation, stretching and contraction of the hamstring muscles [18], with or without confirmation by imaging techniques; and, 4) an injury that should be assessed (Test 1) within 4 weeks after returning to competition ( $2.8 \pm 0.9$  weeks). Inclusion criteria for the control group were 1) unknown history of hamstring injury and 2) currently participating fully in their regular training sessions or matches. Exclusion criteria for both groups were 1) muscular, knee or lumbar-pelvic injury that required professional medical intervention at least 2 years prior to measurements and 2) any known neurological, cardiorespiratory or systemic disorder [42]. To reduce potential confounding, both groups included at least 1 injured and uninjured player for each team. Additionally, the injured and uninjured group were matched according to position (defenders and forwards), status (titular or substitute player) and leg dominance. In addition, teams presented a similar physical load profile. i.e., all subjects underwent three 90-min practices per week and played one official match on the weekend. All subjects provided written informed consent, and ethics approval was granted by the Catholic University of San Antonio (Spain) human research ethics committee, which conforms to the ethical standards of the International Journal of Sports Medicine [21] and those established by the declaration of Helsinki.

## Experimental protocol

The soccer players involved in this study were asked not to train or exercise vigorously for at least 2 days preceding testing. Before the tests (Test 1 and 2), each player performed an identical warm up comprising 5 min of low-pace ( $\sim 10 \text{ km}\cdot\text{h}^{-1}$ ) running, followed by 3 min of lower limb muscle stretching, 5 min of sprint-specific warm-up exercises, and 3 progressive 6-s sprints separated by 2 min of passive rest. Subjects were then allowed 5 min of free cool down before performing two 50-m maximal sprints from a standing start on a natural grass field (Fig. 1). These sprints were separated by 6 min of passive rest and supervised by the same clinician (E.M.R.), who assured that players wore their usual soccer shoes and ran during similar times (i.e., same hour and on different days than their normal soccer training session) and under similar temperature ( $22.0 \pm 5.5^\circ$ ) and wind conditions ( $12.1 \pm 9.5 \text{ km}\cdot\text{h}^{-1}$ ), the latter being measured by a PCE-AM 82 anemometer (PCE Ibérica, Tobarra, Albacete, Spain).

Test 1 was carried out when the injured players returned to sports after the rehabilitation phase (i.e., when they were cleared by their doctors or physiotherapists) and participated in all training/competition activities with the rest of the squad. Simultaneously to the assessment of each injured player, one or more uninjured player of the same team was also assessed. Subsequently, 11 players for the injured group ( $21.6 \pm 2.2$  years;  $172.6 \pm 4.7 \text{ cm}$ ;  $71.2 \pm 5.7 \text{ kg}$ ) performed a second sprint test at  $9.5 \pm 1.5$  weeks after returning to sports (Test 2). During this period, none of the previously injured players was involved in any specific supplementary or preventative training apart from what was implemented in each squad. The 3 remaining players did not undergo testing with Test 2 due to suffering a hamstring re-injury, an ankle sprain injury and due to a personal issue, respectively.

The performance for each sprint was measured by means of a Radar Stalker ATS System™ (Radar Sales, Minneapolis, MN). This device measures the forward sprinting velocity of the subject at a sampling rate of 33.25 Hz, and has been previously validated in human sprint running experiments [8, 11, 36]. It was placed on a tripod 10 m behind the subjects at a height of 1 m corresponding approximately to the height of subjects' CM.

## Data analysis

Horizontal external force, velocity and power were obtained using a recently validated computational method from speed data measured during the acceleration phase of each sprint (ranging from the sprint start to the maximal speed plateau) [40]. For each acceleration phase, the velocity ( $v$ ) – time curve was fitted by a monoexponential function using least square regression [11, 17, 22]:

$$v(t) = v_{max} \cdot (1 - e^{-t/\tau}) \quad (1)$$

with  $v_{max}$  being the maximal velocity reached and  $\tau$  the acceleration time constant. The horizontal acceleration ( $a$ ) of the body center of mass as a function of time during the acceleration phase can be expressed, after derivation of  $v(t)$  over time, as follows:

$$a(t) = (v_{max}/\tau) \cdot e^{-t/\tau} \quad (2)$$

The net horizontal external force ( $F_H$ ) was modeled over time as:

$$F_H(t) = m \cdot a(t) + F_{air} \quad (3)$$

with  $F_{air}$  being the aerodynamic friction force runners have to overcome during sprint running computed from running velocity and an estimation of runner's frontal area and drag coefficient (for details, see Arzac and Locatelli [3]). On the basis of these  $F_H$  and  $v$  values, individual linear force-velocity relationships were determined by least-square linear regressions (33–34) to obtain for each subject  $F_{H0}$  and  $V_0$  (force and velocity-axis intercepts of the force-velocity regression curves, respectively), the F-v profile (slope of the F-v curve) and the maximal horizontal power output ( $P_{max} = F_0 \cdot V_0/4$ ) [39,40].

## Statistical methods

Data in the text are presented as means  $\pm$  SD. Data were analyzed for practical significance using magnitude-based inferences [23] with a modified statistical Excel spreadsheet [24]. We used this qualitative approach because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to athletic performance than any statistically significant effect [23]. Inter-group standardized differences or Cohen effect sizes ( $d$ ) (90% confidence limits, CL) in the selected performance variables were calculated using pooled standard deviations. Effects were evaluated for practical significance by pre-specifying 0.2 between-subject SDs as the smallest worthwhile difference (SWD) [23]. Threshold values for  $d$  statistics were  $<0.20$ , 0.20, 0.60, 1.2 and 2.0 for trivial, small, moderate, large and very large, respectively [23]. Probabilities were also calculated to establish whether the true (unknown) differences were lower, similar or higher than the SWD. Chances of higher or lower differences were evaluated qualitatively as follows:  $\leq 1\%$ , almost certainly not;  $>1-5\%$ , very unlikely;  $>5-25\%$ , unlikely;  $>25-75\%$ , possible;  $>75-95\%$ , likely;  $>95-99\%$ , very likely;  $>99\%$ , almost certain [23]. If the chance of both higher and lower values was  $>5\%$ , the true difference was assessed as unclear [23]. Otherwise, we interpreted that change as the observed chance.

## Results

Both injured and uninjured soccer players were similar in terms of age, height and body mass except for slightly and moderate greater body mass and BMI in the injured players at Test 1. At Test 1 (i.e., return to sport), the injured players were very likely, slower (moderate magnitude differences) at 5, 10 and 40-m than their uninjured counterparts (Table 1). Top speed was also lower in the injured players, while the magnitude of the inter-group differences was smaller. Among the mechanical variables,  $P_{max}$  and  $F_{H0}$  were substantially lower (moderate magnitude differences) in the injured players (Table 1), while the magnitude of the inter-group differences was smaller for  $V_0$ . After  $\sim 2$  months following return to sports (i.e., Test 2) the injured players presented a very likely increase of moderate magnitude in  $P_{max}$  and  $F_{H0}$  concomitant with improvements in sprint performance at 5 and 10 m (Table 1). Performance at 40 m and Top Speed and the remaining mechanical variable ( $V_0$ ) ( $-0.29 \pm -0.98 \pm 0.40$ ) presented small to trivial (typically unclear) changes from Test 1 to Test 2. Thus, as a result of the observed improvements in both sprint performance and mechanical variables observed at Test 2 in the injured players, most of the initially (i.e., Test 1) observed inter-group (i.e., injured vs. uninjured) differences resolved with  $\sim 2$  months' follow-up (Table 1).

**Table 1** Anthropometric, sprinting performance and mechanical variables (mean  $\pm$  SD) for each group and the standardized differences (with 90% confident limits) and probabilistic inferences about the true standardized magnitude in the means between groups.

	Non-injured T1 (n=14)	Injured T1 (n=14)	Injured T2 (n=11)	Non-injured T1 vs. Injured T1	Non-injured T1 vs. Injured T2	Injured T2 vs. Injured T1
				ES (90% CL) chances of better/trivial/ worst	ES (90% CL) chances of better/trivial/ worst	ES (90% CL) chances of better/trivial/ worst
<b>Body mass (kg)</b>	69.3 $\pm$ 5.9	72.4 $\pm$ 7.1	71.2 $\pm$ 5.8	-0.46 (-1.08;0.17) small (4/20/76) likely $\downarrow$	-0.31 (-0.98;0.35) small (10/29/61) unclear	0.18 (-0.48;0.84) trivial (17/35/48) unclear
<b>Height (m)</b>	1.75 $\pm$ 0.05	1.73 $\pm$ 0.05	1.73 $\pm$ 0.05	0.24 (-0.39;0.86) small (54/34/12) unclear	0.41 (-0.26;1.08) small (70/23/7) unclear	0.18 (-0.49;0.85) trivial (48/35/17) unclear
<b>BMI (kg/m<sup>2</sup>)</b>	22.7 $\pm$ 1.5	24.1 $\pm$ 2.4	23.9 $\pm$ 1.6	0.65 (0.02;1.28) moderate (2/10/88) likely $\downarrow$	0.72 (0.05;1.39) moderate (2/8/90) likely $\downarrow$	0.09 (-0.74;0.56) trivial (22/39/39) unclear
<b>5-m (s)</b>	1.4 $\pm$ 0.05	1.5 $\pm$ 0.12	1.4 $\pm$ 0.07	0.90 (0.27;1.53) moderate (97/3/0) very likely $\uparrow$	0.05 (-0.64;0.73) trivial (35/38/27) unclear	0.81 (0.16;1.46) moderate (94/5/1) likely $\uparrow$
<b>10-m (s)</b>	2.2 $\pm$ 0.07	2.3 $\pm$ 0.17	2.2 $\pm$ 0.11	0.87 (0.25;1.50) moderate (96/4/0) very likely $\uparrow$	0.03 (-0.66;0.72) trivial (34/38/28) unclear	0.79 (0.13;1.44) moderate (93/6/1) likely $\uparrow$
<b>40-m (s)</b>	5.9 $\pm$ 0.18	6.1 $\pm$ 0.32	6.0 $\pm$ 0.26	0.83 (0.19;1.46) moderate (95/5/0) very likely $\uparrow$	0.23 (-0.47;0.92) small (53/32/15) unclear	0.56 (-0.10;1.22) small (82/15/3) likely $\uparrow$
<b>Top Speed (km/h)</b>	30.5 $\pm$ 1.1	29.8 $\pm$ 0.9	29.8 $\pm$ 1.3	0.64 (0.01;1.27) moderate (88/11/1) likely $\uparrow$	0.55 (0.13;1.23) small (81/16/3) likely $\uparrow$	-0.02 (-0.70;0.67) trivial (29/38/33) unclear
<b>V<sub>0</sub> (km/h)</b>	31.9 $\pm$ 1.31	31.4 $\pm$ 0.91	31.0 $\pm$ 1.45	0.46 (-0.17;1.09) small (76/20/4) likely $\uparrow$	0.63 (-0.05;1.30) moderate (86/12/2) likely $\uparrow$	-0.29 (-0.98;0.40) small (12/30/58) unclear
<b>F<sub>HO</sub> (N/kg)</b>	6.8 $\pm$ 0.56	6.1 $\pm$ 1.04	6.9 $\pm$ 0.84	0.85 (0.23;1.48) moderate (96/4/0) very likely $\uparrow$	-0.21 (-0.90;0.48) small (16/33/51) unclear	0.92 (0.26;1.58) moderate (97/3/0) very likely $\uparrow$
<b>Pmax (W/kg)</b>	15.0 $\pm$ 1.44	13.1 $\pm$ 2.39	14.9 $\pm$ 2.15	0.91 (0.29;1.54) moderate (97/3/0) very likely $\uparrow$	0.03 (-0.66;0.72) trivial (34/38/28) unclear	0.77 (0.10;1.43) moderate (92/7/1) likely $\uparrow$

## Discussion

Hamstring injury recurrence rates have remained substantially high in soccer [7, 14, 20, 45], which might be indicative of ineffective return-to-sport strategies. Thus, the aim of the present study was to examine the effects of an acute hamstring strain injury on sprinting performance and mechanical properties of sprint running (i. e.,  $V_0$  and  $F_{HO}$  and  $P_{max}$ ) at the time of return to sport and after the subsequent ~2 months. The main findings of the present study were: a) despite being cleared to play, soccer players returning from a recent hamstring injury had substantial lower sprinting speed performance and reduced mechanical horizontal properties compared to the uninjured players, b) the greater magnitude differences in  $F_{HO}$  compared to  $V_0$  suggested that the lower maximal horizontal power observed in the injured player was mainly related to the reduced maximal horizontal force component, and c) approximately 2 months of regular soccer training after return to sports resulted in substantial improvements in sprinting speed (acceleration) concomitant with an increase in maximal horizontal force and power, whereas the speed component ( $V_0$ ) and top speed remained unaltered. The present study is the first, to the authors' knowledge, to assess mechanical horizontal properties during a common on-field sprinting action at the time of returning to sports in soccer players with prior hamstring injuries. Moreover, measurements were performed during the acceleration phase of the sprint. Until now, testing methods were restricted to the flying top speed that could be maintained only for a few steps [5], irrespective of the typically preceding acceleration phase that has been shown to be fundamental to soccer performance and risk of injury. The method used here allowed us to obtain horizontal external force, velocity and power over ground and in field conditions, which could have been only possible using a 50-m long force plate system. This method was recently validated in com-

parison to force plate measurements and presented very low bias (absolute bias < 5%) and good reliability (coefficient of variation < 4%) on force, velocity and power parameters [40]. Specifically, upon return to sports,  $P_{max}$  was moderately lower in the injured players, primarily related to the reduced  $F_{HO}$  component. Present results concur with previous findings showing a decrease in horizontal force production, with no differences in vertical forces, at 80% of maximal velocity on a non-motorized force treadmill in Australian Rules Football players with a previous hamstring injury [5]. The reduced horizontal force component in the present study is particularly relevant for sprinting as a large horizontal component of the force vector is desired in order to maximize forward propulsion [4, 29, 34, 35]. In this regard, the role of the hamstring muscles in the initial contact phase is believed to be essential for producing hip extension and knee flexion power and thereby a more forward-directed force with increasing running speed [4, 33]. Thus, the lower force component (i. e.,  $F_{HO}$ ) at the time of return to sports observed in the present study might be related to the reported hamstring strength deficits, both as a hip extensor and knee flexor, in previously injured hamstrings athletes despite returning to full training and competition [31, 41, 43]. In addition, the injured athlete's apprehension of experiencing pain when producing a high level of force [44] might also play a role in the reduced ability to generate horizontal force and hence forward momentum during sprinting. Future studies should quantify whether the force reductions on the single-joint level (e. g., knee flexion) are causally linked with a limited ability to generate horizontal force vectors during a more functional action (i. e., sprinting). Following the first assessment and approximately 2 months after returning to sports, where soccer training and matches were resumed and re-injury risk is higher [16], the injured players presented a very likely, moderate increase in horizontal power and theoretical maximal force compared to an unclear



small and trivial unclear effect for  $V_0$  and top speed. These changes in the force profile of the players were concomitant to improvements of similar magnitude in the acceleration phase (i.e., 5- and 10-m) of the sprint, while the magnitude of the change in top speed and 40 m performance was much lower and trivial (Table 1). The fact that the horizontal power and force levels, with concomitant substantial improvements mainly in the acceleration phase of sprinting performance, improved to match the levels of uninjured players appears to indicate that the initial differences between injured and uninjured players as discussed above, were most likely related to the hamstring injury itself. Although indirectly these results seem to support the importance of  $F_{H0}$  for achieving greater horizontal power and sprinting performance, especially during the acceleration phase, in soccer. Indeed, it has been recently reported that to improve acceleration in field sport athletes, horizontal force and power production should be developed [32]. In contrast, and given the study design, it is difficult to know if  $V_0$  remained lower and unchanged after 2 months of returning to sports, since the training contents were not appropriate for improving this parameter or because there were initial inter-group differences. It can be speculated that because soccer training and match play involves mainly short sprints [1], supplemental exercises (e.g., long sprints) might be required to overload the top speed factors. In summary, our findings indicate that running mechanics, specifically the ability to produce a high level of horizontal force at low speed ( $F_{H0}$ ) (i.e., first meters of the acceleration phase), and sprinting performance were impaired after returning to sports from a hamstring injury in soccer players. Within ~2 months after returning to sports, the horizontal force production and acceleration capacity were both improved. Therefore, practitioners should consider assessing and training horizontal force production during sprint running after acute hamstring injuries in soccer players. Further research is required to improve our understanding on the effect of vertical and horizontal strength training on sprinting mechanics and performance.

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