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ENTRY

CATEGORY OF SUBMISSION: **COACHING**

"OVERCOME THE HAMSTRING INJURIES: A MULTIDISCIPLINARY APPROACH"

DESCRIPTION OF THE PROJECT

Introduction

Hamstring muscle injury has been reported as the main injury related to athletics practice (Edouard et al., 2011; Alonso et al., 2012; Edouard et al., 2013; Opar et al., 2014). During international athletics competitions, it represented about 11-16% of all injuries (Alonso et al., 2012; Edouard et al., 2014). It represented 24% of all injuries during the three annual competitions of the "Penn Relay Carnival" in the United States that gathered 48,473 athletes (Opar et al., 2014). During the whole athletics season, studies reported that hamstring muscle injury also represented a major injury, ranging from 5% to 50% of all injuries (Ahuja et al., 1985; Watson et al., 1987; Bennell et al., 1996; Rebella et al., 2008; Yeung et al., 2009; Jacobsson et al., 2013; Rebella, 2015).

Hamstring muscle injury also leads to important consequences for athletes including time loss of sports, risk of reinjury, or long-term pain. Since athletics requires a 100% recovery for a full return to sport, time-loss from competition can range from 4-140 days depending on the injury severity, populations, and studies (Malliaropoulos et al., 2010; Malliaropoulos et al., 2011; Askling et al., 2014). A high risk of reinjury have been reported (about 14% (Malliaropoulos et al., 2011)).

Thus, hamstring muscle injury represents the first injury for athletics athletes, especially those practicing explosive events (i.e. sprints, jumps, combined events). Given the prevalence of hamstring muscle injury and its impact on athlete's practice, hamstring muscle injury therefore represents a very important and relevant challenge for athletes, coaches, team leaders, and medical teams. It seems essential to better understand this injury (prevalence and characteristics), to better understand its specific relationship with sprint biomechanics, in order to develop and implement specific prevention measures to reduce its incidence/prevalence and/or severity.

In this context, our goal was to improve the knowledge on 1) hamstring muscle injury characteristics, 2) the specific relationships between hamstring muscles and sprint performance and why these muscles appear more at risk of injury, and 3) the way to screen/detect athletes at risk of hamstring muscle injury.

To this aim, we undertook four distinct research protocols, which correspond to four recently published studies accompanying this entry:

-Part 1: we aimed to determine the prevalence, incidence and characteristics of hamstring muscle injuries among high level athletes (Scientific paper 1);

-Part 2: we aimed to determine the role of hamstring muscles in sprint acceleration performance (Scientific paper 2);

-Part 3: we aimed to validate a simple method to muscular mechanical outputs during sprint acceleration (Scientific paper 3);

-Part 4: we aimed to describe changes in these mechanical outputs in the context of two case reports of hamstring muscle injuries (Scientific paper 4).

Part 1: Hamstring muscle injuries among high level athletes

Methods

During each athletics major championship, all national medical teams were asked to participate in the study and to report daily, on a standardised injury report form, all newly incurred injuries (or the non-occurrence of injuries). Local organising committee physicians (LOC) at medical centres in the stadium, warm-up areas and hotels were similarly asked to report all new injuries. Definitions and classifications of these injuries were given to all medical teams and LOCs (for more information please see: (Junge et al., 2008; Alonso et al., 2009; Timpka et al., 2014)). The confidentiality of all information was ensured so that no individual athlete or team could be identified, and data were kept securely. The study was reviewed and approved by the Oslo University School of Medicine Ethical Committee (for athletics championships from 2007 to 2011 and for the Olympic Games) and the Saint-Etienne University Hospital Ethical Committee (for athletics championships from 2012 to 2015). The IAAF or EAA provided lists of all registered athletes and national medical teams. Data from 9 championships were included (Country participation: 33.3%; registered athletes' coverage: 81.4%; expected injury report forms returned: 92.3% and muscle injury data completeness: 98.7%.).

An injury was defined as "all musculoskeletal injuries (traumatic and overuse) newly incurred during competition or training regardless of the consequences with respect to the athlete's absence from competition or training" (Junge et al., 2008; Alonso et al., 2009; Timpka et al., 2014). In cases where a single incident resulted in more than one injured body part and/or type of injury, each body part and/or type injury was counted as a separate injury (Edouard et al., 2015). In this study we only analysed reported hamstring muscle injuries, defined as those reported as "strain / muscle rupture / tear" or "muscle cramps or spasm" in the injury type section of the injury report form, and whose location was reported as "posterior thigh". The registration of a "strain / muscle rupture / tear", "muscle cramps or spasm" or "posterior thigh" injury was based on clinical examination and/or medical imaging by the national medical teams and/or by LOC physicians; no specific diagnostic criteria were sent out in advance.

Incidence of all (time-loss), training, and in-competition (time-loss) injuries and hamstring injuries were calculated as the number of injuries per 1000 registered athletes using a list of athletes provided by the International Association of Athletics Federations (IAAF) or the European Athletics Association (EAA). Data are presented using frequencies, percentages, cross-tabulations, incidences, relative risks (RR) with 95% confident intervals (95% CI) and magnitude thresholds (Hopkins), and with the Chi^2-test (Edouard et al., 2015). All data were processed using Excel. Significance was accepted at $p < 0.05$.

Results

Of the 1082 injuries recorded during the 9 international athletics championships, there were 185 hamstring muscle injuries, constituting 17.1% of total injuries. Hamstring muscle injury frequencies were significantly higher in male (19.3%) than female (13.5%) athletes (Chi2=6.1; p=0.01). 61.1% (n=113) of these hamstring muscle injuries led to time-loss from the sport; a quarter of all time-loss injuries were hamstring muscle injuries (n=113 out of a total of 480 time-loss injuries; 23.5%). The overall incidence of hamstring muscle injuries was significantly higher in males than females (22.4 ± 3.4 *vs.* 11.5 ± 2.6 injuries per 1000 registered athletes, respectively; RR=1.94; 95% CI: 1.42-2.66, moderate).

Hamstring muscle injury incidences differed significantly between events for males and females for outdoor and total championships (p<0.001), but not for indoor competitions. The 3 prevalent events were sprints, jumps and hurdles for male athletes, and sprints, combined events and hurdles for female athletes. Hamstring muscle injury incidences were higher in combined events, sprints, and hurdles than in other events for male athletes, and in combined events, sprints and hurdles than in other events for female athletes. Comparing between explosive-power events (sprints, hurdles, jumps, throws and combined events) and endurance events (middle and long distances, marathon and race walks) revealed differences (p<0.05) for male athletes only in the distribution of *i)* injury cause (higher proportion of non-contact trauma hamstring muscle injuries in explosive-power events), and *ii)* injury severity (higher proportion of time-loss hamstring injuries in explosive-power events).

Discussion

The main findings of the present study were that the most frequent diagnosis was hamstring muscle injuries, accounting for 19.3% in males and 13.5% in females of all injuries incurred during international athletics championships. Males were more at risk than females (RR=1.94; 95% CI=1.42-2.66), and athletes were more likely to injure themselves during competitive events mainly caused by overuse with sudden onset (44.9%), although the risks varied between the events.

This is the first study to provide a detailed description of the incidence and characteristics of the principal diagnosis of injury during international athletics championships. The large number of championships, and consequently, the number of hamstring muscle injuries included in the present study have allowed us to provide detailed analyses regarding their location, cause, severity, event groups, and age-categories. The present results extend previous smaller studies that reported hamstring muscle injuries as the most common diagnosis during international athletics championships (Alonso et al., 2009; Alonso et al., 2010; Alonso et al., 2012; Edouard et al., 2013; Edouard et al., 2014; Feddermann-Demont et al., 2014; Alonso et al., 2015; Edouard et al., 2015; Edouard et al., 2015), and during the single-meet event of Penn Relay Carnival (Opar et al., 2014).

The hamstring injury risk was clearly higher in explosive-power events (sprints, hurdles, jumps and combined events). In explosive-power events, a higher proportion of hamstring muscle injuries were caused by non-contact trauma and their severity was greater. Our findings extend previous results in combined events (Edouard et al., 2010; Edouard et al., 2012). Thigh muscle injuries have been reported to be the most common diagnosis in national combined event championships (21.6%) (Edouard et al., 2012), and hamstring muscle injuries to be the most frequent diagnosis and cause of dropouts during a decathlon competition (Edouard et al., 2010).

Part 2: The role of hamstring muscles in sprint acceleration performance

Given the very close links between the practice of accelerating activities and sprints, and hamstring muscle injury prevalence, a better understanding of the biomechanical and muscular determinants of sprint performance could be relevant in order to better understand the mechanisms and/or risk factors of this injury (Bahr et al., 2005; Krosshaug et al., 2005).

Sprint is an explosive activity, the ability to develop a great power in the horizontal direction is often presented as a determinant of sprint performance (Cronin et al., 2005). Developing a great power in the horizontal direction is directly related to muscle ability to develop high levels of force at high velocity, but also the ability to effectively orient this force onto the ground, i.e. in the horizontal direction (Morin et al., 2011). Indeed, it has been reported that the ability to correctly orient the force on the ground despite the increase in running speed, quantified by the change in the ratio between the horizontal component of the force and the total force developed when the running speed increases (D_{RF}), was a decisive factor of sprint performance, more important than the magnitude of total force output itself (Morin et al., 2011; Morin et al., 2012). Thus, horizontal force production on the ground, mainly determined by the horizontal orientation of the net force, represents an important determinant of sprint performance. To orient the force on the ground despite the running speed increases during sprint acceleration must therefore be a training objective for athletes (Morin et al., 2011; Morin et al., 2012).

Understanding the role of hamstring muscles in the sprint biomechanics, in the horizontal force production, and in the sprint performance determinants, is also relevant in this prevention process. Hamstring muscles, due to their bi-articular nature, act as an hip extensor and as a knee flexor (Kumazaki et al., 2012). During a sprint stride, hamstring muscle are activated continuously, but particularly during the terminal phase of the swing phase and when ground support (Heiderscheit et al., 2010; Kumazaki et al., 2012; Opar et al., 2012). However, we aimed to determine the role of hamstring muscles in the sprint acceleration performance

Methods

This was a descriptive cross-sectional study analysing the sprint kinetics, isokinetic knee and hip extensors and flexors strength, muscle activity and sagittal plane lower limb motion, during a 6-secondes sprint on a motorised treadmill. The study was approved by the institutional ethics review board of the Faculty of Sport Sciences, and conducted according to the Declaration of Helsinki II.

Fourteen male subjects (body mass (mean ± SD): 79.9 ± 7.9 kg; height 1.79 ± 0.07 m; age 24.2 ± 4.6 years) trained for sprint running (seven soccer and basketball competitive level players, four under-23 high-level rugby union players, and three regional to national-level athletics athletes) volunteered to participate in this study. All subjects were free of musculoskeletal pain or injuries at the time of the experimentation and in the 6 months before. Written informed consent was obtained from the subjects.

A familiarization session for treadmill sprints and isokinetic tests was performed about one week prior to the testing session. For the testing session, the standardized warm-up consisted of 5 min of 10 $km.h^{-1}$ running, followed by 5 min of sprint-specific hamstring warm-up exercises, and three progressive 6-s sprints at increasing velocities separated by 2 min of passive rest. Subjects performed isokinetic warm-up following by maximal isokinetic strength measurements of knee extension (quadriceps strength, Q), knee flexion (hamstring strength, H), hip flexion (HFlex) and Hip extension (HExt). Then, EMG electrodes and reflective markers were placed on the right lower limb. Maximal EMG activity was measured for each muscle group for standardization. Subjects performed a new sprint specific warm-up on treadmill with two submaximal 6-secondes sprints. After 5 min of recovery, subjects performed one maximal 6-s sprint, during which mechanical data, EMG activity and video data were recorded.

Isokinetic muscle strength of H and Q was measured before HFlex and HExt isokinetic muscle strength using a Con-Trex® isokinetic dynamometer (Con-Trex MJ; CMV AG, Dübendorf, Switzerland). For H and Q isokinetic measurements, each subject was seated on the dynamometer, with 105° of coxofemoral flexion, with auto adhesive straps placed across the chest and pelvis, support to stabilize the contralateral limb, and with instruction to grip the seat during maximal measurements (Maffiuletti et al., 2007). The knee rotational axis was aligned with the dynamometer rotational axis. The dynamometer shin pad was attached 2-3 cm proximal to the malleoli. The range of knee motion was fixed at 90° (from full extension to 90° of knee flexion). For HFlex and HExt measurements, each subject lay in the supine position, with pelvis and chest was stabilised by auto adhesive straps, the hip in the sagittal plane and the knee flexed at 90° (Julia et al., 2010). The contralateral leg rested on a support under the foot, with 0° of hip extension and 90° of knee flexion (Julia et al., 2010). The dynamometer rotational axis was aligned with the trochanter major, and the tested side was attached to the dynamometer via a thigh strap. The range of hip motion was fixed at 90° (from 10° of hip extension to 80° of flexion). Peak torque normalized to body weight and agonist-to-antagonist ratios were used (PT_{BW}).

Sprint were performed and sprint kinetics were measured using a motorized instrumented treadmill (ADAL3D-WR, Medical Development – HEF Tecmachine, Andrézieux-Bouthéon, France) (for full details, see: (Morin et al., 2010)). Attached with a leather weightlifting belt and thin stiff rope to the wall behind, subjects start in a typical crouched sprint-start position with their preferred foot forward. According to the previous studies (Morin et al., 2010; Morin et al., 2011; Morin et al., 2012), sprint kinematics (contact time (*tc* in s), aerial time (*ta* in s), swing time (t_{swing}) and step frequency (*SF* in Hz)) and sprint kinetics (vertical force (F_V, BW), horizontal force (F_H, BW), total force (F_{Tot}, BW), Index of force application technique (D_{RF}), maximal velocity (*Vmax*, $m.s^{-1}$), maximal power output (*Pmax*, $W.kg^{-1}$)) were calculated.

EMG activity of the right *vastus lateralis* (VL), *rectus femoris* (RF), *biceps femoris* (BF) and *gluteus maximus* (Glut) muscles was recorded using bipolar silver chloride surface electrodes of 30 mm diameter (Meditrace 100, Tyco healthcare, Mansfield, Canada) placed on the skin according to recommendations by SENIAM,(Hermens et al., 2000) with low impedance ($Z<5$ kΩ) at the skin-electrode surface, and with

the reference electrode on the patella. Vertical GRF and EMG signals for the right leg were time synchronized on LabChart 7.3. EMG activity of each muscle was quantified using the root mean square (RMS) with a 20-ms moving window, and recorded during the following phases of the running cycle for the right leg: i) first half of the stance phase, ii) entire stance phase as detected by a 30-N threshold, iii) entire swing phase (from foot takeoff to the subsequent landing of the same foot), and iv) end-of-swing phase, defined as the aerial phase (no foot-ground contact) preceding the stance phase. RMS data for all phases were normalized to MVIC data obtained during two 3-second duration MVICs.
The motion of the right foot and knee was recorded in the sagittal plane of motion with a camera (sampling rate of 120 frames per second, Basler scA640-120gc, Basler AG, Germany) mounted on a tripod placed 1.5 m away from the treadmill in a lateral view. Retro-reflective markers were placed onto the great trochanter, the lateral femoral epicondyle, the fifth metatarsal head. Marker trajectories in the sagittal plane (vertical and horizontal directions) were tracked and analysed with Simi Motion 2D software (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany).
Correlation between the entire sprint mechanical output data (mainly horizontal force (F_H)) and isokinetic strength, muscular activity and sagittal plane lower limb motion variables was analysed using univariate analysis (Pearson's correlation) and multiple regressions models. The significance level was set at $P < 0.05$.

Results
None of the isokinetic variables measured were significantly correlated with F_H. Furthermore, EMG activity was not significantly correlated with F_H, whatever the muscle group and the part of the running cycle considered. Only a non-significant tendency ($P = 0.074$) was found between EMG activity of the BF over the end-of-the-swing phase and F_H, both averaged over the entire acceleration (i.e. all steps from the first to the step at maximal velocity). When considering data from all steps of the acceleration, the multiple regression analysis showed a significant ($P = 0.024$) relationship between F_H and the combination of both EMG activity of the BF during the end-of-swing phase and knee flexion peak torque in eccentric mode. No significant relationship or tendency was found between the muscular activity and peak torque variables tested and the values of vertical and resultant forces collected during the sprints.

Discussion
The main finding of this study was that the highest level of horizontal ground reaction force production was observed in subjects who had both the highest torque production capability of the hip extensors (especially hamstring muscles in eccentric mode) and the highest hamstring EMG activity during the end-of-swing phase over the entire sprint acceleration.
Moreover, the eccentric hamstring peak torque associated with the hamstring muscle activity of late phase in the swing phase were correlated with the horizontal force production, and consequently with the sprint acceleration performance. In order to develop the largest horizontal force during acceleration sprint, high hamstring muscle activation at the end of the swing phase and high hamstring eccentric strength seemed necessary. Thus, the hamstring muscles are preponderant in the sprint acceleration performance, and their function would be related to the ability to produce the horizontal force necessary to the sprint performance.

Part 3: The concept of the Force-velocity mechanical profile in sprint running and its measurement
In our approach to improve knowledge of the mechanisms and risk factors for hamstring muscle injury, and to develop appropriate screening tools to detect athletes at risk, it seems that the evaluation and/or analysis of the horizontal force production onto the ground may be an indirect marker of the hamstring muscle function.

Mechanical power can be estimated by the product of net force and velocity outputs in the direction of running ($P = F$ x V). During sprint acceleration, power output is the product of the horizontal net force output and the running speed. A relationship exists between these two components of the power, which change in opposite directions during a maximum acceleration (Driss et al., 2013). This inverse relationship is termed Force-velocity relationship (F-v relationship), one of the main features is its slope reflecting the Force-velocity mechanical profile (F-v profile) (Figure 1). This F-v profile indicates the relative importance of force and velocity capabilities in determining the maximum power (P_{max}). Thus, sprint performance may be determined by the power capacity of a subject, and also its Force-velocity mechanical profile and its components of horizontal force and velocity.

This F-v profile in sprint can be summarized by two extreme theoretical values of the neuromuscular system capabilities (Figure 1):

- The theoretical maximum horizontal force that the lower limbs may product during zero-velocity contact phase (F_{H0});
- The theoretical maximum velocity at which the lower limbs could propel the body mass during a contact phase without external constraints (V_0; correspond to the maximum velocity produced without generating any force).

Unfortunately, these mechanical properties could be recorded only using treadmill allowing sprint running or force plateform into the ground, since measuring horizontal antero-posterior and vertical GRF components and forward horizontal velocity during an entire sprint acceleration (~30–60 m) is currently needed to calculate such parameters.

Methods

Nine elite or sub-elite sprinters (age: 23.9 ± 3.4 years; body mass: 76.4 ± 7.1 kg; height: 1.82 ± 0.69 m) gave their written informed consent to participate in this study, which was approved by the local ethical committee and in agreement with the Declaration of Helsinki. Their personal 100-m official best times were 10.37 ± 0.27 s (range: 9.95–10.63 s).

After a standardized 45-min warm-up, subjects performed seven maximal sprints in an indoor stadium (2 × 10m, 2 × 15m, 20m, 30m and 40m with 4-min rest between each trial) in order to collect GRF data over an entire 40-m distance. From these sprints, antero-posterior and vertical GRF components; F–v, P–v, and *RF*–v relationships; and associated variables (F_{H0}, V_0, P_{max}, D_{RF}) were obtained from both force plate measurements, and a computation method based on an inverse dynamic approach applied to the body center of mass, estimates the step-averaged ground reaction forces in runner's sagittal plane of motion during overground sprint acceleration from only anthropometric and spatio-temporal data (for more information about concept and equation, please see scientific paper 3).

Results

There were a high correlation between the computation method and the force plate measurements, with a low bias (<5%) and narrow limits of agreement between both methods for maximal horizontal force, velocity, and power output. In addition, we reported a high reliability between trials (variability <5%).

Discussion

These findings support the validity and reliability of the proposed simple method, using only anthropometric and spatio-temporal data, convenient for field use, to determine power, force, velocity outputs, and mechanical effectiveness of ground force application in sprint running.

In this context, we can suggest to assess the sprint running Force-velocity mechanical profile, in field practice conditions, simply by measuring the instantaneous speed and the mass and size of the subject. In practice, this can be done during a 30- m sprint acceleration, starting in tripod position, at maximum intensity, on the usual sport field (athletics track, football field, handball gymnasium...), after a complete warm-up, with measurement of speed using a radar gun (e.g. the Stalker ATS System™ (Applied Concepts, Inc./Stalker Radar 2609 Technology Drive Plano, Texas 75074) or 4-5 pairs of photocells (e.g. kit Racetime2 Light, Microgate, Bolzano, Italy). More recently, these measurements have been shown possible (validation study under review) using a smart phone such as an iphone 5s or 6 and the application "*My Sprint*". The sprint distance is to adapt the performance of the subject, because the high-level sprinters will be able to accelerate even up to 60m. P_{max}, F_{H0}, V_0, F-v profile are then calculated from the instantaneous speed using the equation presented in Scientific paper 3.

Part 4: Sprint running Force-velocity mechanical profile in the context of hamstring muscle injuries

With the above mentioned conclusions in mind about the prevalence of sprint-related hamstring injuries, and the importance of hamstring muscles in generating horizontal force and power, and in turn sprint acceleration performance, we sought to use the recently developed field method in prospective protocols. The first data of this kind have been obtained in two high-level athletes (one soccer player and one rugby league player) who incurred a sprint-related hamstring injury during a prospective monitoring of their sprint acceleration mechanical outputs.

Methods

Measurements of the Force-velocity mechanical profile using a radar gun such as describe above, were performed in the context of hamstring muscle injuries, after injury, but also just before the occurrence of injury.

Force-velocity profile in sprint after hamstring muscle injury

In a professional football player, we reported a change in the Force-velocity profile in sprint, between before and after hamstring muscle injury, with a decrease of 21% of the slope coefficient of the F-v relationship, a decrease of 21% of F_{H0}, and no change of V_0.

Force-velocity profile in sprint before a hamstring muscle injury

We reported in a rugby player who has a hamstring muscle injury at the 5th sprint in a series of 10 sprints at maximum intensity, that the Force-velocity profile in sprint changed during the sprint in which the injury has occurred, with a 21% increase of the slope coefficient of the F-v relationship, a 14% increase of F_{H0}, and no change V_0 (-6%) compared to other sprints, while the other players decreased F_{H0} and V_0 (8% on average) and showed an unchanged slope coefficient of the F-v relationship.

Discussion

These results showed changes of the Force-velocity mechanical profile within hamstring muscle injury, especially changes in F_{H0}.

We observed a decrease in F_{H0} after hamstring muscle injuries, which could be a consequence of the injury. Moreover, we can hypothesize that the decrease of F_{H0}, corresponding to the decrease in horizontal force production during the sprint, could be a consequence of the decrease in muscle strength induced by the hamstring muscle injury. Indeed, a decrease in muscle strength of hamstring muscles was reported in the literature (Croisier et al., 2000; Dauty et al., 2003; Tol et al., 2014), and in particular on the eccentric strength of the hamstring muscles and the ratio eccentric hamstring to concentric quadriceps strength (Croisier et al., 2000; Dauty et al., 2003). These elements would be consistent for a perspective of use in clinical practice of monitoring the Force-velocity mechanical profile and F_{H0}, to indirectly evaluate the hamstring muscle strength and function, and to guide the return to sprint and optimise the post-injury recovery.

There appears to be a close link between hamstring muscle strength and horizontal force production (results of Part 2), a close link between hamstring muscle strength and a history of hamstring muscle injury (Croisier et al., 2000; Dauty et al., 2003; Tol et al., 2014), and a close link between hamstring muscle injury and the horizontal force production (results of Part 4). Moreover, deficit and/or imbalance in hamstring muscle strength has been reported as predisposing to the occurrence of hamstring muscle injury in football (Croisier et al., 2008) and athletics (Yeung et al., 2009), and as such can be considered as a risk factor for hamstring muscle injury. In this context, we can imagine that the deficit and/or imbalance in hamstring muscle strength might be indirectly assessed by measuring the macroscopic Force-velocity mechanical profile and F_{H0}, and therefore this measure of the Force-velocity mechanical profile and the F_{H0} could be a relevant screening tool of the risk of hamstring muscle injury. Another advantage is that this analysis requires the same testing as for the sprint performance analysis using the sprint Force-velocity profile, i.e. a simple 30-m to 50-m sprint.

Conclusions

Our multidisciplinary approach of the hamstring muscle injury issue, through epidemiological analyses to better determine the extend and characteristics of the problem, and through a biomechanical approach in laboratory and in field conditions, could bring new insights and practical tools to help athletes, coaches, medical teams in hamstring muscle injury prevention. Specifically, we could provide interesting information to better understand why hamstring muscles seem to be more at risk of injury during sprint acceleration given their role in sprint acceleration performance. We also provided a relevant method to measure the mechanical properties of sprint running in sprint-specific field conditions. We showed a relationship between changes in sprint mechanical properties and hamstring muscle injury conditions. Analysing the forward propulsion function of hamstring muscles during a maximum acceleration sprint is promising given the close links between the strength and function of the hamstring muscles and the horizontal force production in sprint, given the very functional and practical evaluation in field conditions, and led to these encouraging preliminary scientific results. This measure of Force-velocity mechanical profile could be used to guide the return to sprint and allow maximum recovery from a hamstring muscle injury, but also to prospectively screen athletes at risk of hamstring muscle injury. All these results represent future directions for hamstring muscle injury prevention by improving the functional follow-up of injured athletes (secondary prevention) but also by screening athletes (primary prevention). Further prospective cohort studies are needed to confirm these preliminary results and hypothesis, and to better define which the parameters and/or criteria are relevant to follow athletes after hamstring muscle injury and/or to screen athletes at risk in a prevention approach.

RECOMMANDATIONS

Sports sciences and medical researches should be conducted together. The aim of athletes, coaches, and medical teams are similar: improve performance and prevent injuries. Injury prevention allows higher performance, and well-conducted training allows injury prevention. Thus, our results could have an impact on both of these sports research aims to help coaches, physicians and athletes to practice Athletics safely and with better performance.

1) Hamstring muscle injury is the main injury diagnosis in athletics, especially in high level athletes during international championships.
   Consequently:
   - Athletics injury prevention research should focus this specific injury,
   - Medical teams should improve their knowledge and skills to take car of hamstring muscle injury,
   - Athletes should pay attention to pain of bad feelings regarding their hamstring muscles.

2) Hamstring muscles play a major role for sprint acceleration performance. Both a high level of eccentric hamstring strength and high level of hamstring EMG activity during the end-of-swing phase over the entire sprint acceleration are important for high level of horizontal ground force production, and consequently of sprint acceleration performance. Thus :
   - Training should be focused on the improvement of eccentric strength and activity of hamstring muscles.
   - That should be beneficial for sprint acceleration performance,
   - But also for hamstring muscle injury prevention since hamstring strength deficit represents a risk factor for hamstring muscle injury.

3) Sprint mechanical and functional Force-velocity properties measurements can be easily done in field conditions using simple tools and methods.
   - Force-velocity mechanical profile measurements is relevant for coaches to monitor and adapt training.
   - Force-velocity mechanical profile measurements is relevant for physiotherapists and medical teams to monitor the return to sports after hamstring muscle injury, and to better determine the decision to return to sport (secondary prevention).
   - Force-velocity mechanical profile measurements seems relevant screen/detect athletes at risks for hamstring muscle injury (primary prevention).