A new testing and training device for hamstring muscle function

Jean-Patrick Giacomo [1], **Johan Lahti** [2], **Andras Hegyi** [3], **Pauline Gerus** [2], **Jean-Benoit Morin** [2]

[1]Centre d'Évaluation et d'Analyse de la Performance Sportive, Carros, France,[2]Université Côte d'Azur, LAMHESS, Nice, France, and [3]Neuromuscular Research Center, Faculty of Sport and Health Sciences, University of Jyvaskyla, Jyvaskyla, Finland

Technical note | Testing | Hamstrings | Injuries

Headline

Modern team sport context is associated with both high training and games demands, and consequently high injury rates. Thus, reducing injuries is key for performance, health and economical reasons. For example, the training, research and medical communities are dedicated to better understand and thus prevent or at least reduce the number of hamstring injuries. This technical report presents a novel field device designed to improve hamstring muscle function via movement patterns closer to those observed when hamstring injuries typically occur.

Aim. Hamstring injury is a major, unresolved, health issue in sports (1), with two main injury mechanisms: sprint-related and overstretching-related strains (2-4). This raises the question of effective prevention and rehabilitation protocols (5,6), during which hamstring strength output, especially during lengthening actions, is a central component (9,10). The aim of this technical report is to introduce a novel device for potentially further optimizing hamstrings strength training and testing.

Description of the device

The *"Hamtech"* (Fig. 1) is a passive device based on an exoskeleton-like light frame, and instrumented with a S-type force sensor (1000 N capacity in traction) for each foot and a potentiometer (P4500, Novotechnik U.S., Inc) for the knee joint. The data is recorded by an acquisition card (National instrument, Austin, TX, USA) at 1000 Hz through a custom program (Labview v 8.5, National instrument, Austin, TX, USA).

The overall motion with the *Hamtech* is similar to the Nordic hamstring exercise (NHE)(7,8). When performing NHE, relatively weaker players are unable to control the movement until full knee extension, which clearly limits the maximal active lengthening of the muscles. This premature ending of the action during the NHE was an important limitation to address since long muscle lengths represent a target zone for injury prevention purpose (9–11). This well-known limitation of the NHE is resolved when using the *Hamtech* since the frame and assistance/resistance systems allow a progressive work targeting a significant range of the hamstrings force-length spectrum (Fig. 1). The specific settings of the *Hamtech* thus allow to individually set exercise intensity by setting both the knee extension and the hip flexion angles (which are both known to directly influence the mechanical constraint put on the hamstrings over a typical knee flexion-extension exercise (11). Finally, as shown in Fig. 1, this device allows enough assistance to the motion that each movement modality can be performed in unilaterally, which may add further value from an adaptation standpoint (12).

Exercises and testing modalities

Nordic Hamstring Exercise with hip at 0° (NHE0). The frame of the device brings a support to the trunk, which helps to maintain the hip angle at 0° throughout the knee range of motion. This improvement compared to the standard NHE will thus provide the opportunities that (i) the hip extension is controlled, and (ii) the muscular work is maintained throughout the full knee range of motion including long muscle lengths.

Nordic Hamstring Exercise with hip at 90° (NHE90). This modality (13) has the main advantage of specifically loading

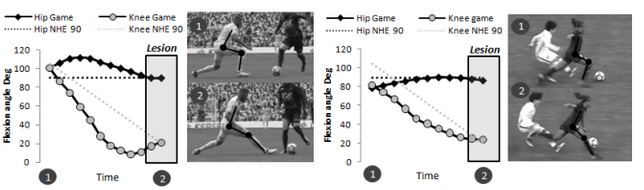

Fig. 2. Schematic analysis of hip and knee angles during a real football game overstretch injury (game video footage analysed with Dartfish™ software) compared to the NHE90 data (hip angle set constant at 90°) and knee angle measured by electronic potentiometer. For the lesion area, the hip-knee angles with the *Hamtech* closely match the estimated angles in the game situation.

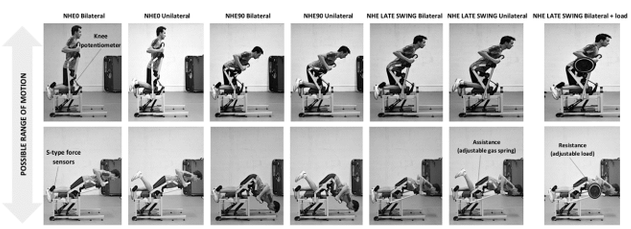

Fig. 1. Description of the *Hamtech* device main exercise modalities: Nordic Hamstring Exercise with extended hip (NHE0), Nordic Hamstring Exercise with 90° hip flexion (NHE90), Nordic Hamstring Exercise with sprint late swing phase kinematics (NHE Late Swing). Note that isometric testing can be performed at any of the possible hip-knee angles within that range of motion. See video in Supplementary material.

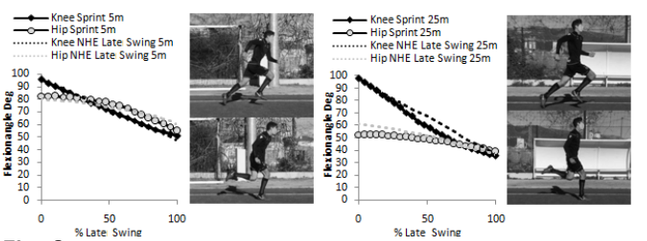

Fig. 3. Schematic illustration of the sprint swing phase hip and knee angles in the sagittal plane (computed from 240 frames per second videos at 5 and 25 m in professional academy football players), in comparison to the hip and knee angles measured with the *Hamtech* device in the NHE Late Swing mode. Zero degree correspond to no hip or knee flexion, and late swing phase is defined as the time between the contralateral foot take-off and the ipsilateral foot landing.

the hamstrings at long muscle length thanks to the constant 90° hip flexion induced by the frame of the device and the trunk support. This possibility is particularly interesting for prevention-rehabilitation work (9,10). A common mechanism of hamstring injury is by an overstretching motion with a flexed hip and a maximally extended knee, which places the hamstring group at particular risk due to substantial lengthening (11). The schematic analysis below (Fig. 2) shows how the hip-knee angles during the NHE90 exercise match the overstretch injury conditions (lesion grey area).

Finally, some of our data under review show higher maximal torque produced during NHE90 than in NHE0. This is in accordance with the results of Guex et al. (11) who discussed the clear influence of hip flexion angle on the hamstring maximal torque capability.

Nordic hamstring exercise with sprint late swing phase hip-knee kinematics (NHE Late Swing). This third modality is based on the idea that a specific training of the hamstring should include training that targets maximal torque output in the hip-knee angle combinations (and thus associated muscle lengths) that are close to the late swing phase of the sprint motion, which is thought to be where most sprint related injuries happen (4,14–17). The *Hamtech* frame allows simulation of the late swing hip and knee angular kinematics (Fig. 1 and 3) at two different phases of the sprint acceleration: early acceleration (5-m zone) and late acceleration (top speed, 25-m zone). As seen in the video (Supplementary material), and in the schematic analysis shown in Fig. 3, the coordinated hip and knee extensions throughout the late swing phase angular sector covered using the *Hamtech* closely match the late swing phase of sprinting, be it at 5 or 25m.

Furthermore, these two sub-settings of the NHE Late Swing mode also allow a stimuli correspondence towards the specific length-tension conditions of the sprint from the early phase (5 m) to the top speed phase (25 m). The latter mode is designed to reproduce the hip-knee angles of top speed running, since at that distance (i) most team sport players reach at least 95% of their individual top running speed, and (ii) hamstring EMG activity showed a relatively stable maximal level (18).

Measurements

In the various types of exercises shown in Fig. 1, the *Hamtech* allows measurements to be performed in concentric, isometric and eccentric modes. The "eccentric action" is seen here as the active lengthening of the hamstring muscle-tendon units during knee extension. The torque output is computed from force measurements and the femoral epicondyle to ankle support distance (standardized at 5 cm above the lateral malleolus, the force sensors being aligned with the ankle support).

Isometric: maximal torque output and rate of torque development. Assessing maximal voluntary isometric contraction (MVIC) torque is a classic of exercise and sport science, due to the safe, easy-to-standardize and high reliability. The *Hamtech* device allows this in bilateral and unilateral testing modes, with a large panel of hip-knee angle combinations (from 0° hip-90° knee to 90° hip-0° knee, as set with the device frame), and thus a large number of muscle length possibilities. Fig. 4 shows a typical unilateral test where the MVIC torque is identified at a stable plateau of a 1-s contraction. The rate of torque development might also be measured as shown in Fig. 4, which is typically used to estimate the explosiveness of the hamstrings (19). This may be of particular interest when assessing fatigue and/or in a rehabilitation context (20,21).

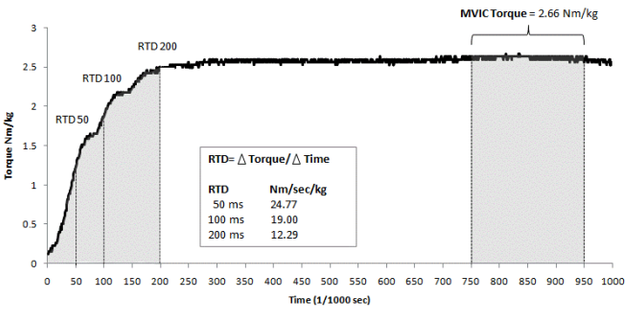

Fig. 4. Illustration of a typical isometric test (raw force data converted into torque data via the measurement of the knee flexion lever arm) and the associated variables of maximal torque and rate of torque development. The maximal torque is computed via a 200 ms moving average.

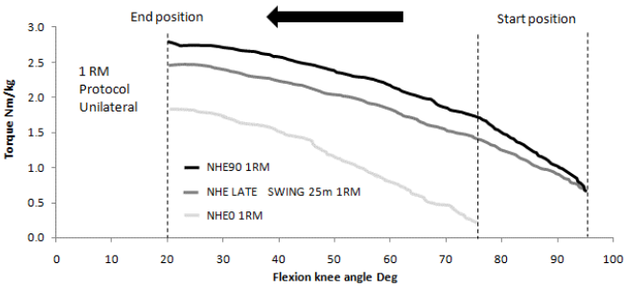

Fig. 5. Typical angle-torque profile for a football player, during a 1RM test in NHE0 exercise (light grey), in the NHE Late Swing mode (dark grey) and in the NHE90 mode (black). After calibration, start and end position angles correspond the actual anatomical knee angle (calibrated, as on an isokinetic machine) and not to the *Hamtech* frame angles.

Finally, this assessment of both maximal isometric and explosive isometric torque output is possible at hip-knee angles close to those typically seen during the sprint motion (see previous section).

Eccentric: peak torque output. Although hamstring muscles lengthening during sprinting is debated (22,23), the concomitant hip flexion and knee extension during the sprint swing phase place the hamstring muscle-tendon units in both lengthening and very high force demand conditions. To our knowledge, *Hamtech* is the only field device that allows measuring eccentric knee flexion torque concomitantly with hip and knee angles in individually maximal conditions (1RM). This is specifically possible thanks to (i) adjustable levels of assistance or resistance (ii) trunk support and (iii) support and guidance added to the knee angle and torque measurements throughout the angular sector covered (Fig. 5). These features remove some limitations of existing systems (e.g. 24,25), with which force assessment does not match some of the previously described specificity criteria. This setting also allows conforming to studies showing recommending that effective hamstring torque assessment should be accompanied by angle-torque assessment (26). Some studies suggest that the key metrics in the eccentric modality should be peak torque (especially expressed relatively to the athlete's body mass (27,28)) and total angular work (i.e. the area under the torque-angular displacement curve (25,29)) (Fig. 5).

Practical Applications

- The *Hamtech* possibly allows an accurate, progressive and individualized training and injury prevention-rehabilitation work. For example, in pre-season, the effects of inter-season break on hamstring function could be assessed in isometric mode (MVIC and rate of torque development) (30) before progressively orienting the work and monitoring towards eccentric actions.
- The modularity of the *Hamtech* (Fig.1) allows a progressive and controlled increase in the mechanical load at the targeted muscle lengths, which seem to be major components of hamstring rehabilitation.
- Rate of torque development might also be of value in the return-to-sport decision (e.g. after hamstring or anterior cruciate ligament injuries) to both ensure an effective rehabilitation and a possibly lower risk of re-injury (31).
- All the aforementioned exercises and modalities can be performed (i) on the training version of the device, that is not equipped with sensors and (ii) in fatigue conditions induced by sport-specific training or exercise repetitions on the *Hamtech*.

Limitations

- As for any ergometer, the *Hamtech* has a limited biomechanical specificity compared to the actual sprint movement. However, as discussed before, its sprint-specificity is possibly further optimized compared to existing devices due to hip-knee angle kinematics, the late swing modality, and the assistance-resistance setting that allows individualized maximal intensity in both bilateral and unilateral conditions.
- The *Hamtech* is not intended to replace actual sprint training and the incomparable stimulation it represents in terms of performance and hamstring injury prevention and rehabilitation (32,33). Thus, it should be considered as a tool for specific, complementary (or preparatory) muscular stimulation and/or assessment.
- Finally, this article aims only at presenting the *Hamtech* device, and some ongoing works will discuss the reliability and reproducibility of the measurements (13).

Conflict of interest

The first author, Jean-Patrick Giacomo is the inventor and patent owner (patent under review) of the Hamtech device. Contact: twitter: @jp_giacomo. More information on the Hamtech and Hamtech Lab . None of the other authors has a potential conflict of interest to declare.

Supplementary Material

This video shows the typical exercise modalities of the device presented.

Twitter: Follow JP Giacomo: @jp_giacomo, J Lahti: @lahti_johan, A Hegyi: @And_Hegyi, P Gerus: @PaulineGerus, JB Morin: @jb_morin

References

1. Ekstrand J, Waldén M, Hägglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. Br J Sports Med. 2016;50(12):731–7.
2. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. Br J Sports Med. 2013;47(15):953–9.
3. Ekstrand J, Healy JC, Waldén M, Lee JC, English B, Hägglund M. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. Br J Sports Med. 2012;46(2):112–7.
4. Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A, et al. The Football Association Medical Research Programme: an audit of injuries in professional football–analysis of hamstring injuries. Br J Sports Med. 2004;38(1):36–41.
5. Mendiguchia J, Martinez-Ruiz E, Edouard P, Morin J-B, Martinez-Martinez F, Idoate F, et al. A Multifactorial, Criteria-based Progressive Algorithm for Hamstring Injury Treatment. Med Sci Sport Exerc. 2017;49(7):1482–92.
6. Mendiguchia J, Alentorn-Geli E, Brughelli M. Hamstring strain injuries: are we heading in the right direction? Br J Sports Med. 2012;46(2):81–5.
7. Petersen J, Thorborg K, Nielsen MB, Budtz-Jørgensen E, Hölmich P. Preventive Effect of Eccentric Training on Acute Hamstring Injuries in Men's Soccer. Am J Sports Med. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21825112
8. van der Horst N, Smits D-W, Petersen J, Goedhart EA, Backx FJG. The Preventive Effect of the Nordic Hamstring Exercise on Hamstring Injuries in Amateur Soccer Players. Am J Sports Med. 2015;43(6):1316–23.
9. Tyler TF, Schmitt BM, Nicholas SJ, McHugh MP. Rehabilitation After Hamstring-Strain Injury Emphasizing Eccentric Strengthening at Long Muscle Lengths: Results of Long-Term Follow-Up. J Sport Rehabil. 2017;26(2):131–40.
10. Schmitt B, Tim T, McHugh M. Hamstring injury rehabilitation and prevention of reinjury using lengthened state eccentric training: a new concept. Int J Sports Phys Ther. 2012;7(3):333–41.
11. Guex K, Gojanovic B, Millet GP. Influence of Hip-Flexion Angle on Hamstrings Isokinetic Activity in Sprinters. J Athl Train. 2012;47(4):390–5.
12. Škarabot J, Cronin N, Strojnik V, Avela J. Bilateral deficit in maximal force production. Eur J Appl Physiol. 2016;116(11–12):2057–84.
13. Lahti J, Giacomo J-P, Gerus P, Noulé T, Hegyi A, Morin J-B. Nordic hamstring exercise torque and sprint acceleration mechanical profile and performance in team sport athletes; are they related? In: World Congress of Biomechanics. Dublin; 2018.
14. Chumanov ES, Heiderscheit BC, Thelen DG. Hamstring Musculotendon Dynamics during Stance and Swing Phases of High-Speed Running. Med Sci Sport Exerc. 2011;43(3):525–32.
15. Heiderscheit BC, Hoerth DM, Chumanov ES, Swanson SC, Thelen BJ, Thelen DG. Identifying the time of occurrence of a hamstring strain injury during treadmill running: A case study. Clin Biomech. 2005;20(10):1072–8.
16. Thelen DG, Chumanov ES, Best TM, Swanson SC, Heiderscheit BC. Simulation of biceps femoris musculotendon mechanics during the swing phase of sprinting. Med Sci Sports Exerc. 2005;37(11):1931–8.
17. Schache AG, Dorn TW, Blanch PD, Brown NAT, Pandy MG. Mechanics of the Human Hamstring Muscles during Sprinting. Med Sci Sport Exerc. 2012;44(4):647–58.
18. Morin J-B, Gimenez P, Edouard P, Arnal P, Jiménez-Reyes P, Samozino P, et al. Sprint Acceleration Mechanics: The Major Role of Hamstrings in Horizontal Force Production. Front Physiol. 2015;6:404.

19. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations. Eur J Appl Physiol. 2016;116(6):1091–116.
20. Marshall PWM, Lovell R, Jeppesen GK, Andersen K, Siegler JC. Hamstring Muscle Fatigue and Central Motor Output during a Simulated Soccer Match. Hug F, editor. PLoS One. 2014;9(7):e102753.
21. Buckthorpe M, Pain MTG, Folland JP. Central fatigue contributes to the greater reductions in explosive than maximal strength with high-intensity fatigue. Exp Physiol. 2014;99(7):964–73.
22. Van Hooren B, Bosch F. Preventing hamstring injuries - Part 2: There is possibly an isometric action of the hamstrings in high-speed running and it does matter. Sport Perform Sci Reports. 2018;Apr. 25.
23. Shield A, Murphy S. Preventing hamstring injuries - Part 1: Is there really an eccentric action of the hamstrings in high speed running and does it matter? Sport Perform Sci Reports. 2018;Apr. 25.
24. Opar DA, Piatkowski T, Williams MD, Shield AJ. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. J Orthop Sports Phys Ther. 2013;43(9):636–40.
25. Hickey JT, Hickey PF, Maniar N, Timmins RG, Williams MD, Pitcher CA, et al. A Novel Apparatus to Measure Knee Flexor Strength During Various Hamstring Exercises: A Reliability and Retrospective Injury Study. J Orthop Sport Phys Ther. 2018;48(2):72–80.
26. Brockett CL, Morgan DL, Proske U. Predicting hamstring strain injury in elite athletes. Med Sci Sports Exerc. 2004;36(3):379–87.
27. Buchheit M, Cholley Y, Nagel M, Poulos N. The Effect of Body Mass on Eccentric Knee-Flexor Strength Assessed With an Instrumented Nordic Hamstring Device (Nordbord) in Football Players. Int J Sports Physiol Perform. 2016;11(6):721–6.
28. Roe M, Malone S, Delahunt E, Collins K, Gissane C, Persson UM, et al. Eccentric knee flexor strength profiles of 341 elite male academy and senior Gaelic football players: Do body mass and previous hamstring injury impact performance? Phys Ther Sport. 2018;31:68–74.
29. Opar DA, Williams MD, Timmins RG, Dear NM, Shield AJ. Rate of Torque and Electromyographic Development During Anticipated Eccentric Contraction Is Lower in Previously Strained Hamstrings. Am J Sports Med. 2013;41(1):116–25.
30. Presland JD, Timmins RG, Bourne MN, Williams MD, Opar DA. The effect of Nordic hamstring exercise training volume on biceps femoris long head architectural adaptation. Scand J Med Sci Sports. 2018;28(7):1775–83.
31. Angelozzi M, Madama M, Corsica C, Calvisi V, Properzi G, McCaw ST, et al. Rate of Force Development as an Adjunctive Outcome Measure for Return-to-Sport Decisions After Anterior Cruciate Ligament Reconstruction. J Orthop Sport Phys Ther. 2012;42(9):772–80.
32. Malone S, Roe M, Doran DA, Gabbett TJ, Collins K. High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. J Sci Med Sport. 2017;20(3):250–4.
33. Stares J, Dawson B, Peeling P, Drew M, Heasman J, Rogalski B, et al. How much is enough in rehabilitation? High running workloads following lower limb muscle injury delay return to play but protect against subsequent injury. J Sci Med Sport. 2018;21(10):1019–24.