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NEW FIELD ERGOMETER TO REPRODUCIBLY MEASURE MAXIMUM STRENGTH AND RATE OF FORCE DEVELOPMENT OF HAMSTRINGS

Nouvel ergomètre de terrain pour mesurer de manière reproductible la force maximale et le taux de développement de la force des ischio-jambiers

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Résumé

Objectifs : Les blessures aux ischio-jambiers sont fréquentes dans les activités basées sur le sprint et sont multifactorielles. L'un des principaux facteurs de risque est le déficit de force excentrique des ischio-jambiers, qui n'est pas facile à évaluer sur le terrain. Par conséquent, un nouvel ergomètre appelé "Hamtech" a été développé pour évaluer de manière précise et pratique, la force des ischio-jambiers. L'objectif de cette étude était de tester la reproductibilité de ce nouvel ergomètre lors de contractions isométriques et excentriques maximales.

Matériels et Méthodes : Treize joueurs de football (âge : $20,7 \pm 1,6$ ans ; stature : $178,1 \pm 4,9$ cm ; masse corporelle : $72,1 \pm 6,3$ kg) ont été recrutés. Après deux séances de familiarisation, la production de force des ischio-jambiers a été enregistrée lors de contractions isométriques et excentriques maximales à l'aide de l'Hamtech. Les coefficients de variations et de corrélations intra-classes ont été utilisés pour quantifier la reproductibilité.

Résultats : Cet ergomètre permet des mesures reproductibles de la force maximale unilatérale (isométrique + excentrique) et bilatérale (excentrique). Cependant, la reproductibilité était moyenne à bonne (unilatéral) et faible (bilatéral) pour l'angle du genou lors du pic de force excentrique. Une bonne reproductibilité a été observée pour le taux de développement à 200-ms de la force lors des contractions isométriques maximales.

L'Hamtech offre une solution simple et reproductible pour mesurer la production de force des ischio-jambiers lors de contractions isométriques et excentriques. L'utilisation des ischio-jambiers en unilatéral à grande longueur musculaire pourrait constituer une alternative intéressante à la condition bilatérale classique pour évaluer la production de force des ischio-jambiers.

Mots clés : Blessure aux ischio-jambiers ; production de force ; taux de développement de la force ; prévention des blessures ; ergomètre.

Abstract

Objectives: Hamstring strain injuries are common in sprint-based activities and multifactorial. One of the main risk factors is the deficit of hamstring eccentric strength, which is not easily assessed in field conditions. Therefore, a new ergometer named “Hamtech” has been developed to accurately and practically assess hamstring force output. The aim of this study was to test the reproducibility of this novel ergometer during maximal isometric and eccentric contractions.

Materials and Methods: Thirteen soccer players (age: 20.7 ± 1.6 years; stature: 178.1 ± 4.9 cm; body mass: 72.1 ± 6.3 kg) were recruited. After two familiarization sessions, hamstring force production was recorded during maximal isometric and eccentric contractions using the Hamtech. The coefficients of variations and intra-class correlations coefficients were used to quantify reproducibility.

Results: This ergometer allows reproducible measurements of unilateral (isometric + eccentric) and bilateral (eccentric) peak force. However, the reproducibility was moderate to good (unilateral) and poor (bilateral) for the knee angle at the eccentric peak force. A good reproducibility was observed for the rate of force development at 200-ms during maximal isometric contractions.

The Hamtech offers a simple and reproducible solution to measure hamstring force production during isometric and eccentric contractions. The use of unilateral hamstring muscles at long muscular length might provide a valuable alternative to the classical bilateral condition to assess the hamstring force production.

Keywords: Hamstring strain injury; force output; rate of force development; injury prevention; ergometer.

1. Introduction

Hamstring strain injuries are the most common non-contact injuries in sprint-based activities such as soccer [1], and classically occur at long muscular length during high-speed running. Their occurrence is greatest during the late swing phase of the stride cycle [2], when both hamstring activation [3] and muscle-tendon unit length peak [4].

An important modifiable risk factor is the capacity to produce high force at these specific (i.e. long) muscle lengths [5-6]. In order to train and improve this capacity using the Nordic Hamstring Exercise (NHE) has been explored for injury prevention and rehabilitation [7-8]. While recent recommendations [9] may have led to a slight drop in hamstring strain injury incidence [10], few limits must be overcoming to accentuate the success of training and prevention strategies, including the NHE. Indeed, the classical NHE movement is monoarticular (knee flexion), bilateral and some players are too weak to withstand the load (i.e. their own body mass) imposed by the movement [11]. The exercise is not performed over the full knee-hip range of motion, especially involving specific articular angles at which hamstring strain injuries mostly occur. This premature ending of the action limits the maximal active lengthening of the muscles, which is an important purpose for injury prevention [12]. Finally, external loading cannot be adjusted (increased/decreased) to match each player’s individual capacity in testing and training [11].

Understanding the mechanisms underlying hamstring strain injuries and optimizing hamstring strength training and testing are a real necessity in the modern sports context from a social, financial and performance point of view. All the aforementioned limitations may be potentially limited by using specific ergometer. Recently, a novel field ergometer named “Hamtech” ([13],

Human Kinematic, Carros, France) has been developed to improve hamstring muscle function via specific movement patterns at which injury typically occur. Indeed, this ergometer allows performing the NHE movement from different hip and knee angles combinations under both bi- and unilateral conditions during eccentric, concentric and isometric actions with continuous measurement of the force output and the knee angle of each lower limb. Thanks to its frame support and assistance/resistance system, the “Hamtech” possibly allows an individualized, progressive and accurate control of work at the targeted muscle length (i.e. long muscle length). However, it would be necessary to test the reproducibility of this field ergometer, taking into account the movement pattern of the injury context to arrive at consensual observations.

Thus, the purpose of the present study was to test the reproducibility of this new ergometer to assess hamstring force production during maximal isometric and eccentric contractions. Because of its features, we hypothesize that using the Hamtech will ensure a reproducible assessment of both isometric and eccentric hamstring force production during bi- and unilateral contractions.

2. Methods

2.1. Population

Thirteen healthy and physically active soccer players (age: 20.7 ± 1.6 years; stature: 178.1 ± 4.9 cm; body mass: 72.1 ± 6.3 kg) were recruited from an university football team. Participants had no history of lower limb injury during the 6 months preceding the study and provided written informed consent prior to testing. All procedures were conducted according to the Declaration of Helsinki.

2.2. Experimental procedure

Four experimental sessions were performed (two familiarization sessions, one test and one re-test session), separated by at least one week, and following the same experimental protocol. The specific warm up consisted in 2×6 repetitions of “Extender” exercise per lower limb, 2×6 repetitions of “Diver” per lower limb [14] and 3 unilateral hamstring isometric contractions on the Hamtech up to $\sim 50\%$, $\sim 70\%$ and $\sim 100\%$ of their maximal voluntary force for each lower limb (30-s rest). Once participants were kneeling on the Hamtech, the lever arm was adapted to their individual anatomical characteristics and set at above 5 cm above the malleolus, onto the Achilles tendon. The contact points at the heels, knees, thighs, and torso had to be maintained during all the contractions (Figure 1.A). Hamstring force output were measured directly on the Hamtech. Throughout the protocol, isometric contractions were performed at a standardized position of 30° knee flexion and 43° hip flexion (0° = full extension). This specific hip-knee angle combination was set to match the late swing phase articular angulations (unpublished 2D motion analysis data collected on soccer players).

After the warm-up, participants performed a 1-s maximal voluntary isometric hamstring contraction (MVC) for each lower limb with 30-s rest. Another trial was performed two minutes later. Then, after 3-min recovery, the same protocol was performed, this time with 3-s contractions. During these MVC, participants were instructed and strongly encouraged verbally to “contract as hard and as fast as possible” with no countermovement. Classically, performing 3-s contractions is a “gold-standard” to assess maximal force production capacity [15]. However, shorter contractions (i.e. 1-s) are recommended to assess rate of force development [16] and are more suitable to field context (i.e. less time consuming) than longer ones (i.e. 3-s).

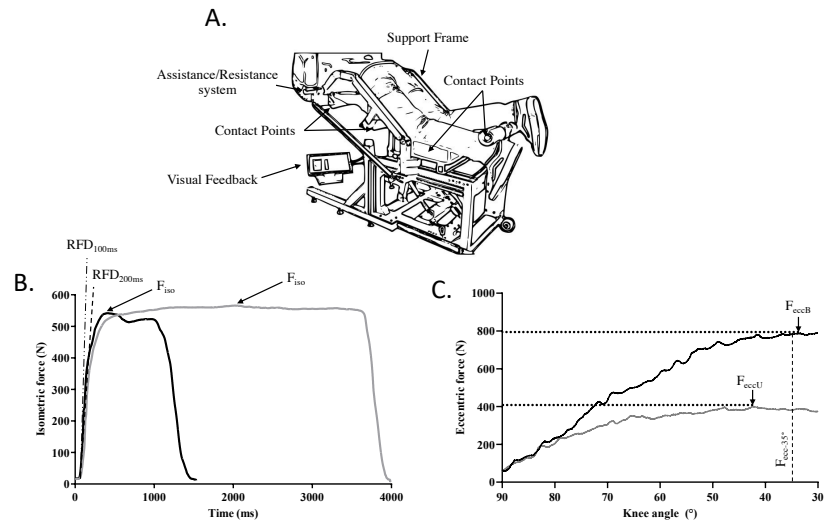


Figure 1: A. Representation of the position adapted on the Hamtech during maximal voluntary isometric contraction (MVC). B. Typical 1-s (black line) and 3-s (grey line) force trace during MVC and the associated variables. C. Typical unilateral (grey line) and bilateral (black line) force trace during eccentric contractions and the associated variables. F_{iso} : isometric peak force; RFD_{100ms} and RFD_{200ms} : rate of force development during the initial 100ms and 200ms, respectively; F_{eccU} and F_{eccB} : eccentric peak force during unilateral and bilateral condition, respectively, F_{ecc-35° : eccentric force at 35° knee flexion.

After the isometric trials, they performed two unilateral (30-s rest) and two bilateral eccentric contractions (30-s rest) with each lower limb. During the unilateral eccentric contractions, the range of motion was 90° to 30° knee flexion and 60 to 43° hip flexion to mimic the late swing movement. During the bilateral condition, the same knee's range of motion was performed, but with a hip angle fixed at 0° to simulate the classic NHE (perform without ergometer). All eccentric contractions were performed at a controlled angular velocity ranging from 5 to 12.5°/s. These values were determined to maintain all contact points and ensure a control of the contraction even at long muscle length. Participants regulated themselves their movement velocity thanks to a visual feedback displayed on a screen in front of them. Eccentric contractions were performed in the individually maximal condition for each lower limb (i.e. eccentric 1 repetition maximum: 1 RM). Each participant's 1 RM was determined during the familiarization session. Participants had to perform the eccentric movement with increasing loads on the ergometer (start: own body mass, increment: 5 kg, 1-min rest between trials). A trial was deemed valid when the participant could voluntary maintain an angular velocity between 5 and 12.5°/s over the full knee range of motion. Two valid trials were necessary to complete the step. The highest loading step validated was retained as the eccentric 1 RM and was verified during each testing (test and re-test) session just after the warm-up, to maintain or adapt it.

2.3. Data collection

Force data was collected for each lower limb with S-beam classic force transducers (capacity of 1000 N each, LS02-S, Tech Co. Ltd, Shenzhen, China) and a potentiometer (P4500, Novotechnik U.S., Inc., Southborough, MA, USA) for the knee joint angle, and sampled at 1000 Hz via a 64-bit acquisition card (National instrument, Austin, TX, USA) and a custom program (Labview version 14.0, National instrument, Austin, TX, USA).

During MVC the peak force (F_{iso}) and the rate of force development (RFD) were analyzed for each lower limb (Figure 1.B) [15, 16] Following the recommendations of Maffiuletti et al., (2016), quantifying RFD was made at two time points: during the initial 100-ms (RFD_{100ms}) and 200-ms (RFD_{200ms}) of the contraction [16]. The force onset was automatically set at three SD (standard deviation) of the last 200-ms of baseline. If a countermovement was visible prior to force onset, the trial was discarded and repeated. The RFD_{100ms} and RFD_{200ms} were

respectively calculated by linear fitting of the first 100-ms and 200-ms after force onset, respectively.

During eccentric contractions, the peak force (F_{ecc}), knee angle at peak force ($\theta_{F_{ecc}}$) and force developed at 35° knee flexion (i.e. long muscle length; F_{ecc-35°) were analyzed for each condition (unilateral and bilateral) (Figure 1.C). Indeed, the deficit of both eccentric peak force and eccentric force at long muscle length were reported as main factors of hamstring strain injury.

2.4. Statistical analysis

Data were screened for normality of distribution and homogeneity of variances using Shapiro-Wilk normality test and the Bartlett test, respectively. The intra- and inter-session reproducibility were respectively assessed by comparing the values of the two trials during one session and by comparing the maximal value obtained during each session. The intra-class correlation coefficient (ICC) with a 95% confidence interval (95% CI) was also used to quantify reproducibility and ranked as follow: < 0.5 = poor, < 0.75 = moderate and > 0.75 = good reproducibility [17]. Calculations of the coefficients of variations (CV) and errors standard of measurements (SEM) were also made. Student's T-test for paired series were used to compare parameters between modalities (1-s vs 3-s and unilateral vs bilateral). Data were analyzed using IBM SPSS Statistics software (IBM SPSS Statistics, NY: IBM Corp) with a significance level set at $p < .05$.

3. Results

All variables assessed during the two sessions and ICCs were reported in (Table 1). A color code was used to represent the different reproducibilities reported (green = good; orange = moderate; red = poor). In isometric modalities, a good reproducibility was observed for both 1-s and 3-s F_{iso} and RFD_{200ms} . However, a moderate to poor reproducibility was found for RFD_{100ms} . In eccentric modalities, a good reproducibility was observed for both unilateral and bilateral F_{ecc} and F_{ecc-35° . In contrast, a moderate to poor reproducibility was found for $\theta_{F_{ecc}}$.

No significant difference was reported between 1-s and 3-s for F_{iso} ($p > .05$ for both right and left lower limbs), RFD_{100ms} and RFD_{200ms} ($p > .05$ only for the right lower limbs). However, a significant difference was found for both RFD assessed on the left lower limb ($p < .05$). Moreover, a significant differences were found between F_{ecc} and F_{ecc-35° for the three modalities: unilateral ($p < .01$ for both right and left lower limbs) and bilateral ($p < .001$). During the bilateral condition, F_{ecc} was significantly lower than the unilateral ones (left + right) ($p < .01$).

Table 1: Isometric and eccentric contractions parameters and intra class correlation coefficients (ICC) with a 95% confidence interval (95% CI), coefficients of variations (CV), errors standards of measurements (SEM) in intra- and inter-session.

	Parameters	Intra Session 1			Intra Session 2			Inter Session			
		CV (%)	SEM	ICC (95% CI)	CV (%)	SEM	ICC (95% CI)	CV (%)	SEM	ICC (95% CI)	
1-s MVIC	Right Leg	F _{iso} (N)									
		RFD _{100-ms} (N.s)	2.7	0.7	0.98 (0.92 – 0.99)	2.1	0.5	0.99 (0.96 – 1.00)	3.8	1.0	0.95 (0.82 – 0.98)
		RFD _{200-ms} (N.s)	9.3	2.3	0.58 (-0.23 – 0.87)	4.9	1.2	0.92 (0.75 – 0.98)	7.5	1.9	0.76 (0.26 – 0.93)
	Left Leg	F _{iso} (N)									
		RFD _{100-ms} (N.s)	2.6	0.7	0.98 (0.93 – 0.99)	2.6	0.7	0.99 (0.95 – 1.00)	4.8	1.2	0.92 (0.73 – 0.97)
		RFD _{200-ms} (N.s)	11.1	2.8	0.57 (-0.47 – 0.87)	9.5	2.4	0.82 (0.39 – 0.95)	8.4	2.1	0.66 (-0.01 – 0.89)
3-s MVIC	Right Leg	F _{iso} (N)									
		RFD _{100-ms} (N.s)	3.0	0.8	0.97 (0.92 – 0.99)	2.11	0.5	0.99 (0.96 – 1.00)	3.9	1.0	0.96 (0.86 – 0.99)
		RFD _{200-ms} (N.s)	12.4	3.1	0.73 (0.16 – 0.92)	8.2	2.1	0.70 (0.05 – 0.91)	6.0	1.5	0.84 (0.50 – 0.95)
	Left Leg	F _{iso} (N)									
		RFD _{100ms} (N.s)	2.5	0.6	0.98 (0.93 – 0.99)	2.0	0.5	0.99 (0.96 – 1.00)	3.6	1.0	0.96 (0.88 – 0.99)
		RFD _{200ms} (N.s)	8.3	2.1	0.84 (0.46 – 0.95)	9.5	2.4	0.58 (-0.37 – 0.87)	11.5	2.9	0.29 (-1.66 – 0.79)
Eccentric contractions	Right Leg	F _{ecc} (N)	2.8	0.7	0.99 (0.88 – 1.00)	4.5	1.1	0.96 (0.88 – 0.99)	5.2	1.3	0.95 (0.84 – 0.98)
		θ _{F_{ecc}} (°)	6.5	1.6	0.76 (0.22 – 0.93)	6.8	1.7	0.81 (0.40 – 0.94)	5.4	1.3	0.84 (0.49 – 0.95)
		F _{ecc-35°} (N)	2.9	0.7	0.99 (0.95 – 1.00)	3.3	0.8	0.98 (0.93 – 0.99)	5.0	1.3	0.96 (0.88 – 0.99)
	Left Leg	F _{ecc} (N)	4.6	1.2	0.96 (0.87 – 0.99)	2.9	0.7	0.98 (0.94 – 0.99)	5.2	1.3	0.94 (0.82 – 0.98)
		θ _{F_{ecc}} (°)	7.3	1.8	0.23 (-1.78 – 0.77)	5.5	1.4	0.80 (0.36 – 0.94)	5.9	1.5	0.67 (-0.16 – 0.90)
		F _{ecc-35°} (N)	3.9	1.0	0.97 (0.92 – 0.99)	2.9	0.7	0.99 (0.95 – 1.00)	5.3	1.3	0.95 (0.83 – 0.98)
	Bilateral	F _{ecc} (N)	2.2	0.5	0.99 (0.97 – 1.00)	2.5	0.6	0.99 (0.96 – 1.00)	2.5	0.6	0.98 (0.95 – 1.00)
		θ _{F_{ecc}} (°)	5.2	1.3	-0.33 (-0.82 – 0.30)	2.7	0.7	0.05 (-1.70 – 0.71)	4.0	1.0	0.34 (-0.59 – 0.77)
		F _{ecc-35°} (N)	2.2	0.6	0.99 (0.97 – 1.00)	2.8	0.7	0.99 (0.95 – 1.00)	2.9	0.7	0.98 (0.93 – 0.99)

MVC: maximal voluntary isometric contraction; **F_{iso}:** isometric peak force; **RFD_{100-ms}** and **RFD_{200-ms}:** rate of force development during the initial 100-ms and 200-ms, respectively; **F_{ecc}:** eccentric peak force; **θ_{F_{ecc}}:** knee angle at F_{ecc}; **F_{ecc-35°}:** force developed at 35° knee flexion.

4. Discussion

The main finding of the present study was that the Hamtech allows reproducible measurements of hamstring force production capacity during isometric (F_{iso} and RFD_{200ms}) and eccentric contractions (F_{ecc-35°} and F_{ecc}) both in unilateral and bilateral condition. These findings suggest that the ergometer can be used as a reproducible field ergometer to assess and / or train hamstring muscles. Indeed, the technological features of the present ergometer permit the assessment to be based on the individualized external loading apply during the NHE, thanks to the assistance/resistance system. Thus, it may facilitate a progressive approach of the training or rehabilitation by adapting loading modalities and magnitude of knee-hip angles to train hamstring muscles at target muscle length at which hamstring strain injury occurs.

In isometric modalities, no significant difference for F_{iso} (both lower limbs), RFD_{100-ms} and

RFD_{200-ms} (only for the right lower limb) between 1-s and 3-s MVC were found, suggesting that these two durations may be used interchangeably, and supporting the use of 1-s MVC in field context to minimize testing duration and burden for the players. On the other hand, RFD_{100-ms} was found to be less reproducible (poor to moderate reproducibility) than RFD_{200-ms} (good reproducibility) during both 1-s and 3-s MVC. This highest RFD variability during early phase of voluntary contraction had been already observed on knee extensors muscles [18]. The authors reported that early RFD during electrically evoked contractions (supramaximal evoked octet) was less variable. Thus, the less reproducibility of early RFD during voluntary contractions could be more related to neural factors than contractile properties. Despite this finding, assessing the rate of force development might also be necessary in a rehabilitation context to justify the return to play decision [15]. Then, performing short MVC (i.e. 1-s) during rehabilitation phase could be more accepted by the athletes than longer MVC (i.e. 3-s) and may be offering a value to ensure an effective rehabilitation and potentially a lower risk of re-injury. In the eccentric modalities, the significant difference between F_{ecc-35° and F_{ecc} ($p < .01$ for both the right and left lower limb; $p < .001$ for the bilateral) suggests that the only assessment of eccentric peak force might generate some misleading information. A specific assessment at the knee angle closer to the hamstring strain injuries context is likely more informative. In the present study, a significant decrease of force production output was observed during unilateral contraction, after the peak was reached. Considering that eccentric force deficit at long muscle length is an important risk factor for hamstring strain injuries [5-6], strengthen and assess hamstring eccentric force at these specific muscle length were important issues. Furthermore, the present study reported that eccentric peak force was significantly lower during bilateral than the sum of the unilateral ones (left + right) ($p < .01$). This phenomenon is named bilateral deficit [19] and is principally explain by neurological effects [20]. Then, to assess the maximal force production capacity of each lower limb, it would be more recommended to perform unilateral MVC.

Finally, poor reproducibility (both intra- and inter-session) of the $\theta_{F_{ecc}}$ during bilateral eccentric contractions was observed. Moreover, the $\theta_{F_{ecc}}$ was significantly lower during bilateral contractions compared to the unilateral ones ($p < .001$ for both lower limbs). This suggests a possibly different muscle recruitment strategy between the two lower limbs. Nonetheless, no significant difference for $\theta_{F_{ecc}}$ was observed between lower limbs during unilateral eccentric contractions, making this modality available to assess hamstring capacity, due to its better reproducibility within each lower limb.

5. Conclusion

Thus, the “Hamtech” can be considered as a reproducible field ergometer to assess hamstring force production both in isometric and eccentric contraction modes with individualized and accurate evaluation. In addition, using unilateral contractions was more appropriated to assess hamstring maximal force production capacity than bilateral contractions. Finally, the 1-s and 3-s MVC modalities could be used interchangeably to assess isometric peak force and RFD but the shorter duration might be preferred in terms of practical applications in field context.

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7. References

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