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Posterior thigh muscles activity during the active H-test: An electromyographic and kinematic analysis

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ABSTRACT

The Askling's H-test is considered a useful return to play criterion after a hamstring muscle injury (HMI). However, it assesses only the active and passive flexibility of posterior thigh muscles. This may lead the practitioner to underestimate a compensation or abnormal movement pattern. The aim of this study was to analyze these kinematic aspects and their reliability, and evaluate the hamstring (HM) and gluteus maximus (GM) muscles' activities. Twelve healthy male volunteers were tested during two session of three trials for passive and active tests. Dynamic flexibility (97.2 ± 6.0°) was significantly greater than the passive one (70.5 ± 14.7°) ($p < 0.001$), and good intra-individual reproductibility for most kinematic characteristics was observed. Biceps Femoris long head, semitendinosus and GM mean activities (20.1 ± 11.2%; 14.3 ± 7.3% and 25.2 ± 22.1%, respectively) were found to be low to moderate, indicating that only a moderate level of activity occurred during the active H-test, in comparison to other movements such as sprinting itself. In addition, the activity of the posterior thigh muscles during the active H-test appeared to be variable among the volunteers. These findings suggest that the H-test should be interpreted on an individual basis rather than relying on general characteristics, and be considered as an intermediate tool before more strenuous activities such as returning to sprint. With this comprehensive approach, clinicians can gain a more accurate understanding of their patients' progress and make more informed decisions about their readiness to return to play.

1. Introduction

Hamstring muscle injury (HMI) is the most frequent non-contact injury especially in soccer (12–15%) or on the track field [Opar et al., 2012], and represents as much as 37% of all non-contact muscular injuries in these sports [Opar and Serpell, 2014]. This injury is found in 80% of the cases in the upper third of the biceps femoris long head (BFlh), near the myotendinous junction [Fiorentino and Blemker, 2014].

HMI mainly occurs in explosive movements characterized by acceleration and deceleration efforts [Brooks et al., 2005; Williams et al., 2013]. These are particularly found in the switching phase between the early first stance [Orchard 2012] and the very last swing phases of sprinting [Chumanov et al., 2012], when the high magnitude of mechanical strain in opposite directions causes hip flexion and knee extension [Liu et al., 2017; MacDonald et al., 2019] with the higher hamstring muscle activity found among other movements (100% of maximal voluntary activation; the maximum mechanical load applied to a muscle increases with its activity) [Koh and Brooks, 2007; Blemker, 2014].

Despite a concentrated effort to prevent or rehabilitate hamstrings injuries, its significant incidence stays high in both competition and training, with a high re-injury rate (18–30%) [Williams et al., 2013; Ekstrand et al., 2016]. In numerous sports, this leads to major financial costs and a decrease in sports participation as it negatively impacts the individual and global teammate performance. Even with many helpful remediation strategies [Buckthorpe et al., 2019], it remains difficult in daily practice to decide when an athlete can safely return to training and competition after an HMI [Bisciotti et al., 2019].

The purpose of Askling's study was to establish the reliability and validity of an active hamstring flexibility test (an active version of the straight leg raise) and to investigate whether it could detect differences between previously injured and healthy legs at a point in the rehabilitation when conventional clinical tests, including a passive flexibility test, showed no difference and thus would have allowed return to sport [Askling et al., 2010]. It seems helpful to evaluate the subjective feeling of insecurity associated with an explosive stretching movement, in

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addition to measuring the active range of motion (ROM) asymmetry between legs. However, in the original protocol, the authors did not examine many kinematic aspects during the active H-test (e.g. peak/-mean velocity of movement or angle at peak velocity) nor the muscle activity of the major the posterior thigh muscles (hamstrings and gluteus maximus, known as the major hip extensors which decelerate the leg during extended hip flexion movements). This may potentially lead the practitioner to underestimate a specific deficit of a hamstring muscle group, as compensatory and abnormal movement patterns (e.g. involuntary refrained maximal velocity intent and explosive start) may go undetected during this isolated hip flexion movement.

A first objective in our observational study was to define if kinematic characteristics of the H-test (range of motion, peak/mean velocity, hip flexion movement duration and angle at maximum velocity) are useful for characterizing the individual movement pattern, using 3D-motion analysis. The second aim of our study was to assess whether the reliability and reproducibility of these different characteristics is acceptable in healthy male volunteers. Finally, a third aim was to determine whether the hip flexion movement of the active H-test implies a high muscle recruitment of the long head of biceps femoris (BFlh), semitendinosus (ST) and gluteus maximus (GM) muscles using surface electromyography (sEMG), resulting from the stretch movement of the H-test which is perform in a ballistic manner with a maximal intent.

Our hypotheses are that additional kinematic characteristics could provide valuable insights to characterize individual movement pattern during the H-test in a reliable way. We hypothesized that a high recruitment of hamstrings and gluteus maximus muscles occurred during this pure hip flexion movement performed with maximal intent (and a presumed high mechanical stress), and ultimately may serve as reliable assessment tools.

2. Materials and methods

2.1. Participants

Twelve healthy male volunteers (23.0 ± 3.2 years, 180.9 ± 7.4 cm, 73.7 ± 7.2 kg) with a dominant right leg were included in the study. The sample size was determined using G-Power (3.1; http://www.gpower.hhu.de) (effect size = 0.30; alpha significant level = 0.1 and power = 0.70) [Delvaux et al., 2020; Serdar et al., 2021]. The volunteers were recruited to be active in a variety of explosive sports (soccer and rugby) with particular emphasis on the lower-limbs, but were excluded if they had suffered from a previous or current injury to the lower back or lower limbs that had resulted to at least three weeks of rest [Pollock et al., 2021]. In addition, all volunteers were asked not to practice any intensive sport within the two days preceding the test. The local ethics committee of Liège approved the study, and all volunteers signed an informed consent form beforehand.

2.2. Experimental procedure

The experimentation was conducted between January and April in 2021. It consisted of two sessions separated by a 30-min break interval. Each session consisted of one practice trial and three tests trials of passive and active test, performed in a random order with a 15-s rest interval between each trial. Before the H-test, the skin was shaved, prepared with sandpaper and cleaned with alcohol prior to the placement of sEMG sensors. These were placed on GM, BF and ST muscles to record their activities during the test (known as the main hip extensors muscles). The recording electrodes were placed on the muscle bellies identified by palpation and based on sEMG recommendations [Barbero et al., 2012]. sEMG activity of these muscles were recorded using Delsys Trigno Sensors with silver-contact wireless bipolar bar electrodes and 10 mm fixed inter-electrode spacing (Delsys Inc, Natick, MA, USA). The maximal voluntary activity (MVA) of each muscle was measured during maximal voluntary isometric contraction (MVIC), in a standard sitting position with 90 degree of hip and knee flexion for HM, and in a supine lying with 45 degree of hip flexion and 90 degree of knee flexion for GM (following the same procedure than in Delvaux et al. study) [Delvaux et al., 2020]. More specifically, each participant was asked to practice three trials of isometric contractions (5 s in which they had to maintain the contraction before relaxing during the sixth second). During the entire task, the volunteers were supported by verbal encouragements. Rest periods of 30 s were also accorded between each MVIC trial to avoid peripheral fatigue.

For the H-test, the participants were positioned in a standard supine position on the table [Fig. 1; Boland and Adams, 2000; Delvaux et al., 2020]. For the experimentation, a knee brace ensured full extension of the tested leg (dominant leg) and two straps were used to stabilize the upper body and the controlateral leg. To determine the leg dominance, we previously asked to participants, “If you were to shoot a ball at a target, which leg should you use to shoot the ball?” [Van Melick et al., 2017]. The foot of the tested leg was to be kept in a slight plantar-flexed position. An optoelectronic 3D system was used because of its high precision [Schwartz et al., 2015] with one marker attached to the lateral femoral epicondyle and a second marker on the lateral malleolus. The marker’s 3D positions were measured using four Codamotion CX1 units [Charnwood Dynamics, Rothley, UK] (and synchronized with Delsys Trigno Sensors system) at a sampling rate of 200 Hz. With the software of this device, different parameters of the H-test were calculated such as the hip angle at peak velocity (express as a percentage of the range of motion of the active H-test), total range of motion of passive and active straight leg raise, mean and peak velocity and test duration of the active H-test. For the passive test, the investigator slowly raised the examined leg. The subject was instructed to relax and say “stop” as the movement reached the maximal range of motion (ROM) when he reported a strong but tolerable stretching sensation in the hamstring musculature. The other part of the flexibility test, the active test, was an adapted version of the Askling H-test [Askling et al., 2010]. Contrary to the Askling’s protocol (passive test was done immediately before the active test), we randomly performed the active and passive test to avoid any influence of stretching on posterior thigh flexibility [Shrier, 2004]. The whole procedure was identical to the passive test, but the instructions given to the participant were to perform a hip flexion as fast as possible to the highest point without risking injury. Like the passive test, one practice trial and three test trials were executed with a 15-s rest interval. Passive as well as active flexibility were measured as the largest ROM of the three trials.

2.3. Data processing

The EMG signal was first band pass filtered (20–500 Hz, zero-phase 4th order Butterworth) and then processed using a root-mean-square algorithm (100 ms and 500 ms moving window for the H-tests and the MVIC trials respectively) [Castelein et al., 2015; Schwartz et al., 2017]. The muscle activity level during each H-test trial was expressed as a

Fig. 1. Passive H-test.

percentage of the maximal MVA found among the three MVIC repetitions.

2.4. Data analysis

From kinematic (passive and active ROM, test duration of the hip flexion motion only, angle at peak velocity, mean and peak velocity) and sEMG analysis (BF, ST and GM), the Shapiro-Wilk test was applied to examine and confirm the distribution normality. The mean values and the standard deviation (SD) were then calculated. In addition, each test's reliability was estimated by comparing the two sessions of the H-test and calculating the Intraclass Coefficient Correlation (ICC; Two-way mixed effects, absolute agreement, single rater/measurement based on Koo and Li, 2016) with 95% confident interval (95% CI) and coefficient of variation (% CV) (Statistical Analysis System package - SAS; World headquarters, SAS Institute Inc., Cary, NC, USA). We considered an ICC over 0.90 as very high, from 0.70 to 0.89 as high and finally from 0.50 to 0.69 as moderate [Denegar and Ball, 1993]. The maximum of the two sessions for active and passive ROM was compared using paired-Student t-tests. One-way repeated-measures analysis of variance (ANOVA) was used to compare the sEMG mean activity of the three muscles. A Bonferroni adjustment was used for post-hoc tests when the ANOVA results showed a statistically significant effect (with significance level set at $p < 0.05$).

3. RESULTS

3.1. 3D motion analysis

Active flexibility was significantly greater than the passive one in the two sessions by 27% (ROM of 70.2 ± 14.5° and 70.7 ± 14.8° in the first and second session of the passive test, versus 95.8 ± 5.4° and 98.5 ± 6.5° in the active one; p < 0.001; Table 1). The mean test duration of the active H-test was 0.40 ± 0.05s for both sessions (Table 2; Fig. 2). Moreover, the mean velocity for the active test showed significant differences between the first (242.8 ± 26.4°/s) and second test (251.4 ± 30.2°/s) with faster values for the latter (p-value = 0.045; Table 2). Finally, the main kinematic parameters of the H-test in both active and passive modalities were found to be reliable between the two sessions (ICC >0.75) except for the angle at peak velocity, which was only moderately reliable (0.54 [−0.12–0.87]).

3.2. sEMG analysis

Mean values of muscle recruitment were fund globally low for the GM (25.7 ± 23.5% and 24.7 ± 20.6%), the BFlh (21.0 ± 12.5% and 19.2 ± 9.9%) and the ST muscle (13.7 ± 8.1% and 14.8 ± 6.4%) (Table 3). sEMG muscle activity values were found to be moderately reliable between the first and second session of the active test for the HM (ICC of 0.63 [−0.01–0.90] for BFlh and 0.73 [0.18–0.93] for ST) and highly reliable for the GM (ICC of 0.98 [0.91–0.99]). Mean values of each muscle activity were not statistically different between the first and second session (p > 0.05; Table 3, Fig. 2).

Table 1
Mean range of motion (ROM) for the two sessions of the passive and active H-test with the dominant right leg in healthy male volunteers.

	Passive ROM		Active ROM	
	S1	S2	S1	S2
Mean ± SD (°)	70.2 ± 14.5	70.7 ± 14.8	95.8 ± 5.4	98.5 ± 6.5
ICC (95% CI)	0.98 (0.93–0.99)		0.87 (0.52–0.96)	
CV (%)	3.07		3.31	
Inter-session comparison (p-value)	0.42		0.19	
Passive vs active ROM comparison (p-value)	<0.001			

S1 = first session; S2 = second session; Mean amplitude in degrees (°); SD = standard deviation; 95% CI = 95% Confidence Interval; ICC = Intraclass Coefficient Correlation; CV = Coefficients of Variation.

4. Discussion and implication

The aims of the study were to analyze, the kinematic aspects, the reliability of the H-test characteristics and the HM and the GM's recruitment pattern in healthy male volunteers.

This study highlights two main results: 1) the active H-test demonstrated a good intra-individual reproductibility for most of its kinematic parameters and for muscular recruitment in healthy male volunteers 2) an important variability in posterior thigh muscular recruitment (and low activity) was observed during the active H-test among volunteers.

4.1. Kinematic analysis of the H-test

Our results showed that active flexibility was significantly greater than passive flexibility (+27%), probably because the active movement was done in a ballistic manner with high kinetic energy produced from the movement leg. This difference was found in similar proportions than in Askling and Delvaux's studies (+20–23%) [Askling et al., 2010; Delvaux et al., 2020], but with lower absolute results (around 10° less for the passive movement and 5° less for active movement in our study). That may be explained by the different characteristics of the groups (twelve soccer and rugby players in our study, male and female athletes together in Askling's study, and active volunteers from different sports in Delvaux et al.'s study). In addition, we observed a significant but limited increase in mean velocity (+3% from 242.8°/s to 251.4°/s) between the two sessions of the active H-test with higher mean velocity that in Prince et al. study (199.8–212.9°/s) and Askling et al. study (183–190°/s). This is probably explained by the difference of population as explained earlier. Our difference between the two sessions could result from a learning effect or lower apprehension that improved movement efficiency among volunteers. The good between-session reliability of most of the kinematic parameters (ROM, mean/peak velocity and duration) was found to be similar in magnitude to previous studies (0.95–0.99 for ROM in Askling et al., 2010; 0.57–0.91 for velocity and ROM respectively in Prince et al., 2023). It demonstrated that the volunteers keep constant their movement strategy pattern. Additionally, the wide range of mean and peak velocity values between volunteers highlight an important interindividual variability in speed movement and kinematic pattern, e.g. as found in Hegyi et al. study during a running task [Hegyi et al., 2019]. As a result, caution is warranted when the practitioner wants to compare the velocity characteristics of their subject with normative values, due to the highly individual movement pattern funded during the active H-test (Table 3). Moreover, kinematic data such as the mean/peak hip flexion velocity values were found hardly comparable with those observed during sprinting (peak hip velocity of 370.3°/s during the active H-test, in comparison with peak hip velocity >700°/s during sprinting) [Kivi et al., 2002; Clark et al., 2020]. In this regard, we would advise careful extrapolation of those results during functional movements like sprinting, which correspond to very fast and reflexive repetitive stretch-shortening cycles of the two legs. Nonetheless, the mean test duration in the active H-test (that correspond to the hip flexion only) demonstrated its relevance in assessing the subject posterior chain in maximal velocity intent, as its value was only slightly superior to the mean duration of the total swing time of sprinting, evaluated at 0.30s in the literature [Morin et al., 2015]. As a consequence, the active H-test represents a safer alternative for HM evaluation in comparison to sprinting, and could be useful to assess the stretch tolerance before returning to more mechanically stressful tasks like sprinting. We suggest incorporating the kinematic parameters of the active H-test (mean/peak velocity, mean duration, active and passive ROM and angle at peak velocity) into the evaluation routine, e.g. using 2D analysis as proposed by Prince et al. [Prince et al.,

Table 2
Parameters collected with the 3D captation system in the active H-test in healthy volunteers.

	Test duration (s)		Peak Velocity (°/s)		Mean Velocity (°/s)		Angle at peak velocity (% of the ROM)	
	S1	S2	S1	S2	S1	S2	S1	S2
Mean ± SD	0.40 ±0.05	0.40 ±0.05	372.3 ±51.8	368.2 ±38.1	242.8 ±26.4	251.4 ±30.2	49.7 ±5.9	47.9 ±6.3
ICC (95% CI)	0.94 (0.75–0.99)		0.98 (0.92–0.99)		0.91 (0.67–0.98)		0.74 (0.29–0.93)	
CV (%)	4.11		3.21		5.31		0.21	
Inter-session comparison (P-value)	0.08		0.18		0.045		0.09	

S1 = first session; S2 = second session; SD = Standard Deviation; 95% CI = 95% Confidence Interval; ICC = intraclass Coefficient Correlation; CV = Coefficient of Variation.

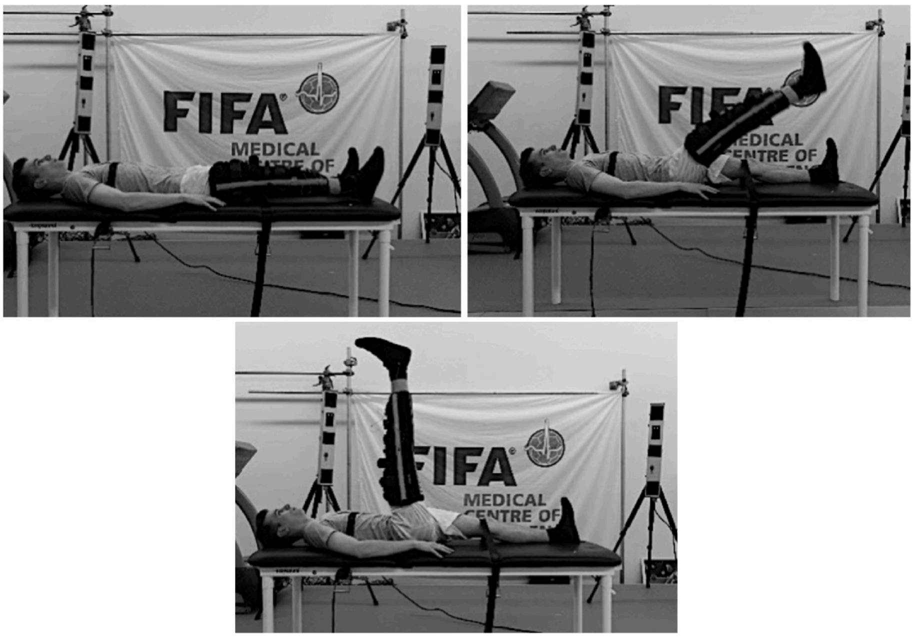

Fig. 2. Active H-test (standard supine starting position on the left picture, maximal active hip flexion on the right one).

Table 3
sEMG activation values for each muscle (% MVA or maximal voluntary activation) during the active H-test.

	Biceps femoris long head		Semitendinosus		Gluteus maximus	
	S1	S2	S1	S2	S1	S2
Mean ± SD (% MVA)	21.0 ±12.5	19.2 ±9.9	13.7 ±8.1	14.8 ±6.4	25.7 ±23.5	24.7 ±20.6
ICC (95% CI)	0.63 (−0.01–0.90)		0.73 (0.18–0.93)		0.98 (0.91–0.99)	
CV (%)	50.4		43.2		0.88	
Inter-session comparison (p-value)	0.11		0.20		0.25	
Between muscles comparison (p-value)			0.12			

S1 = first session; S2 = second session; MVA = maximal muscle activation; SD = standard deviation; ICC = interval coefficient correlation; 95% CI = 95% Confidence Interval.

2023]. It is recommended that the results be compared with the contralateral leg to ensure that the volunteersperformed with full confidence a maximal hip flexion at maximal velocity with an explosive start.

4.2. EMG analysis

Global sEMG recruitment values were found to be reproducible between the first and second test for both the BFlh and ST as well as for the GM. However, the important standard deviations of HM and particularly GM highlights that the recruitment pattern of these posterior thigh muscles might differ among individuals during the active H-test. This is in accordance with different findings [Higashihara et al., 2017; Schuermans et al., 2014; Hegyi et al., 2019] that showed the recruitment's pattern of GM (referred to as a "mono-articular muscle" and major hip extensor) and HM (that are rather referred to as "bi-articular muscles" and major knee flexors) could importantly vary among volunteers during activities involving fast hip movements. Although different authors have described that a "protective mechanism" of GM recruitment might occurs during hip stretching movements (an eccentric contraction of GM supposed to allow a reduction in the strain forces that the HM must endure). This mechanism is likely to be highly variable among individuals, as was found during the active H-test, and could help explain the important variability found in our study, especially for this muscle, and to a lesser extent for HM [Holt and Azizi, 2016; Edouard et al., 2018; Schuermans et al., 2017; Yu et al., 2008].

In addition, a relatively low mean activation value was found for both HM and GM during the active H-test. For comparison purposes, these values were comparable to those founded in pure fast stretch movement, e.g. the Standing Kick exercise [Prince et al., 2021]. However, this comparison should be handled with caution because of the different characteristics of the movements assess. The reason as to why the HM and GM muscles recruitment is moderate in our study (e.g. in comparison to sprinting that demonstrates very high muscular activation) could be explained by the fact that the active H-test is a purely isolated hip flexion, also performed with an indirect HM and GM eccentric force production without intentional reversal movement of the leg. However, it seems relevant to remember that this global lengthening force imposed on HM during the active H-test is non-uniformly shared inside their muscles groups, and not necessarily correlated to muscle fibers strain or even lengthening for all muscle fibers, despite they contract in a global eccentric mode [Brooks et al., 2005; Butterfield 2005; Herbert et al., 2015; Hooren and Bosch, 2017; Koh and Brooks, 2007]. Moreover, Cavagna [Cavagna 2006] showed that during very fast movements as in sprinting, the relative length and work changes in contractile elastic elements (CEE: muscle fibers) might be less important compared to the changes in serial elastic elements (SEE: tendon and aponevrosis) within the muscle-tendon unit (MTU) [Clark et al., 2020]. Nevertheless, as the greatest mechanical stress applied on a muscle rises with its activation rather than the global lengthening movement, the increase in muscle force or the mean speed [Koh and Brooks, 2007; Blemker, 2014], the active H-test seems to induce a lower amount of stress than the one found during the late swing phase of sprinting.

These H-test characteristics can be used but individually, and further studies analyzing these new data in combination with the H-test are warranted to potentially improve the assessment of HMI risk factors. Based on kinematic and EMG data, H-test can be used as an assessment tool of HM (or as a stretching exercise) prior to the more mechanically demanding tasks (such as sprinting) to ensure a gradual and safe return to play process. Since global muscle recruitment during the H-test was low to moderate, we thought further flexibility tests involving a hamstring Stretch-Shortening-Cycle would provide a more ecological assessment of hamstring flexibility.

Finally, some limitations should be mentioned. First, the moderate sample size and the characteristics of our volunteers (participating in soccer or rugby) may limit the interpretation of our results to other sports that have their own specific kinematic characteristics. We also urge the clinician to use these data with caution in terms of extrapolation.

5. Conclusion

The study aimed to provide further insights to analyze the active H-test's characteristics such as active ROM, test duration, mean/peak velocity, angle at peak velocity, passive straight leg raise and posterior thigh muscles' recruitment pattern. Moreover, this study led to three important conclusions. Firstly, we observed a good intra-individual reproducibility for most parameters of the H-test. Second, our results highlight the interindividual variability of hamstring and gluteus maximus muscle activity that occurs during the active H-test, underscoring how complex the behavior of posterior thigh muscles recruitment is, even during pure hip flexion. Finally, our study revealed that the active H-test induced relatively low activation for the HM and GM muscles compared to other exercises such as sprinting, highlighting its usefulness as an intermediate tool before participating to activities with higher velocity (such as sprinting), and in making informed decisions about the athlete's readiness to progress in the return to play process.

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Data availability and integrity

The data used for this article are available on request from the corresponding author. All authors have read and approved the final version of the manuscript and had full access to all the data in this study and take complete responsibility for the integrity of the data and the accuracy of the data analysis.

CRediT authorship contribution statement

A. Ferré: Writing – original draft, Software, Investigation, Formal analysis, Data curation. **F. Delvaux:** Writing – review & editing, Validation, Supervision, Methodology. **C. Schwartz:** Writing – review & editing, Validation, Supervision, Project administration, Methodology. **J.-L. Croisier:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors have no conflicts of interest that are relevant to findings of this manuscript.

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