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ORIGINAL ARTICLE

Lower eccentric hamstring strength and single leg hop for distance predict hamstring injury in PETE students

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Abstract

Hamstring injuries have not been under research in physical education teacher education (PETE) students so far. Within the frame of the development of an injury prevention program, for this study we conducted an analysis of modifiable risk factors for hamstring injuries in PETE students. Hamstring injuries of 102 freshmen bachelor PETE students were registered prospectively during one academic year. Eighty-one students completed maximum muscle strength tests of hip extensors, hamstrings, quadriceps (isometric) and hamstrings (eccentric) at the start of the academic year. Sixty-nine of the latter completed a single leg hop for distance (SLHD). Risk factors for hamstring injuries were statistically detected using logistic regression. Sixteen hamstring injuries (0.16 injuries/student/academic year; 0.46 injuries/1000 h) occurred to 10 participants. Eight cases were included in the risk factor analysis. Lower eccentric hamstring strength (odds ratio (ODD) = 0.977; p = 0.043), higher isometric/eccentric hamstring strength ratio (ODD = 970.500; p = 0.019) and lower score on the SLHD (ODD = 0.884; p = 0.005) were significant risk factors for hamstring injury. A combination of eccentric hamstring strength test and SLHD could give a good risk analysis of hamstring injuries in PETE students. This might offer great perspectives for easily applicable screening in a clinical setting.

Keywords: *Sports injuries, physical education, hamstring strength, handheld dynamometer, functional tasks*

Introduction

The problem of hamstring injuries in sports has been described and discussed widely. Several epidemiological studies reported high incidences in a varied field of sports (Brooks, Fuller, Kemp, & Reddin, 2006; Meeuwisse, Sellmer, & Hagel, 2003; Orchard & Seward, 2002), in both genders (Arnason et al., 2004; Söderman, Alfredson, Pietilä, & Werner, 2001), with often large periods of inactivity (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001) and high recurrence rates (Petersen, Thorborg, Nielsen, Budtz-Jorgensen, & Hölmich, 2011) as a consequence.

Despite thorough research concerning intrinsic risk factors for hamstring injury in the past, Freckleton and Pizzari (2013) recently concluded from a meta-analysis that only age, previous hamstring injury, and increased quadriceps peak torque were consistently associated with hamstring injury. Notwithstanding a broad spectrum of variables (hamstring flexibility, weight, hip flexor flexibility, quadriceps flexibility, ankle dorsiflexion lunge range of motion (ROM), and proprioception) has been under research, much attention has been paid to the role of strength measures. In this area, conflicting results have been found; Yamamoto (1993) showed that a decrease in an isometric hamstrings to quadriceps ratio (H:Q) was a risk factor for hamstring injury, whereas Bennell et al. (1998) did not find similar results for isokinetic H:Q ratio. Neither concentric (Freckleton & Pizzari, 2013) nor eccentric (Bennell et al., 1998) hamstring peak torque values seemed to be a risk factor for hamstring injury. Higher concentric quadriceps peak torque was shown to be a risk factor for hamstring injuries (Freckleton & Pizzari, 2013) but eccentric quadriceps peak torque not (Bennell et al., 1998). Fousekis, Tsepis, Poulmedis, Athanasopoulos, and

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Vagenas (2011) found that eccentric hamstring strength asymmetries could predict hamstring injury while concentric hamstring strength asymmetries could not. The role of hip extensor strength in predicting hamstring injury has not been under research so far, but Mendiguchia, Alentorn-Geli, and Brughelli (2012) recently suggested to assess concentric strength of the gluteus as they help the hamstring muscle to extend the hip.

The risk factor analyses mentioned above took peak strength measures in a single-joint task into consideration. Although these offer highly valuable information, during sports muscles most often work together and function in a multi-joint task, making the detection of a functional task as predictor of hamstring injury worthwhile. Moreover, recently more research effort has been put in setting up test batteries which can be easily used in a clinical setting. For this reason, several researchers investigated functional tasks as predictors of hamstring injury. Henderson, Barnes, and Portas (2010) found that hamstring injury risk increased with a better score on the non-counter movement jump (CMJ) test. On the other hand, Arnason et al. (2004) found no correlation of the non-CMJ, CMJ or CMJ on one leg with the occurrence of hamstring injury, nor did Engebretsen, Myklebust, Holme, Engebretsen, and Bahr (2010) find the CMJ to be a predictor of hamstring injury. Bennell et al. (1998) hypothesized that functional tests such as the single leg hop provide a better indication of the function of the hamstring muscles and thus injury risk and van der Harst, Gokeler, and Hof (2007) stated that the single leg hop and hold is in line with the high functional demands in sports.

Since the intracurricular sports activities of first-year bachelor physical education teacher education (PETE) students are characterized predominantly with locomotor activities, the assumption was made that also these multi-sport athletes suffer from a relatively high hamstring injury incidence. Considering the important role of physical education professionals in today's sports landscape, the development of an intervention for the prevention of sports injuries in PETE students and concomitant risk factor analysis including several intrinsic, modifiable variables is at issue. Because adolescent sports participation often has a multi-sport character (Kutz & Secrest, 2009), the findings of this study might also be of great importance for the general sports-active population.

The aim of this research was to investigate whether peak strength measures of quadriceps, hamstrings and hip extensors and scores on the single leg hop for distance (SLHD) were risk factors for the occurrence of hamstring injuries.

Methods

Participants were all 2011–2012 freshmen academic bachelor PETE students at Ghent University. One hundred and two participants (61 males, mean 18.2, s = 1.0 years; 41 females, mean 18.1, s = 0.6 years) were followed prospectively for the occurrence of hamstring injuries during one academic year. At the beginning of the academic year, after receiving all information concerning the study through an oral presentation and an information letter, students signed an informed consent form and completed a questionnaire including sports participation (time of exposure (TOE) to sports during the last year before entering the training; whether or not following a sports and/or physical education curriculum during the last year of secondary school) and sports injury history (injuries during the last 6 months before entering the study and more severe injuries in the past). Reliability of this questionnaire was proved in an earlier study (average kappa coefficient = 0.73 ± 0.20; range: 0.58; P < 0.01) (Goossens, Verrelst, Cardon, & De Clercq, 2014). An online injury and TOE registration form was filled out weekly and detailed information was obtained through a retrospective interview (Goossens et al., 2014). Eighty-one of all participants (49 males, mean 18.0, s = 0.8 years; 32 females, mean 18.3, s = 0.9 years) completed maximum muscle strength tests at the start of the academic year. Sixty-nine of these also completed a SLHD test. Not all participants completed all tests and this for diverse reasons: sickness, injury, unavailability at the moment of testing, etc.

The definition of an injury was based on the recommendation by the council of Europe

> any hamstring injury suffered from during periods of teaching activities or periods of intensive practicing in function of the sports courses and as a result of participation in sports activities with one or more of the following consequences: the student having to stop the activity and/or suffering from pain during sports participation and/or not being able to (fully) participate in the next planned sports class, training session or match. (Van Mechelen et al., 1996)

Before the start of the tests, participants completed a 10-minute warm-up including jogging alternated with dynamic stretching exercises of all muscle groups of the lower limbs. For the maximum strength tests, a handheld dynamometer (HHD) was used. Kelln, McKeon, Gontkof, and Hertel (2008) showed that intra- and intertester reliability of HHD testing are both high. Participants were given instructions for each position (Figure 1) and test prior to testing. For each test, the leg was first moved to the start position, where the participant was instructed to hold and exert as much strength as possible against the HHD. All tests were isometric,

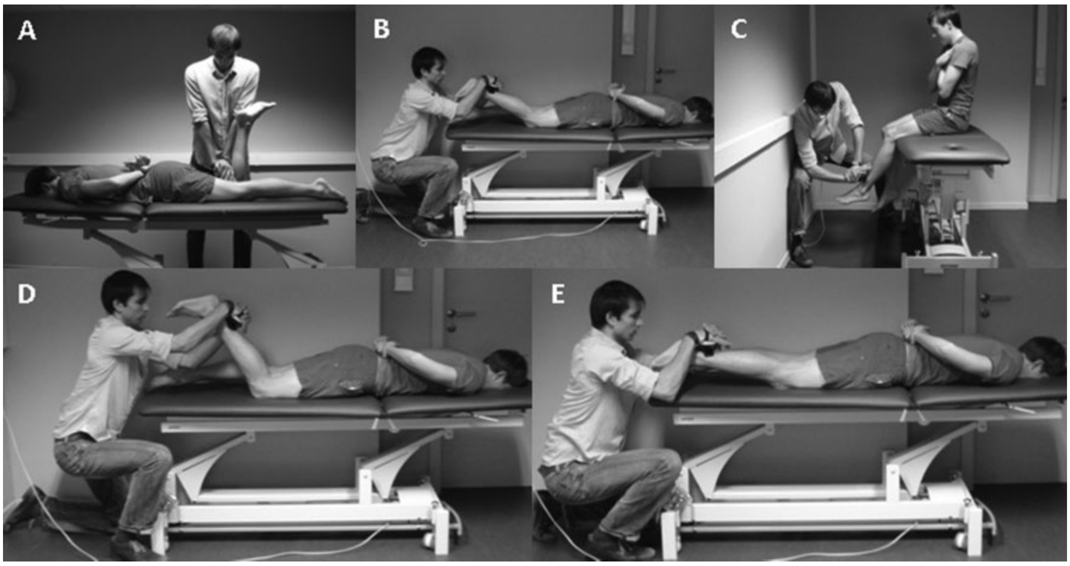

Figure 1. Strength test positions. (A) Hip extensor: the HHD was placed just proximal to the popliteal fossa. (B) Hamstring – isometric: the tested leg was flexed 30° in the knee. The HHD was placed 2 cm proximal to the malleoli of the ankle. (C) Quadriceps: the tested leg was flexed 60° in the knee. The popliteal fossa of both legs touched the table. The HHD was placed just proximal from the ankle. (D) Hamstring – eccentric start position: the tested leg was flexed 60° in the knee. The HHD was placed 2 cm proximal to the malleoli of the ankle. And (E) hamstring – eccentric end position.

except for the hamstring muscle which was measured isometrically as well as eccentrically. For the isometric tests, the tester avoided movement of the leg by placing the HHD perpendicular to the limb and by not breaking his hold. Participants gradually built up to the maximum strength exertion in three seconds. For the eccentric test of the hamstring muscle, the instruction was given to do the exact same thing as during the isometric test, but he/she was also informed that the tester would pull the lower leg down in the given time interval. Two trials were performed for each leg. The highest peak strength achieved was used for analysis. Intraclass correlations showed high intrarater reliability between both trials for all tests (Table I). The order of testing was: Hip extensor, hamstring – isometric, hamstring – eccentric, and quadriceps. For each test first the right and then the left leg was tested. The tests were taken by six different testers. The protocol was taught to each tester and extensively practiced under supervision of the researcher prior to testing. If any discomfort was experienced during the execution of a test, this test was not further performed and thus marked as a missing value. The students were not given the results in order not to influence the predictive value of it. The participants also completed an SLHD wearing sport shoes. The protocol described by Munro and Herrington (2011) was followed, however with a few minor changes. Participants were given the instruction to perform a single leg jump as far as possible whereby the landing position was maintained for three seconds in the same footprint. No restrictions were given concerning the use of arm movements. Participants had three attempts for each leg, and subsequent best result was the outcome of the test. The ethical committee of the Ghent University hospital approved the protocol.

Injury risks were calculated including all registered injuries that met the injury definition criteria. For the risk factor analysis, only a participant's first injury

Table I. Intrarater reliabilities of maximum strength tests

	Left			Right		
	Mean 1st*	Mean 2nd*	SMIC	Mean 1st*	Mean 2nd*	SMIC
Hip extensors	200.9 ± 63	197.5 ± 58	0.880	218.0 ± 69	214.9 ± 70	0.880
Hamstring – isometric	224.7 ± 62	225.5 ± 64	0.913	224.2 ± 62	227.2 ± 64	0.938
Hamstring – eccentric	257.8 ± 65	253.6 ± 66	0.911	263.3 ± 63	261.0 ± 74	0.837
Quadriceps	265.0 ± 71	275.4 ± 67	0.920	265.1 ± 68	277.5 ± 71	0.886

*Values are expressed in Newton.
SMIC, Single Measure Intraclass Correlation.

was taken into account. Of all injured participants, values of only the injured leg (dominant or non-dominant) were used. Participants without injury were randomly assigned to the "dominant leg" or "non-dominant leg" group, with a proportion equal to this of the injured participants. For participants in the "dominant leg" group, values of only the dominant leg were used whereas in the "non-dominant leg" group, values of only the non-dominant leg were used. Also, isometric/eccentric hamstring strength ratios, isometric hamstring/isometric quadriceps ratios, and eccentric hamstring/isometric quadriceps ratios were calculated.

All statistical tests were done using "IBM SPSS statistics 19". First, for all continuous variables independent *T*-tests and for history of hamstring injury a Chi^2 test were run to determine if there were significant differences between injured and uninjured participants. Then, all variables with a *p*-value < 0.05 were brought into a separate logistic regression analysis with gender as a covariate. Each model quality was measured by making a receiver operating characteristic (ROC)-curve analysis. The "Area Under the Curve" (AUC) values were interpreted according to the following classification: 0.90–1.00 = excellent; 0.80–0.90 = good; 0.70–0.80 = reasonable; 0.60–0.70 = weak; and 0.50–0.60 = unusable. Correlations were calculated with Pearson correlation tests.

Results

Sixteen hamstring injuries (17% of all injuries; injury risk: 0.16 injuries/student/academic year; incidence rate (IR): 0.46 injuries/1000 h of sports participation), all of which were non-contact, occurred to 10 participants (9.8% of all participants), with 9 "first" hamstring injuries. Of these, one participant did not execute the maximum strength tests, so risk factor analysis was effectuated with eight cases of hamstring injury. Among these, five injuries occurred to females and three occurred to males. Six hamstring injuries occurred to the dominant limb whereas only two occurred to the non-dominant limb. None of the injured participants had a history of hamstring injury, and no difference was found between the injured and the non-injured group concerning history of hamstring injury ($p = 0.657$).

For the individual muscle strength variables, independent *T*-tests revealed a significantly lower eccentric hamstring strength (222 ± 70 vs. 280 ± 63; $p = 0.019$) and isometric quadriceps strength (237 ± 69 vs. 289 ± 70; $p = 0.046$) in participants with a hamstring injury compared to participants without a hamstring injury. With regard to ratios, independent *T*-tests revealed a significantly higher isometric/eccentric hamstring ratio (1.02 ± 0.27 vs. 0.84 ± 0.13; $p = 0.003$) in participants with a hamstring injury. Independent *T*-tests also showed that participants with a hamstring injury had significantly lower scores on the SLHD (143 ± 18 Vs. 166 ± 21; $p = 0.004$).

Logistic regression analysis showed that, even after taking account of gender, eccentric hamstring strength (odds ratio (ODD) = 0.977; confidence interval (CI): 0.956–0.999; $p = 0.043$; AUC = 0.740), isometric/eccentric hamstring strength ratio (ODD = 970.500; CI: 3.057–308087.275; $p = 0.019$; AUC = 0.780) and SLHD (ODD = 0.884; CI: 0.811–0.963; $p = 0.005$; AUC = 0.850) were significant risk factors for the occurrence of a hamstring injury.

Discussion

A lower maximum eccentric hamstring strength, a higher isometric/eccentric hamstring strength ratio, and a lower score on the SLHD seem to be risk factors for hamstring injury. Concerning the strength measurements, these results should not surprise since both the magnitude of muscle strain and the high-force eccentric contractions have repeatedly been associated with hamstring injuries (Opar, Williams, & Shield, 2012). Opar et al. (2012) suggest that it is mainly the combination of both factors that lead to hamstring injuries. This means there is a higher risk for hamstring injuries in fast movements, where eccentric muscle contraction is required. During these movements, the hamstring muscle is prevented from excessive strain by high-force eccentric contractions. It is thus possible that hamstring injuries are caused by an insufficiently high eccentric force production, leading to excessive muscle strain. In line with this argumentation, Sugiura, Sito, Sakuraba, Sakuma, and Suzuki (2008) found a significantly lower eccentric peak torque of the knee flexors measured isokinetically at 60°/second in the hamstring injured limb compared to the uninjured limb. Nevertheless, other studies that investigated the role of eccentric hamstring strength as a possible risk factor for hamstring injury did not reveal eccentric hamstring strength as a significant risk factor (Bennell et al., 1998; Engebretsen et al., 2010). Bennell et al. (1998) found no significant differences between injured and non-injured Australian rules football players regarding preseason maximum isokinetic eccentric hamstring strength at 60° and 180°/second. The upright sitting position of the participants in comparison with the prone position in our study might be an explanation for the contrasting results. We assume the task with the hip extended as executed in our study biomechanically approaches more the function of the hamstring during the late swing phase while running, which is the timing during which hamstring injury probably most often occurs (Chumanov, Schache, Heiderscheidt, & Thelen, 2012). Engebretsen et al. (2010) used the Nordic Hamstring Strength test as a surrogate marker for hamstring strength and found no differences between injured and non-injured soccer players. Despite the high value of a prospective study of this kind, differences in pain tolerance and experience with the test might be confounding factors, raising questions about the use of this test as a screening tool. Moreover, appliance of hamstring strength as a dichotomous variable might explain the discrepancy with the results from our study.

Regarding the isometric/eccentric hamstring strength ratio, since this has not been used previously, some explanation is necessary. Sole, Milosavljevic, Nicholson, and Sullivan (2011) found significantly lower hamstrings electromyographic root-mean-squares for the eccentric quartiles of movement both in the hamstring injured and the uninjured leg compared to the bilateral average of the control group. The authors argue that this is mainly due to neural inhibitory mechanisms, a rationale that is supported by other authors (Opar, Williams, Timmins, Dear, & Shield, 2013). Consequently, the significantly higher isometric/eccentric hamstring strength ratio in participants with a subsequent hamstring injury in our study might be mainly attributed to a higher eccentric hamstring inhibition in general in participants with a subsequent hamstring injury. Moreover, it could be suggested that the similar observations in both the hamstring injured and the hamstring uninjured leg in the retrospective study by Sole et al. (2011) reflected pre-injured information about people who are at risk of injury. As such, eccentric hamstring inhibition might be a risk factor for hamstring injuries, and the isometric/eccentric hamstring strength ratio could be a potential surrogate marker for eccentric hamstring inhibition.

For the first time a lower score on the SLHD has been found to be a risk factor for hamstring injury. To our knowledge, the predictive value of the SLHD for hamstring injury has not been tested before, despite suggestions in the literature (Bennell et al., 1998). The important role of the hamstring muscle in the performance of the single leg hop was indicated by Pincivero, Lephart, and Karunakara (1997). They assumed that the ability to generate higher concentric hamstring torque is more important of single leg hop performance than the quadriceps, because of the high levels of hip extensor torque during the propulsive phase. In contrast to our study, participants in the study of Pincivero et al. (1997) performed a single leg hop for maximal distance, without explicit instruction to remain in the same footprint after landing. This is an important difference because if one needs to remain in the same footprint, the body momentum needs to be completely stopped. This requires a substantial negative power to decelerate hip flexion during landing, implying eccentric contraction of the hamstring muscle (Augustsson et al., 2006). Several elements support this rationale of high eccentric hamstring contribution to perform a stable landing in a single leg hop and hold. van der Harst et al. (2007) found higher performance scores along with more hip flexion during landing in the dominant leg compared to the non-dominant leg. In line with the results of Augustsson et al. (2006), it could be suggested that the participants in the study of van der Harst et al. (2007) had higher eccentric hamstring strength in the dominant leg, allowing more hip flexion during landing with a further hopping distance as a result. This could possibly mean that the hamstring's disability to eccentrically contract in order to slow down hip flexion, with the typical frontwards trunk inclination during landing, partly explains the lower performance scores of the injured participants in our study. Second, the importance of knee frontal plane stability in the performance of single leg hop tasks has been underscored extensively in the literature (Fitzgerald, Lephart, Hwang, & Wainner, 2001; Myer, Ford, Brent, & Hewett, 2006; Myer, Ford, Palumbo, & Hewett, 2005; Roberts, Ageberg, Andersson, & Fridén, 2007; Struminger, Lewek, Goto, Hibberd, & Blackburn, 2013). Therefore, possible contributions of the hamstring muscle work to dynamic knee frontal plane stability in the SLHD could further substantiate the predicting value of the SLHD for hamstring injuries. Lloyd, Buchanan, and Besier (2005) found that the hamstrings control knee varus and valgus motions during dynamic tasks that challenge knee stability. Also, Claiborne, Armstrong, Gandhi, and Pincivero (2006) found that the hamstrings were a significant predictor of frontal plane knee motion during a single leg squat. Moreover, according to the findings by Flaxman, Speirs, and Benoit (2012) the m. Biceps Femoris can be classified as a specific joint stabilizer that opposes knee valgus loads. The considerable function of the hamstrings in stabilizing the knee in the frontal plane during dynamic tasks such as the SLHD could partly explain the lower performance on the SLHD as a risk factor for hamstring injuries.

The number of cases was reasonably low for conducting a risk factor analysis. Bahr and Holme (2003) proposed at least 200 participants and 20–50 injuries in order to be considered minimum quality. Because we found significant results on a small study sample as such, measurements of eccentric hamstrings strength, isometric/eccentric hamstring strength ratio, and SLHD should be included in large-scale prospective studies in at-risk populations for hamstring injuries in the future.

Perspective

The risk for hamstring injuries is considerable in freshmen PETE students. Lower maximum eccentric hamstring strength and higher isometric/eccentric hamstring strength ratio were significant risk factors for a subsequent hamstring injury. Also a lower score on the SLHD test was found to be a significant risk factor for hamstring injuries. These findings offer a better insight into the etiology of hamstring injuries. The issue needs further research, but both an eccentric hamstring strength test and the SLHD could provide easily applicable on-field screening tools. Future large-scale prospective studies in at-risk populations for hamstring injuries might help identify whether their combined use brings the predictive value above that of each individual test separately. Our findings also concur with earlier research concerning the efficacy of eccentric hamstring exercises in the prevention of hamstring injuries (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008; Petersen et al., 2011).

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