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**Author(s):** Rossi, Marleena Katariina; Pasanen, Kati; Heinonen, Ari; Äyrämö, Sami; Leppänen, Mari; Myklebust, Grethe; Vasankari, Tommi; Kannus, Pekka; Parkkari, Jari

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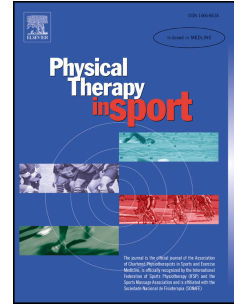
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# Journal Pre-proof

The standing knee lift test is not a useful screening tool for time loss from low back pain in youth basketball and floorball players

Rossi Marleena Katariina, Pasanen Kati, Heinonen Ari, Äyrämö Sami, Leppänen Mari, Myklebust Grethe, Vasankari Tommi, Kannus Pekka, Parkkari Jari



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**Authors (Family name, given name, degrees)**

Rossi, Marleena Katariina, PT, MSc<sup>1,2</sup>, Pasanen, Kati, PT, MSc, PhD<sup>1,3,4,5</sup>, Heinonen, Ari, PT, PhD<sup>2</sup>, Äyrämö, Sami, PhD<sup>6</sup>, Leppänen, Mari, PhD<sup>1</sup>, Myklebust, Grethe, PT, PhD<sup>7</sup>, Vasankari, Tommi, MD, PhD<sup>1</sup>, Kannus, Pekka, MD, PhD<sup>1,9</sup>, Parkkari, Jari, MD, PhD<sup>1,8</sup>

**Affiliations (Address):**

1 Tampere Research Center of Sports Medicine, The UKK Institute for Health Promotion Research, Kaupinpuistonkatu 1, 33500 Tampere, Finland

2 Faculty of Sport and Health Sciences, P.O. Box 35 40014 University of Jyväskylä, Jyväskylä, Finland

3 Sport Injury Prevention Reserch Centre, Faculty of Kinesiology, University of Calgary, 2500 Universtity Drive NW, Calgary, AB, T2N 1N4, Canada

4 Alberta Children's Hospital Research Institute, University of Calgary, 3330 Hospital Drive NW, Calgary, AB, T2n 4N1, Canada

5 McCaig Insitute for Bone and Joint Health, 3280 Hospital Drvie NW, Calgary, AB, T2N 4Z6, Canada

6 Faculty of Information Technology, P.O. Box 35 40014 University of Jyväskylä, Jyväskylä, Finland,

7 Oslo Sports Trauma Research Center, Department of Sports Sciences, Norwegian School of Sport Sciences, Sognsveien 220, 0806 Oslo, Norway

8 Tampere University Hospital, Central Hospital, PO BOX 2000, FI-33521 Tampere, Finland

9 Department of Orthopedics & Traumatology, Central Hospital, PO BOX 2000, FI-33521 Tampere, Finland

**Twitter:**

Marleena Rossi (a)MarleenaRossi

Mari Leppänen ((a)mari\_leppanen

Grethe Myklebust (a)MyklebustGrethe

Kati Pasanen (a)KatiPasanen

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**Corresponding author:**

Marleena Rossi, MSc, PT

Tampere Research Center of Sports Medicine/The UKK Institute for Health Promotion Research

Kaupinpuistonkatu 1, 33500 Tampere, Finland

PL 30

33501 Tampere, Finland

Phone: +358-407283228

email: marleena.rossi@gmail.com

**The standing knee lift test is not a useful screening tool for time loss from low back pain in youth basketball and floorball players**

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**ABSTRACT**

1  
2 **Objectives:** The aim of this study was to investigate the association between pelvic  
3 kinematics during the standing knee lift (SKL) test and low back pain (LBP) in youth  
4 floorball and basketball players.

5 **Design:** A prospective cohort study.

6 **Setting:** Finnish elite youth floorball and basketball players.

7 **Participants:** Finnish elite youth female and male floorball and basketball players  
8 (n=258, mean age 15.7±1.8).

9 **Main Outcome Measures:** LBP resulting in time loss from practice and games was rec-  
10 orded over a 12-month period and verified by a study physician. Associations between  
11 LBP and sagittal plane pelvic tilt and frontal plane pelvic obliquity during the SKL test as  
12 measured at baseline were investigated. Individual training and game hours were rec-  
13 orded, and Cox's proportional hazard models with mixed effects were used for the  
14 analysis.

15 **Results:** Cox analyses revealed that sagittal plane pelvic tilt and frontal plane pelvic  
16 obliquity were not associated with LBP in floorball and basketball players during the  
17 follow-up. The hazard ratios for pelvic tilt and pelvic obliquity ranged between 0.93  
18 and 1.08 (95% CIs between 0.91 and 1.07 and 0.83 and 1.29), respectively.

19 **Conclusions:** Pelvic movement during the SKL test is not associated with future LBP in  
20 youth floorball and basketball players.

21 **Keywords:** low back pain, risk factors, prospective study, youth athletes

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22

## **INTRODUCTION**

23 Low back pain (LBP) is common in youth and presents with a mean lifetime prevalence  
24 of 39% (range 8% to 64%) (Calvo-Muñoz, Gómez-Conesa, & Sánchez-Meca, 2013). LBP  
25 in youth results in absence from work or school and interference with normal daily ac-  
26 tivities and recreational physical activities (Coenen et al., 2017). In Finland, nearly half  
27 of youth between 11 and 15 years of age participate in organised sports. Studies ana-  
28 lysing any association between LBP and physical activity have been inconsistent  
29 (Kamper, Yamato, & Williams, 2017), but participation in organised sports might in-  
30 crease the risk for LBP (Franz, Jespersen, Rexen, Leboeuf-Yde, & Wedderkopp, 2016;  
31 Hangai et al., 2010). However, prospective studies investigating the risk factors for LBP  
32 in youth sports are limited. To effectively decrease the incidence of LBP in youth ath-  
33 letes, the risk factors for LBP should be identified.

34

35 LBP prevalence is high in youth floorball (an indoor team sport that resembles floor  
36 hockey) and basketball players. In our previous investigation, 44% and 62% of the bas-  
37 ketball and floorball players, respectively, reported having had LBP within the previous  
38 12 months (XXX). Both sports include running, sudden turns and stops, as well as other  
39 movements performed on single-leg support. In addition, basketball players perform  
40 lots of jumping and landing, and floorball includes a lot of positions and movements  
41 with a bended trunk because of the relatively short stick used.

42

43 The standing knee lift (SKL) test has been used to evaluate hip and pelvic stability  
44 (Corkery et al., 2014; DiMattia, Livengood, Uhl, Mattacola, & Malone, 2005;



45 Elphinston, 2008; Hardcastle & Nade, 1985). Especially in the LBP population, the SKL  
46 test and its modifications are often used in clinics to assess if there are impairments in  
47 hip and pelvic movement control (i.e., inability to maintain neutral hip and pelvic  
48 alignment), and its use has been suggested as a part of functional screening for ath-  
49 letes (Elphinston, 2008). Increased pelvic movement, for example, increased pelvic  
50 obliquity or tilt during the SKL test, may be because of impaired movement control. In  
51 theory, altered movement control in single-leg tasks may result in increased loading  
52 and strain in the lower back area (posterior lumbo-pelvic area) in these floorball and  
53 basketball players. Indeed, alignment of the lumbo-pelvic area has been shown to be  
54 associated with lumbar loading (Bassani, Casaroli, & Galbusera, 2019; Popovich et al.,  
55 2013).

56

57 Further investigations analysing any association between LBP and movement patterns  
58 in sports is needed (O'Sullivan, Smith, Beales, & Straker, 2017). Hence, the overall aim  
59 of the current study was to investigate the association between LBP incidence and pel-  
60 vic kinematics during the SKL test in youth floorball and basketball players. The study  
61 objective was to assess whether increased sagittal or frontal plane pelvic movement  
62 during the SKL test is a risk factor for future LBP that would result in time loss from  
63 sports participation in youth floorball and basketball players. Our hypothesis was that  
64 players with increased pelvic movement during the SKL test would have an increased  
65 risk for LBP.

66

67

## **METHODS**

68 This prospective cohort study was approved by the Ethics Committee of X Hospital Dis-  
69 trict (ETL-code R10169) and carried out in accordance with the Declaration of Helsinki  
70 and the guidelines for good scientific practice. Written informed consent was acquired  
71 from the players (and legal guardian if the player was under 18 years old).

72

### 73 **Participants and data collection**

74 The present 12-month follow-up study is part of a larger three-year follow-up study  
75 (2011 to 2014) investigating lower extremity injuries in youth elite-level floorball and  
76 basketball players (XXXXXX) (XXXX). Ten female and male basketball and 10 floorball  
77 elite-level teams were recruited from the six local sports clubs in Tampere, Finland, for  
78 the prospective three-year follow-up study. Three of the 20 teams invited were adult  
79 elite-level teams. These adult teams were invited because almost half of the players in  
80 the teams were under 21 years old (junior players). Players were excluded if they were  
81 older than 21 years old, had an ongoing acute injury affecting the baseline test or did  
82 not participate in the test or in the follow-up.

83

84 The baseline questionnaire was answered, and the baseline tests (XXX) were per-  
85 formed over one day at the beginning of the study in April 2013. The baseline ques-  
86 tionnaire covered basic demographics, sports participation and history of musculo-  
87 skeletal complaints. The Standardised Nordic questionnaire of musculoskeletal symp-  
88 toms (the modified version for athletes) was used to assess if the players had a history  
89 of LBP complaints (Bahr et al., 2004; Kuorinka et al., 1987). The history of previous LBP  
90 was determined based on the following question: 'How many days have you had LBP

91 during the past 12 months: none (no LBP history), 1–7 days, 8–30 days, >30 days but  
92 not daily or daily (history of LBP)?'

93

94 ***Test procedure***

95 The SKL test was used to assess hip and pelvic stability; the test procedure was de-  
96 scribed in an earlier study by Leppänen et al. (2020). This test is a modified Trendelen-  
97 burg test (Hardcastle & Nade, 1985) and is often used as a clinical screening test for  
98 LBP patients. For the purposes of the current study, a 3D motion analysis was used to  
99 assess the performance in the SKL test. The 3D motion analysis comprised eight cam-  
100 eras (Vicon T40, Oxford, UK), 16 lower body markers (Plug-In Gait, Vicon, Oxford, UK)  
101 and two force plates (AMTI, Watertown, Massachusetts), where data were recorded  
102 synchronously at 300 fps and 1500 Hz.

103

104 Prior to the test, 16 reflective markers were placed by one physiotherapist on anatom-  
105 ical landmarks on the lower extremities on both sides (anterior spina iliac superior  
106 (ASIS), posterior spina iliac superior (PSIS), lateral thigh, lateral knee joint line, lateral  
107 tibia, lateral malleolus and over the shoe on second metatarsal and calcaneus); a static  
108 calibration trial was performed.

109

110 During the test, the players stood with their feet 20 cm apart (standardised using a 20  
111 cm wide wooden block), one foot on each force plate and arms by their sides. The  
112 players were instructed to lift one knee twice to a horizontal level by flexing the hip  
113 and knee and holding the position for a few seconds. The stance leg was the side un-

114 der investigation. The trial was regarded as valid if the player lifted their leg to at least  
115 45 degrees hip flexion and if all markers stayed firmly on the player's skin throughout  
116 the test. Prior to the test, one to three practice trials were allowed. The test started by  
117 lifting the dominant leg and then the nondominant leg. Leg dominance was deter-  
118 mined by asking about their preferred kicking leg. Trials were excluded as invalid if the  
119 hip angle was below 45 degrees, they touched the floor with their foot or the standing  
120 foot moved.

121

122 The Vicon Nexus Plug-in Gait model was used for the analyses. All the kinetic meas-  
123 urements were performed from foot lift to foot contact, that is, the period when the  
124 unfiltered ground reaction force was lower than a threshold of 25 N. The players per-  
125 formed two trials on each leg.

126

127 A custom Python (2.7.13) script was used to calculate the pelvic orientations from 3D  
128 marker trajectories. For reading and modifying motion capture frames and force plate  
129 acquisitions, an open-source Python wrapping of Biomechanical ToolKit platform (BTK  
130 0.3) was used. A standard, open-source Python library for scientific computing (NumPy  
131 1.15.4), data analysis (pandas 0.19.2) and data visualisation (Matplotlib 2.0.0) were  
132 utilised for the script. Vertical trajectories of the heel and toe markers were used to  
133 detect the knee lift performance from the trial files, and 1000 milliseconds was set as  
134 the threshold time for the minimum duration of the valid test trial. Then, the synchro-  
135 nously recorded analogue force plate signals were used to determine the exact timings  
136 (motion capture frames) of the foot off and foot strike events. Here, 25N was set as

137 the threshold value. All incorrect or incomplete recordings were removed prior to the  
 138 analysis because the extracted test trials were checked visually. The plug-in-gait model  
 139 output specification for pelvic angles was used to determine the peak values for each  
 140 test trial.

141

142 Sagittal and frontal plane pelvic kinematics were investigated, and the following varia-  
 143 bles were calculated: peak pelvic anterior tilt, peak pelvic posterior tilt (sagittal plane),  
 144 peak contralateral pelvic hike angle and peak contralateral pelvic drop (frontal plane).  
 145 The stance leg was the tested leg. The variables are described in Table 1 and Figure 1.  
 146 For all the investigated risk factors, the mean of two trials was calculated for the right  
 147 and left legs.

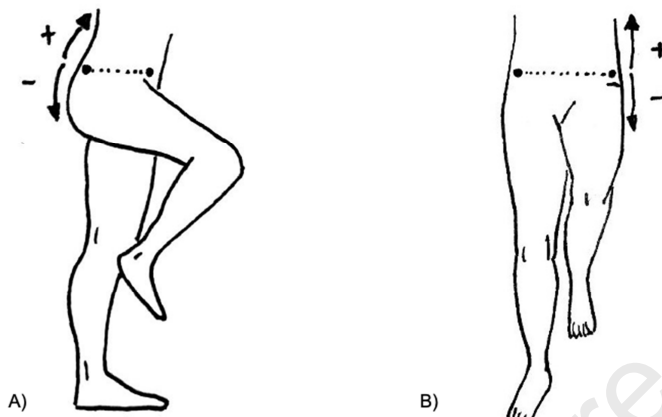
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149 Table 1. The investigated pelvic kinematics

Variables	Description	Interpretation of values
Peak pelvic anterior tilt	Maximal point of the anterior tilt in relation to the global vertical line during the knee lift (mean of two trials).	Positive value = Pelvic tilts anteriorly (PSIS superior to ASIS).
Peak pelvic posterior tilt	Maximal point of posterior tilt in relation to global vertical line during the knee lift (mean of two trials).	Negative value = Pelvis tilts posteriorly (ASIS superior to PSIS).
Pelvic obliquity - Peak contralateral <sup>^</sup> drop angle	Angle between the horizontal line and line between left and right ASIS when the contralateral pelvic ASIS is at its lowest point during the knee lift (mean of two trials).	Negative value= contralateral pelvic drop (ASIS drops below horizontal line). Positive value = contrala-

Pelvic obliquity - Peak contralateral <sup>^</sup> hike angle	Angle between the horizontal and line between left and right ASIS, when the contralateral pelvic ASIS is at its highest point during the knee lift (mean of two trials).	teral pelvic hike (ASIS stays above horizontal line).
---	--	---

<sup>^</sup>Contralateral refers to the side of the lifted leg, i.e., contralateral to the tested stance leg.



150

151 **Figure 1.** SKL test A) Sagittal plane positive value interpreted as anterior pelvic tilt and  
 152 negative value as posterior pelvic tilt. B) Frontal plane positive value interpreted as  
 153 contralateral pelvic hike and negative values as contralateral pelvic drop.

154

#### 155 ***Injury and sport exposure registration***

156 The primary outcome was time loss LBP. Time loss LBP was defined as acute traumatic  
 157 or gradual nontraumatic onset pain in the lower back area that resulted in time loss  
 158 from full participation in team practices and games for at least 24 hours. LBP com-  
 159 plaints with radiation to the lower legs were not excluded. Direct contact injuries were  
 160 excluded. A direct contact injury was defined as LBP sustained as a result of direct con-  
 161 tact to the lower back (Olsen, Myklebust, Engebretsen, & Bahr, 2004) (e.g., blow to the  
 162 lower back).

163

164 Two study physicians contacted the team coaches weekly to interview the injured  
165 players. Information on new complaints was collected using a structured injury ques-  
166 tionnaire (Supplementary Table 1), which was based on the recommendations from  
167 Fuller et al. (2006). The study did not include systematic clinical examinations or radio-  
168 logical investigations, but a free clinical examination at the UKK Institute was offered  
169 to injured players during the study follow-up. During the follow-up, the coaches rec-  
170 orded player attendance in a training session (yes/no), duration of a training session  
171 (h), contents of the training session (sports-specific training/condition training) and  
172 attendance in each period of a game (yes/no) individually for each player on a player  
173 attendance paper form during all team activities. Training and game exposure were  
174 defined as suggested by Fuller et al. (2006). If the player did not attend or was injured  
175 during the activity, the coach recorded the absence/injury.

176

### 177 **Statistical methods**

178 IBM SPSS Statistics (v. 23-24.0) was used to conduct chi-square tests and a t-test  
179 (Mann-Whitney tests when appropriate) for descriptive analyses. The results are re-  
180 ported as the mean, standard deviation (SD) and 95% confidence intervals (CIs).

181

182 Cox's proportional hazard model with mixed effects was used to study the relationship  
183 between the investigated risk factors and LBP incidence. The analyses were performed  
184 using R (v 3.1.2; R Foundation for Statistical Computing (R Core Team, 2016)) and the  
185 package `coxme` (Therneau, 2015). Sports club was used as a random effect, and indi-

186 vidual game and practice hours from the start of the follow-up until the first event of  
187 LBP or the end of the follow-up (if no event) were included in the Cox analyses. Data  
188 from all eligible players entering the follow-up were included for the time when they  
189 participated.

190

191 Univariate analyses were followed by multivariable analyses. Two adjusting variables  
192 were used in the multivariable analyses because it has been recommended to have 10  
193 events per included variable in the Cox analyses (Peduzzi, Concato, Feinstein, & Hol-  
194 ford, 1995; Peduzzi, Concato, Kemper, Holford, & Feinstein, 1996). First, we included  
195 the following factors into one model: age, sex, body mass index (BMI), nicotine use, leg  
196 dominance, family history of LBP and history of LBP. Leg dominance was used as two  
197 category variables; the categories 'left' and 'right' were merged into 'unilateral leg  
198 dominance' and the category 'don't know/both' into 'bilateral/unknown leg domi-  
199 nance'. Then, the factors were dropped one by one from the model based on their sta-  
200 tistical significance (the factors with the largest p-values were dropped). Finally, a his-  
201 tory of LBP and leg dominance were entered into the final model because of having  
202 the highest statistical significance (smallest p-value). The results are presented as haz-  
203 ard ratios (HRs), 95% CIs and p-values. The player was considered the unit of analysis,  
204 and analyses for right and left legs were performed separately.

205

206

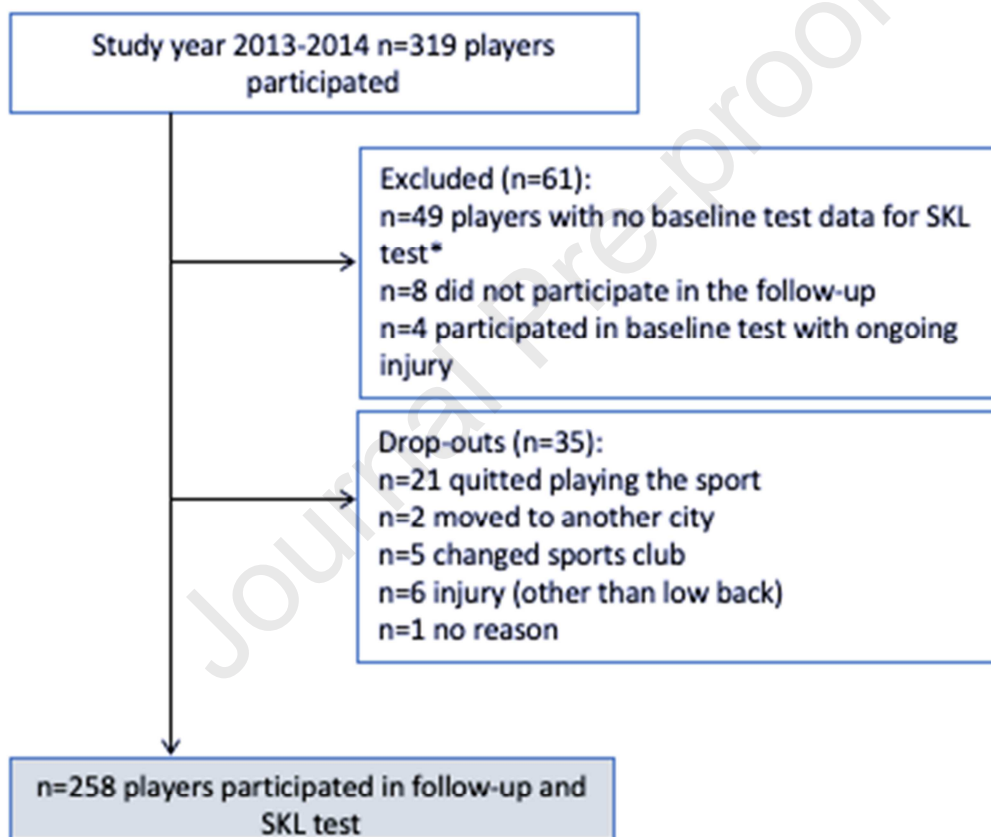
## **RESULTS**

207 Nine basketball and nine floorball teams participated in the current study. Thirty-seven  
208 players declined and 403 players agreed to participate in the three-year open cohort



209 study. Seventy-nine percent (n=319) of the players agreed to participate during the  
210 third study year (2013–2014). Forty-nine players did not have complete SKL test data,  
211 eight players did not participate in the follow-up, and four players reported an ongoing  
212 acute unilateral injury at the time of testing and were excluded from the analyses (Fig-  
213 ure 2).

214



215

216 Figure 2. Study flow of the participating players. \*Incomplete SKL test data (no testing  
217 data n=29, technical reasons n=16, incorrect performance n=4).

218

219 The baseline player demographics are presented in Table 2. Two-hundred-and-fifty-  
220 eight players participated in the follow-up and SKL test. The mean, minimum and max-

221 imum values for the investigated risk factors are presented in Table 3. There was a  
 222 small number of players (n=40) with actual pelvic drop movements, and the maximum  
 223 pelvic drop was 3.5 degrees.

224

225 Table 2. Baseline characteristics (n=258)

Variables	Basketball		Floorball		P-value
	Female (n=61)	Male (n=67)	Female (n=50)	Male (n=80)	
Age, years (mean, (SD))	14.4 (1.3)	15.1 (1.8)	17.3 (1.8)	16.9 (1.3)	≤0.001
Height, cm (mean, SD)	168.5 (6.5)	179.2 (10.3)	167.0 (6.0)	177.3 (6.0)	0.633
Weight, kg (mean, SD)	60.9 (8.6)	68.2 (13.8)	62.3 (7.6)	69.2 (8.6)	0.087
BMI (mean, SD)	21.4 (2.7)	21.0 (3.0)	22.3 (2.5)	21.9 (2.2)	0.003
Playing years (mean, SD)	6.6 (2.5)	6.8 (3.0)	7.2 (2.5)	8.8 (3.0)	≤0.001
Training hours * (mean, SD)	170.9 (73.4)	246.8 (134.6)	231.7 (106.4)	257.7 (133.5)	0.010
Game hours † (mean, SD)	7.6 (4.7)	7.5 (3.9)	10.7 (7.4)	10.0 (6.9)	0.001

Body mass index, BMI; SD, standard deviation.

p-values shown refer to the t-test/Mann-Whitney test between sports groups, including both sexes.

\*Team practice hours/season.

† Active playing time in games during the season.

226

227 Table 3. Baseline test results for players with and without LBP during follow-up

Outcome Variables	No LBP during follow-up <sup>#</sup>	LBP during follow-up (n=32)	P-value	All players		
	Mean (95% CI)	Mean (95% CI)		Mean (95% CI)	Min. value	Max value
Right leg						
Peak pelvic anterior tilt, degrees //	9.6 (9.1 to 10.2)	9.3 (7.8 to 10.8)	0.854	9.6 (9.1 to 10.1)	0.7	20.6
Peak pelvic posterior tilt, degrees //	-4.3 (-5.1 to -3.5)	-4.0 (-6.0 to -2.0)	0.797	-4.2 (-4.9 to -3.5)	-23.3	9.9
Peak contralateral hike angle, degrees <sup>^</sup>	13.8 (13.4 to 14.2)	13.0 (11.9 to 14.1)	0.793	13.7 (13.3 to 14.1)	5.2	22.4
Peak contralateral	1.9 (1.6 to 2.1)	1.5 (0.7 to 2.3)	0.934	1.8 (1.6 to 2.1)	-3.5	8.0

drop angle, degrees <sup>^</sup>				to 2.1)		
Left leg						
Peak pelvic anterior tilt, degrees <sup>//</sup>	9.2 (8.6 to 9.7)	9.4 (7.8 to 10.9)	0.691	9.2 (8.7 to 9.7)	-1.7	19.9
Peak pelvic posterior tilt, degrees <sup>//</sup>	-4.7 (-5.5 to -3.9)	-4.1 (-6.1 to -2.1)	0.814	-4.6 (-5.3 to -3.9)	-24.4	9.9
Peak contralateral hike angle, degrees <sup>^</sup>	14.2 (13.7 to 14.7)	13.9 (12.8 to 15.0)	0.189	14.1 (13.7 to 14.5)	6.5	27.0
Peak contralateral drop angle, degrees <sup>^</sup>	2.2 (1.9 to 2.5)	2.2 (1.5 to 2.9)	0.361	2.2 (2.0 to 2.3)	-3.4	8.9

LBP; low back pain, CI; confidence interval

<sup>#</sup>Because of an insufficient number of valid trials (< 2 valid trials), four players were excluded from the right side test and six players from the left side test. Right leg n=222, Left leg n=220.

<sup>//</sup>Positive value in pelvic tilt corresponds to pelvic anterior tilt and a negative value to pelvic posterior tilt.

<sup>^</sup>Positive value in pelvic obliquity corresponds to contralateral pelvic hike and a negative value to contralateral pelvic drop.

228

229 Time loss LBP was recorded 39 times during the 12-month follow-up in 35 players.

230 Three of these were direct contact injuries (n=1 sacrum contusion, n=2 low back con-

231 tusion) and, hence, were excluded from the analysis. LBP in 78% (n=25) of the players

232 had gradual nontraumatic onset, and 22% (n=7) had acute traumatic onset. Seventy-six

233 percent of the nontraumatic onset and 86% of the acute onset LBP resulted in at least

234 an absence of seven days from normal training (mean (SD) nontraumatic onset LBP:

235 54.5±86.0, acute onset traumatic LBP 72.4±131.8 days). The median absence was 14

236 days, which corresponds to moderate severity (Fuller et al., 2006). The incidence of

237 time loss LBP, including only the first episode of LBP during the follow-up, was 0.5 per

238 1000 player hours. The incidence rate was 12% in the floorball players and 12% in the

239 basketball players. There were no statistically significant differences between the

240 players with and without time loss LBP during the follow-up in the baseline character-

241 istics (age, sex, height, weight, BMI, playing years, team training or game hours).

242

243 **Risk factor analyses**

244 The results from the univariate analyses are shown in Table 4. None of the investigated  
 245 risk factors were associated with LBP in the univariate Cox analyses.

246

247 Table 4. Unadjusted hazard ratios (HRs) and confidence intervals (CIs) from the Cox  
 248 mixed-effect analyses.

Risk factors	HR	95 % CI	P
Left leg			
Peak pelvic anterior tilt	1.00	(0.92, 1.09)	0.930
Peak pelvic posterior tilt <sup>#</sup>	0.98	(0.93, 1.05)	0.610
Peak contralateral hike angle	0.98	(0.89, 1.09)	0.710
Peak contralateral drop angle <sup>^</sup>	1.01	(0.85, 1.18)	0.950
Right leg			
Peak pelvic anterior tilt	0.98	(0.90, 1.07)	0.630
Peak pelvic posterior tilt <sup>#</sup>	0.99	(0.94, 1.06)	0.860
Peak contralateral hike angle	0.94	(0.85, 1.04)	0.250
Peak contralateral drop angle <sup>^</sup>	1.08	(0.90, 1.28)	0.410

HR calculated per one-degree increase.

<sup>#</sup>HR converted so that one-unit increase is interpreted as more pelvic posterior tilt.

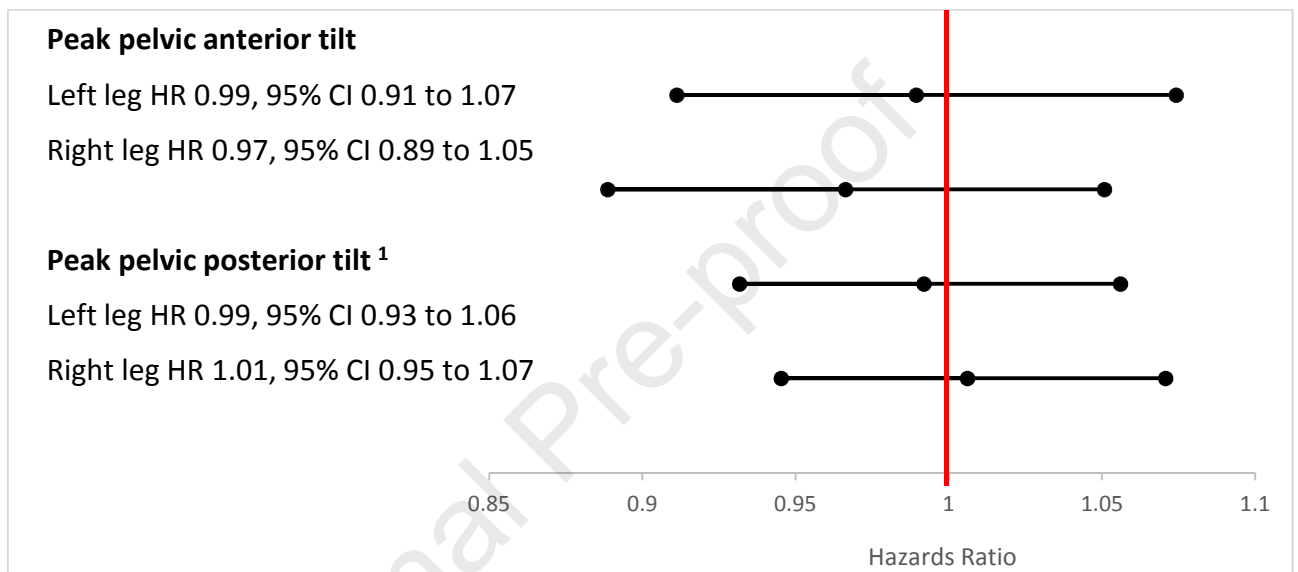
<sup>^</sup>HR converted so that a one-unit increase is interpreted as more pelvic movement towards pelvic drop.

249

250 In the adjusted Cox regression analysis, no association between sagittal plane pelvic tilt  
 251 and LBP was found when adjusted for a history of LBP and leg dominance (Figure 3).

252 Furthermore, none of the analyses between pelvic obliquity and LBP revealed signifi-

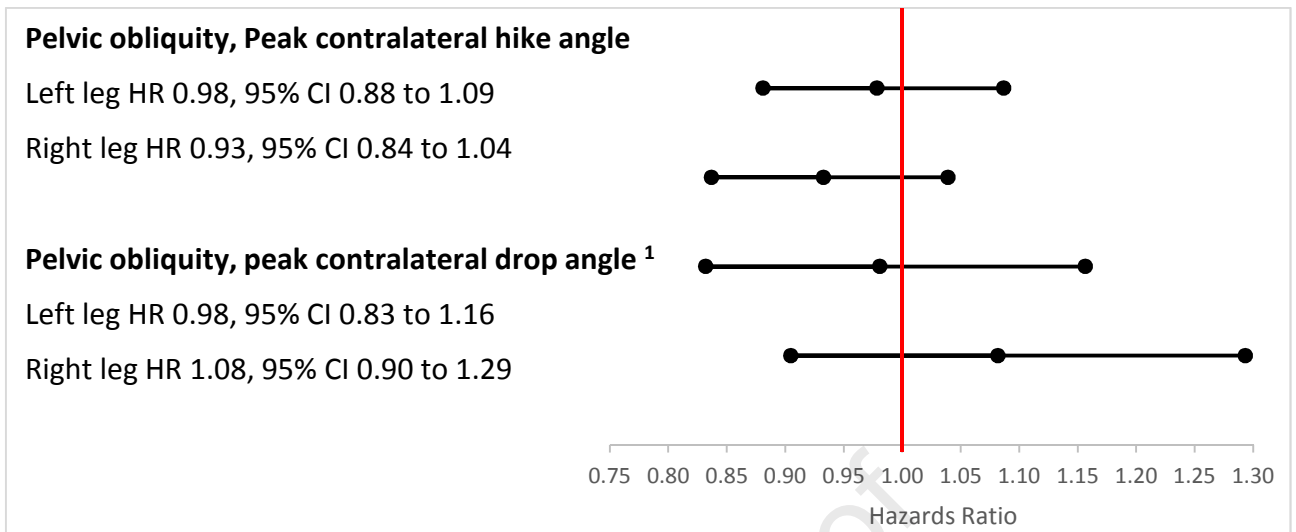
253 cant associations (Figure 4). The peak pelvic drop angle was also analysed as a catego-  
 254 rised risk factor (no pelvic drop = contralateral pelvic drop values at zero or higher,  
 255 small pelvic drop = contralateral pelvic drop values smaller than zero). The results  
 256 showed no significant difference in risk between players with or without pelvic drop.  
 257



258

259 **Figure 3.** Adjusted hazard ratios (HR) and confidence intervals (CIs) from the Cox  
 260 mixed-effect analyses with incidence of LBP as the outcome and peak pelvic tilt as a  
 261 risk factor. Adjusted for history of LBP and leg dominance (unilateral leg domi-  
 262 nance/bilateral leg dominance). <sup>1</sup> HR converted so that a one-unit increase is inter-  
 263 preted as more pelvic posterior tilt.

264



265

266 **Figure 4.** Adjusted hazard ratios (HR) and confidence intervals (CIs) from the Cox  
 267 mixed-effect analyses with incidence of LBP as the outcome and peak pelvic obliquity  
 268 as a risk factor. Adjusted for history of LBP and leg dominance (unilateral leg domi-  
 269 nance/bilateral leg dominance). <sup>1</sup> HR converted so that a one-unit increase is inter-  
 270 preted as a smaller minimal value, that is, pelvic movement towards pelvic drop.

271

272

### DISCUSSION

273 The current prospective study showed that sagittal plane pelvic tilt during the SKL test  
 274 is not a risk factor for LBP in youth basketball and floorball players. We observed no  
 275 association between LBP incidence and sagittal plane pelvic tilt or frontal plane pelvic  
 276 obliquity during the SKL test, which was in opposition to our hypothesis.

277

278 Our hypothesis was that increased pelvic movement during the SKL test could result in  
 279 compensatory movement in the low back area and increase the risk for LBP. In theory,  
 280 increased pelvic movement might lead to increased load and strain in the low back ar-

281 ea. Our hypothesis was based on the widely known kinematic chain theory, where  
282 movement in one section affects the other sections of the kinetic chain (Karandikar &  
283 Vargas, 2011); this theory is supported by Leppänen et al. (2020), who showed that  
284 pelvic hike during the SKL test increases the risk for knee injuries in youth athletes. In  
285 addition, it has previously been shown that lower extremity kinematics (Bayne, Elliott,  
286 Campbell, & Alderson, 2016) and movement control of the lumbo-pelvic area  
287 (Grosdent et al., 2016; Roussel et al., 2009) might be associated with LBP in youth ath-  
288 letes. For example, Roussel et al. (2009) prospectively investigated the relationship be-  
289 tween movement control of the lumbo-pelvic area during hip movements and future  
290 lower extremity injuries and LBP; they observed an increased risk for lower extremity  
291 injuries and LBP in dancers with altered lumbo-pelvic movement control (Roussel et al.,  
292 2009). Chaudhari, McKenzie, Pan and Oñate (2014) observed increased odds for time  
293 loss from a sports injury in baseball pitchers with larger sagittal plane lumbo-pelvic  
294 movement during a single-leg raise test in standing. We were unable to find significant  
295 risk factors in pelvic kinematics during hip flexion movement in youth basketball and  
296 floorball players using the SKL test. Our results are in line with those of Olivier, Stew-  
297 art, Olorunju and McKinon (2015), who noticed that lumbo-pelvic movement control  
298 did not predict injuries in cricket players.

299

300 We hypothesised that increased pelvic obliquity might predispose players to LBP be-  
301 cause earlier studies suggest that pelvic obliquity can increase facet joint forces and  
302 disc pressure (Popovich et al., 2013). However, we did not find an association between  
303 pelvic obliquity and LBP. This might be because the data presented only a few and min-

304 imal values of pelvic drop. On the other hand, the data show that excessive pelvic drop  
305 during the SKL test is not common in youth basketball and floorball players and that  
306 the SKL test might not be suitable for detecting players with altered pelvic control dur-  
307 ing single-leg tasks.

308

309 In the present study, we did not consider that the risk factors for LBP might differ  
310 based on many factors, such as tissue injury, onset mechanism, sports-specific re-  
311 quirements, symptom picture, such as pain provoked by certain movement directions,  
312 as well as other characteristics of LBP and the characteristics of the players, such as  
313 sex. For example, when investigating LBP—irrespective of the onset or duration of LBP  
314 or presence or absence of movement control impairments and provocative movement  
315 directions (Astfalck et al., 2010; Dankaerts, O'Sullivan, Burnett, & Straker, 2006)—this  
316 so-called 'wash out' effect may happen. For example, when investigating nonspecific  
317 LBP classified into subgroups based on the presence of movement control impairments  
318 and provocative movement directions, differences in movement patterns in people  
319 with and without LBP can be seen (Astfalck et al., 2010; Dankaerts et al., 2006; Danka-  
320 erts et al., 2009). Thus, it might be beneficial to investigate risk factors for LBP in dif-  
321 ferent kinds of LBP and subgroups.

322

323 Furthermore, LBP complaints are a heterogeneous group, and with most of the com-  
324 plaints, the exact cause for pain cannot be identified. Also, psychosocial factors affect  
325 the pain experience. This makes it more difficult to subgroup LBP based on, for exam-  
326 ple, injured tissue and, hence, to identify risk factors for LBP complaints.



327

328 For the Cox analysis, we did not enter all adjusting factors available, such as age, sex,  
329 BMI and family history of LBP, into the final risk factor analyses, even though prior  
330 studies have stated them as plausible predisposing factors for LBP (Ferreira, Beck-  
331 enkamp, Maher, Hopper, & Ferreira, 2013; Kamper et al., 2017). This was because of  
332 applying the rule of 10 incidents per variable in the model (Peduzzi et al., 1995; Peduz-  
333 zi et al., 1996). We included age, sex, BMI, nicotine use, leg dominance, family history  
334 of LBP and history of LBP in the same model, and one by one, we dropped the least  
335 significant variables from the model. We noticed that only nicotine use, history of LBP  
336 and leg dominance were statistically significant factors. Interestingly, sex, age and BMI  
337 were not statistically significant. History of LBP and leg dominance had the lowest p-  
338 value and were included in the final adjusted analyses. Out of curiosity, we also ran the  
339 analyses using nicotine and history of LBP as adjusting factors, but the results re-  
340 mained the same.

341

#### 342 **Strengths and limitations**

343 The strengths of this investigation were the 12-month follow-up and prospective regis-  
344 tration of the individual training hours, game hours and LBP complaints. The sample  
345 can also be seen as representative of youth basketball and floorball players of the  
346 same level in Finland.

347

348 Despite the strengths, there are also limitations to consider. We did not perform a reli-  
349 ability analysis of the 3D SKL test. However, one trained physiotherapist performed the

350 marker placement, which decreased the risk of error because of inconsistent marker  
351 placements. Aberrant marker movement can also affect the results in a 3D movement  
352 analysis, and ASIS markers have been shown to have relatively more artefacts com-  
353 pared with PSIS (Hara, Sangeux, Baker, & McGinley, 2013).

354

355 Also, the starting leg was not randomised, so the players might have been more famil-  
356 iar with the test when performing the test on their dominant leg. In addition, even  
357 though the players were asked to lift their knee to a horizontal position (hip to 90 de-  
358 grees flexion), we also included players who bent their hip only to 45 degrees while  
359 lifting their knee. This might have affected the results because it is very likely that the  
360 movement of the pelvis changes if one lifts the knee into 90 degrees hip flexion in-  
361 stead of 45 degrees hip flexion.

362

363 Our sample size and number of events were relatively small, and it is possible that  
364 there was not enough statistical power to detect small to moderate associations. Bahr  
365 et al. (Bahr & Holme, 2003) stated that one would need 30 to 40 events to detect  
366 moderate to strong associations and more than 200 events for small to moderate as-  
367 sociations. Because of the sample size, we did not stratify the analyses by sex. Thus,  
368 we added sex to the risk factor models, but because sex was an insignificant covariate,  
369 it was dropped from the final models. However, in future investigations, it would be  
370 better to explore the risk factors for LBP in more homogenous samples, such as within  
371 one sport or females or males separately.

372

373 Because we investigated the risk factors for LBP resulting in time loss from training and  
374 games, it should be noted that the results might be different if all low back complaints  
375 were included. If the OSTRC questionnaire were used, we could have captured more  
376 injuries affecting the player in different ways (Clarsen, Myklebust, & Bahr, 2013). For  
377 example, Clarsen et al. (2015) has shown that back pain complaints are very common  
378 in the athletic population of young adults and youth and do not often lead to absence  
379 from sport activity, even though they can affect participation and performance. Using  
380 time loss as a determinant of severity might underestimate the influence of psycho-  
381 social factors (e.g., fear avoidance) when a player is unable to fully participate in train-  
382 ing and games. The OSTRC questionnaire gives more information on how the player  
383 has perceived LBP to affect their participation.

384

385 The aetiology of LBP has been shown to be multifactorial, meaning that in addition to  
386 external loading, internal loading such as psychosocial stress, as well as other socioec-  
387 onomic, health and health-behaviour factors, should also be considered and recorded  
388 in future LBP studies focusing on youth athletes.

389

390

### **CONCLUSIONS**

391 The SKL test, as measured in the current study, is not a useful screening test to identify  
392 youth basketball and floorball players at increased risk for future LBP.

393

**REFERENCES**

394

395 Astfalck, R. G., O'Sullivan, P. B., Straker, L. M., Smith, A. J., Burnett, A., Caneiro, J. P., &  
396 Dankaerts, W. (2010). Sitting postures and trunk muscle activity in adolescents  
397 with and without nonspecific chronic low back pain: an analysis based on subclass-  
398 sification. *Spine*, 35(14), 1387-1395. doi:10.1097/BRS.0b013e3181bd3ea6

399 Bahr, R., & Holme, I. (2003). Risk factors for sports injuries—A methodological ap-  
400 proach. *British Journal of Sports Medicine*, 37(5), 384-392.  
401 doi:10.1136/bjism.37.5.384

402 Bahr, R., Andersen, S. O., Løken, S., Fossan, B., Hansen, T., & Holme, I. (2004). Low back  
403 pain among endurance athletes with and without specific back loading—A cross-  
404 sectional survey of cross-country skiers, rowers, orienteers, and nonathletic  
405 controls. *Spine*, 29(4), 449-454. doi:10.1097/01.brs.0000096176.92881.37

406 Bassani, T., Casaroli, G., & Galbusera, F. (2019). Dependence of lumbar loads on  
407 spinopelvic sagittal alignment: An evaluation based on musculoskeletal modeling.  
408 *PLoS One*, 14(3), e0207997. doi:10.1371/journal.pone.0207997

409 Bayne, H., Elliott, B., Campbell, A., & Alderson, J. (2016). Lumbar load in adolescent  
410 fast bowlers: A prospective injury study. *Journal of Science and Medicine in Sport*,  
411 19(2), 117-122. doi:10.1016/j.jsams.2015.02.011

- 412 Calvo-Muñoz, I., Gómez-Conesa, A., & Sánchez-Meca, J. (2013). Prevalence of low back  
413 pain in children and adolescents: a meta-analysis. *BMC Pediatrics*, *13*(1), 14.  
414 doi:10.1186/1471-2431-13-14
- 415 Chaudhari, A. M. W., McKenzie, C. S., Pan, X., & Oñate, J. A. (2014). Lumbopelvic con-  
416 trol and days missed because of injury in professional baseball pitchers. *The Amer-  
417 ican Journal of Sports Medicine*, *42*(11), 2734-2740.  
418 doi:10.1177/0363546514545861
- 419 Clarsen, B., Bahr, R., Heymans, M., Engedahl, M., Midsundstad, G., Rosenlund, L., . . .  
420 Myklebust, G. (2015). The prevalence and impact of overuse injuries in five Nor-  
421 wegian sports: Application of a new surveillance method. *Scandinavian Journal of  
422 Medicine and Science in Sports*, *25*(3), 323-330. doi:10.1111/sms.12223
- 423 Clarsen, B., Myklebust, G., & Bahr, R. (2013). Development and validation of a new  
424 method for the registration of overuse injuries in sports injury epidemiology: The  
425 Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire. *Brit-  
426 ish Journal of Sports Medicine*, *47*(8), 495-502. doi:10.1136/bjsports-2012-091524
- 427 Coenen, P., Smith, A., Paananen, M., O'Sullivan, P., Beales, D., & Straker, L. (2017). Tra-  
428 jectories of low back pain from adolescence to young adulthood. *Arthritis Care &  
429 Research*, *69*(3), 403-412. doi:10.1002/acr.22949
- 430 Corkery, M. B., O'Rourke, B., Viola, S., Yen, S., Rigby, J., Singer, K., & Thomas, A. (2014).  
431 An exploratory examination of the association between altered lumbar motor

- 432 control, joint mobility and low back pain in athletes. *Asian Journal of Sports Medi-*  
433 *cine*, 5(4), e24283. doi:10.5812/asjms.24283
- 434 Dankaerts, W., O'Sullivan, P., Burnett, A., & Straker, L. (2006). Differences in sitting  
435 postures are associated with nonspecific chronic low back pain disorders when  
436 patients are subclassified. *Spine*, 31(6), 698-704.  
437 doi:10.1097/01.brs.0000202532.76925.d2
- 438 Dankaerts, W., O'Sullivan, P., Burnett, A., Straker, L., Davey, P., & Gupta, R. (2009). Dis-  
439 criminating healthy controls and two clinical subgroups of nonspecific chronic low  
440 back pain patients using trunk muscle activation and lumbosacral kinematics of  
441 postures and movements: A statistical classification model. *Spine*, 34(15), 1610-  
442 1618. doi:10.1097/BRS.0b013e3181aa6175
- 443 DiMattia, M. A., Livengood, A. L., Uhl, T. L., Mattacola, C. G., & Malone, T. R. (2005).  
444 What are the validity of the single-leg-squat test and its relationship to hip-  
445 abduction strength? *Journal of Sport Rehabilitation*, 14(2), 108-123.  
446 doi:10.1123/jsr.14.2.108
- 447 Elphinston, J. (2008). *Stability, sport, and performance movement: Great technique*  
448 *without injury* (1st ed.). Berkley, CA: North Atlantic Books.
- 449 Ferreira, P. H., Beckenkamp, P., Maher, C. G., Hopper, J. L., & Ferreira, M. L. (2013).  
450 Nature or nurture in low back pain? Results of a systematic review of studies  
451 based on twin samples. *European Journal of Pain*, 17(7), 957-971.  
452 doi:10.1002/j.1532-2149.2012.00277.x

- 453 Franz, C., Jespersen, E., Rexen, C. T., Leboeuf-Yde, C., & Wedderkopp, N. (2016). Back  
454 injuries in a cohort of schoolchildren aged 6–12. *Scandinavian Journal of Medicine  
455 & Science in Sports, 26*(8), 918. doi:10.1111/sms.12519
- 456 Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., . . . Meeu-  
457 wisse, W. H. (2006). Consensus statement on injury definitions and data collection  
458 procedures in studies of football (soccer) injuries. *British Journal of Sports Medi-  
459 cine, 40*(3), 193-201. doi:10.1136/bjism.2005.025270
- 460 Grosdent, S., Demoulin, C., Rodriguez de La Cruz, Carlos, Giop, R., Tomasella, M.,  
461 Crielaard, J., & Vanderthommen, M. (2016). Lumbopelvic motor control and low  
462 back pain in elite soccer players: a cross-sectional study. *Journal of Sports Scienc-  
463 es, 34*(11), 1021-1029. doi:10.1080/02640414.2015.1085077
- 464 Hangai, M., Kaneoka, K., Okubo, Y., Miyakawa, S., Hinotsu, S., Mukai, N., . . . Ochiai, N.  
465 (2010). Relationship between low back pain and competitive sports activities dur-  
466 ing youth. *The American Journal of Sports Medicine, 38*(4), 791-796.  
467 doi:10.1177/0363546509350297
- 468 Hara, R., Sangeux, M., Baker, R., & McGinley, J. (2013). Quantification of pelvic soft tis-  
469 sue artifact in multiple static positions. *Gait & Posture, 39*(2), 712-717.  
470 doi:10.1016/j.gaitpost.2013.10.001
- 471 Hardcastle, P., & Nade, S. (1985). The significance of the Trendelenburg test. *The Jour-  
472 nal of Bone and Joint Surgery, 67*(5), 741-746. doi:10.1016/0268-0033(86)90096-3

- 473 Kamper, S. J., Yamato, T. P., & Williams, C. M. (2017). The prevalence, risk factors,  
474 prognosis and treatment for back pain in children and adolescents: An overview of  
475 systematic reviews. *Best Practice & Research: Clinical Rheumatology*, 30(6), 1021-  
476 1036. doi:10.1016/j.berh.2017.04.003
- 477 Karandikar, N., & Vargas, O. O. (2011). Kinetic chains: A review of the concept and its  
478 clinical applications. *PM&R*, 3(8), 739-745. doi:10.1016/j.pmrj.2011.02.021
- 479 Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G.,  
480 & Jørgensen, K. (1987). Standardised Nordic questionnaires for the analysis of  
481 musculoskeletal symptoms. *Applied Ergonomics*, 18(3), 233-237.  
482 doi:10.1016/0003-6870(87)90010-X
- 483 Leppänen, M., Rossi, M. T., Parkkari, J., Heinonen, A., Äyrämö, S., Krosshaug, T., . . .  
484 Pasanen, K. (2020). Altered hip control during a standing knee-lift test is associat-  
485 ed with increased risk of knee injuries. *Scandinavian Journal of Medicine & Science*  
486 *in Sports*, 30(5), 922-931. doi:10.1111/sms.13626
- 487 Olivier, B., Stewart, A. V., Olorunju, S. A. S., & McKinon, W. (2015). Static and dynamic  
488 balance ability, lumbo-pelvic movement control and injury incidence in cricket  
489 pace bowlers. *Journal of Science and Medicine in Sport*, 18(1), 19-25.  
490 doi:10.1016/j.jsams.2013.10.245
- 491 Olsen, O., Myklebust, G., Engebretsen, L., & Bahr, R. (2004). Injury mechanisms for an-  
492 terior cruciate ligament injuries in team handball. *The American Journal of Sports*  
493 *Medicine*, 32(4), 1002-1012. doi:10.1177/0363546503261724



- 494 O'Sullivan, P., Smith, A., Beales, D., & Straker, L. (2017). Understanding adolescent low  
495 back pain from a multidimensional perspective: Implications for management. *The*  
496 *Journal of Orthopaedic and Sports Physical Therapy*, 47(10), 741-751.  
497 doi:10.2519/jospt.2017.7376
- 498 XXXX
- 499 XXX
- 500 Peduzzi, P., Concato, J., Feinstein, A. R., & Holford, T. R. (1995). Importance of events  
501 per independent variable in proportional hazards regression analysis II. Accuracy  
502 and precision of regression estimates. *Journal of Clinical Epidemiology*, 48(12),  
503 1503-1510. doi:10.1016/0895-4356(95)00048-8
- 504 Peduzzi, P., Concato, J., Kemper, E., Holford, T. R., & Feinstein, A. R. (1996). A simula-  
505 tion study of the number of events per variable in logistic regression analysis.  
506 *Journal of Clinical Epidemiology*, 49(12), 1373-1379. doi:10.1016/S0895-  
507 4356(96)00236-3
- 508 Popovich, J. M., Welcher, J. B., Hedman, T. P., Tawackoli, W., Anand, N., Chen, T. C., &  
509 Kulig, K. (2013). Lumbar facet joint and intervertebral disc loading during simulat-  
510 ed pelvic obliquity. *The Spine Journal*, 13(11), 1581-1589.  
511 doi:10.1016/j.spinee.2013.04.011
- 512 R Core Team. (2016). *R: A language and environment for statistical computing* [com-  
513 puter software]. Vienna, Austria: R Foundation for Statistical Computing.

514 Roussel, N. A., Nijs, J., Mottram, S., Van Moorsel, A., Truijen, S., & Stassijns, G. (2009).  
515 Altered lumbopelvic movement control but not generalized joint hypermobility is  
516 associated with increased injury in dancers. A prospective study. *Manual Therapy*,  
517 *14*(6), 630-635. doi:10.1016/j.math.2008.12.004

518 Therneau, T. M. (2015). *coxme: Mixed effects Cox models*. R package  
519 [computer software]

520

Journal Pre-proof

### HIGHLIGHTS

- The association between LBP and pelvic kinematics in youth floorball and basketball players was investigated in this cohort study.
- Three-dimensional movement analysis was used, and pelvic kinematics were calculated from standing knee lift test.
- Individual training and game hours and time-loss LBP were recorded during the 12-month follow-up.
- Neither pelvic tilt, or obliquity, during standing knee lift test were associated with future LBP in youth floorball and basketball players.

**Ethical approval** Ethics Committee of Pirkanmaa Hospital District (ETL-code R10169). The study was carried out in accordance with the Declaration of Helsinki and the guidelines for good scientific practice.

Journal Pre-proof

**Conflict of Interest** None to declare

**Ethical Statements** Ethics Committee of Pirkanmaa Hospital District (ETL-code R10169). The study was carried out in accordance with the Declaration of Helsinki and the guidelines for good scientific practice.

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**Availability of data and materials** The data can not be shared because permission was not asked from the participants or their parents.

**Authors' contributions** All authors contributed to study concept and design. KP was responsible for conducting the data acquisition. ML was responsible for preparation of the 3D motion capture data. MR was responsible for the main data analysis, interpretation and writing the first draft of the manuscript. KP, AH, SÄ, ML, GM, TV, PK, and JP were significant manuscript revisers. All authors have approved the submitted version of the manuscript. KP is the guarantor.