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Short communication

The effect of leg preference on postural stability in healthy athletes

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ABSTRACT

In research regarding postural stability, leg preference is often tested and controlled for. However, leg preference may vary between tasks. As athletes are a group of interest for postural stability testing, we evaluated the effect of five leg preference tasks categorization (step up, hop, ball kick, balance, pick up) on single-leg postural stability of 16 field hockey athletes. The 'center of pressure speed' was calculated as the primary outcome variable of single-leg postural stability. Secondary variables were 'mean length of the GRF vector in the horizontal plane', 'mean length of the ankle angular velocity vector', and 'mean length of the hip angular velocity vector', as well as the separate outcomes per degree of freedom. Results showed that leg preference was inconsistent between leg preference tasks. Moreover, the primary and secondary variables yielded no significant difference between the preferred and non-preferred legs, regardless of the applied leg preference task categorization ($p > 0.05$). The present findings do not support the usability of leg preference tasks in controlling for bias of postural stability. In conclusion, none of the applied leg preference tasks revealed a significant effect on postural stability in healthy field hockey athletes.

1. Introduction

Diminished postural stability is associated with primary and secondary ankle and knee injuries (Witchalls et al., 2012; Hrysomallis, 2007; Negahban et al., 2013). Single leg stance is the most frequently used method to test postural stability. However, asymmetry in single leg stance postural control that is independent of injury, may reduce the usability of comparisons between the injured and uninjured legs, and may bias group comparisons as well. Various factors have been put forward as a cause of asymmetrical postural stability, such as asymmetrical training, morphological differences, or differential neuroanatomic organization (Peters, 1988; Teixeira et al., 2011; Kapreli et al., 2006). It has been proposed that one leg is tuned for mobilizing features and the other leg for postural stability (Grouios et al., 2009), while others argue that one leg is predominantly used for the most difficult aspect of a task (Hart and Gabbard, 1997). As the etiology of leg dominancy and leg preference is not yet elucidated (Olex-Zarychta and Raczek, 2008), the common employment of leg preference as a control variable in designing experiments may lead to bias and limit experimental design options.

As athletes are a group of interest for postural stability testing, the aim of the present study was to evaluate if leg preference should be considered as a control variable in static single-leg postural stability testing in athletes. Hence, the effect of leg preference on static single-leg postural stability was considered in field hockey athletes by means of force plate and kinematics outcome measures and five leg preference tasks that differ in features of functional behavior of the lower extremities (Schneiders et al., 2010): step up, hop, ball kick, balance and pick up. As field hockey does not involve specific asymmetrical training of single-leg standing, we hypothesized that none of our leg preference tasks would have significant effects on static single-leg postural stability.

2. Methods

2.1. Participants

Sixteen field hockey athletes (8 men, 8 women; mean ± SD; age 19.1 ± 1.96 years; height 174 ± 9.3 cm; body mass 66.9 ± 9.12 kg) participated voluntarily in the present study. All participants competed in the Dutch field hockey competition at either inter-district or national level, and had at least six years of field hockey experience. A sample of field hockey athletes was recruited, since field hockey encompasses high incidence rates of ankle and knee injuries (Schmikli et al., 2009). Comparable to many other sports (e.g., tennis, volleyball, basketball), field hockey

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may involve some asymmetrical behavior which could originate from the handling of the hockey stick. However, in contrast to soccer, there is no specific asymmetrical training of single-leg standing.

All participants were healthy and did not report any (history of) neuromusculoskeletal injuries or other diseases that may affect balance performance. Furthermore, none of the participants reported any experience with balance training in particular. Written informed consent was obtained once the purpose, nature and potential risks had been explained. The study was performed according to the Declaration of Helsinki and approved by the local ethics committee. A priori estimated sample size for $\beta = 0.80$ with $\alpha = 0.05$ was calculated based on 'center of pressure speed' data from Hoffman et al. (1998). For a detectable difference of 10% of the mean outcome, at least 12 participants were needed.

2.2. Testing procedures

The participants performed five different motor tasks to evaluate leg preference (Hart and Gabbard, 1997; Hoffman et al., 1998, Schneiders et al., 2010; Verhagen et al., 2003): (1) *step up;* step onto a 25 cm high box, (2) *hop*; stand on one leg and hop as high as possible, (3) *ball kick*; kick a soccer ball with maximal accuracy at a 1 m wide goal, 10 m from the participant, (4) *balance*; balance on a wobble board on one leg during 10 s, and (5) *pick up*; pick up and place three marbles into a cup, one by one, using the toes while sitting on a chair. The leg that was used to step up, hop, kick a ball, balance or pick up marbles was recorded as the outcome. Each task was performed three times and tasks were performed in random order. When participants switched legs within a task, a fourth attempt was carried out. Hence, there was a possibility of a 'mixed' outcome. All tasks were performed barefoot. To ensure that preference tasks were carried out with as little contemplation on leg preference as possible, the participants were told that the tasks graded their general motor skills and thus had to be performed at maximum effort. These motor tasks were chosen as they adequately represent important features of functional behavior of the lower extremities, i.e. motor tasks with fine, unilateral non-fine, and bilateral non-fine features (Schneiders et al., 2010).

Subsequently, three valid single-leg standing trials of 20 s with the eyes open for each leg were carried out (Ross et al., 2009), during which ground reaction forces and motion capture measurements were performed. The foot orientation was aligned to a marked line on the force plate. Participants had to stand as still as possible and keep their hands on their hips. A trial was considered invalid if a participant displaced his/her standing leg, touched the floor with the contralateral leg or if a hand was used to regain balance. All trials were performed barefoot. Participants were given two practice opportunities with each leg before actual testing commenced. The initial testing leg was randomly assigned, and counterbalanced.

2.3. Data acquisition

Ground reaction force (GRF) data were collected with a 60 by 40 cm force plate (type 9218B, Kistler Instrument Corp, Winterthur, Switzerland) and sampled at 1000 Hz. Furthermore, motion capture data of the lower extremity were collected with the OPTOTRAK® optoelectronic camera system (Northern Digital Inc, Waterloo CA), which consisted of two cameras containing three sensors each. The Optotrak system measures the three-dimensional position of light-emitting diodes (LEDs) in a global reference frame with random errors < 0.05 mm. The sample frequency was 200 Hz. Ten LED markers were attached to the participants' skin on positions with minimal soft tissue deformations during movement (Fig. 1). Additionally, a custom-made aluminum object with three LED markers was positioned over the sacrum. Prior to stance testing, while participants stood upright, facing the positive X-axis of the system, bony landmarks were digitized using a pointing device. The locations of these landmark relative to the technical coordinate system based on the cluster LED markers locations during task execution, were used to construct an anatomical axis system at each instant of time for each body segment (Cappozzo et al., 1995).

2.4. Data analysis

A custom MATLAB (The Mathworks, Natick, RI, USA) program was designed for data analysis. The GRF and motion capture data were filtered with a second order Butterworth low-pass filter with estimated optimal cut-off frequencies of 43 Hz and 16 Hz, respectively (Yu et al., 1999, Bisseling and Hof, 2006). Center of pressure (CoP) calculations were based on vertical and horizontal GRF in accordance with the manufacturer's manual. Joint angular velocity vectors were calculated from the instantaneous distal relative to the proximal segment anatomical axes orientation matrices according to Berme et al. (1990).

Our primary outcome measure of postural stability was the resultant 'CoP speed' (total CoP path length divided by trial time). The 'CoP speed' has been shown to be reliable (Doyle et al., 2007), and discriminative concerning single-leg stance balance (Jakobsen et al., 2011; Paillard et al., 2006; Ross et al., 2009; Wikstrom et al., 2010). Additionally, the following resultant parameters were added as secondary outcome measures: the 'horizontal GRF' (mean length of the GRF vector in the horizontal plane), the 'ankle angular velocity' (mean length of the ankle angular velocity vector), and the 'hip angular velocity' (mean length of the hip angular velocity vector). The 'horizontal GRF' is related to the amount of sway of the center of mass and to the corrective shear forces due to counter rotation acceleration of the trunk (Hof, 2007; Pintsaar et al., 1996). This parameter has been shown in few studies to be discriminative as well (Pintsaar et al., 1996; Ross et al., 2009). Angular velocities of the ankle and the hip were added since most motor corrections in single leg stance are made by ankle and hip/trunk movements (Hof, 2007; Lin et al., 2011; Tropp and Odenrick, 1988). As separate analyses of direction might provide additional information (Ross et al., 2004), all outcome measures were analyzed for each degree of freedom as well.

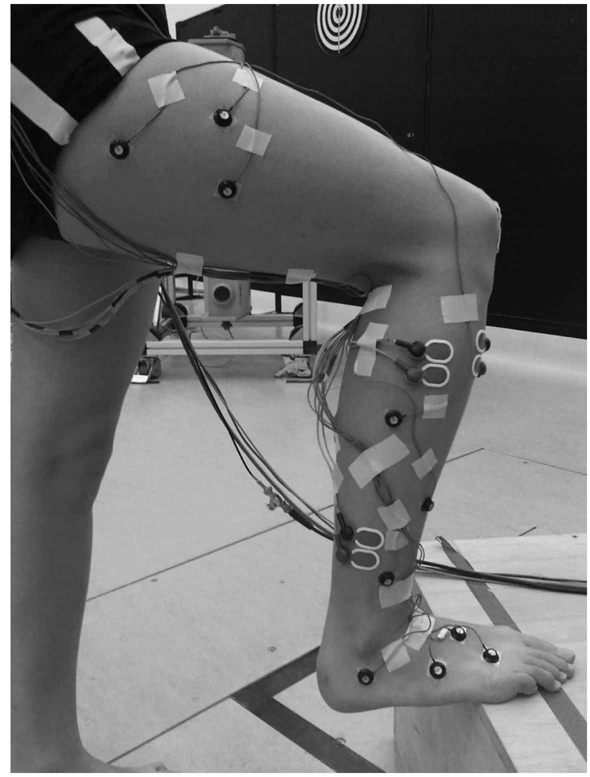

Fig. 1. Typical LED marker positioning on the lower extremity.

For each leg, the postural stability parameter outcomes were averaged over the three single-leg stance trials. Subsequently, after checking normal distribution of the data, comparisons between the preferred and non-preferred leg were performed using a paired two-way student *t*-test. The preferred and non-preferred leg may change according to the preference task evaluated. Since five leg preference tasks were performed, the postural stability outcome was analyzed according to five ways of categorizing the preferred and non-preferred leg. As the statistical analyses were performed for each categorization separately, five statistical tests were performed for the primary outcome measure. Participants with a 'mixed' outcome on a leg preference task were removed from analysis with respect to that leg preference task categorization. In view of the purpose and hypothesis of the present study, we chose not to correct the *P*-value for the multiple testing, as it would increase the chance of type 2 errors. Nevertheless, it is obvious that possible significant findings should be interpreted with the family wise error in mind.

3. Results

The results of the preference tasks are shown in Table 1 and indicate that leg preference was not consistent across tasks. The postural stability parameters are outlined in Table 2, and present the difference between the preferred and non-preferred leg, while grouping of legs was performed according to each preference task outcome. The primary outcome measure, resultant 'CoP speed', as well as the secondary outcome measures, were not significantly different ($P > 0.100$) between the preferred and non-preferred legs, regardless of the employed leg preference task. Fig. 2 illustrates the effect sizes (% of mean) and 95% confidence intervals per leg preference task categorization.

Table 1
Leg preference tasks.

	p01	p02	p03	p04	p05	p06	p07	p08	p09	p10	p11	p12	p13	p14	p15	p16
Step up	L	M	M	R	R	L	R	R	R	R	R	L	R	R	R	R
Hop	R	R	L	L	R	L	R	M	R	R	M	R	R	R	R	R
Ball kick	R	R	L	L	R	R	R	R	R	R	R	R	R	R	R	R
Balance	L	R	L	L	R	L	R	R	R	R	R	L	R	R	R	R
Pick up	L	M	L	L	R	R	R	R	R	R	R	L	R	R	R	R

p, Participant number; R, right leg preference; L, left leg preference; M, mixed preference; *Step up*, stepping onto a box with one leg; *Hop*, maximal vertical hop with one leg; *Ball kick*, kicking a ball on goal; *Balance*, single-leg balancing on a wobble board; *Pick up*, picking up marbles and putting them into a cup using the toes of one leg.

Table 2
Difference in single-leg stance postural stability between the preferred (P) and non-preferred (NP) leg based on step up, hop, ball kick, balance, or pick up preference task.

	Mean ± SD	*P vs NP*	**Step up** $n=14$	**Hop** $n=14$	**Ball kick** $n=16$	**Balance** $n=16$	**Pick up** $n=15$
Primary outcome measure							
Mean CoP speed RES		Diff	7.10%	−3.00%	−2.80%	4.40%	3.80%
	48.0 ± 13.3 mm s^{-1}	SD of diff	17.20%	18.50%	17.40%	17.00%	17.60%
		P-value	0.15	0.54	0.53	0.31	0.42
Secondary outcome measures [a]							
Mean CoP speed AP		Diff	9.30%	−5.00%	−3.80%	6.20%	5.00%
	31.4 ± 9.4 mm s^{-1}	SD of diff	24.20%	25.80%	24.40%	23.90%	24.70%
Mean CoP speed ML		Diff	4.90%	−0.20%	−1.30%	2.60%	2.50%
	30.1 ± 8.0 mm s^{-1}	SD of diff	12.90%	13.80%	13.50%	13.30%	13.80%
|Mean| horizontal GRF RES		Diff	6.40%	−9.70%	−1.70%	3.70%	9,5%
	3.6 ± 1.2 N	SD of diff	30.10%	28.80%	28.70%	28.50%	28.00%
|Mean| horizontal GRF AP		Diff	8.30%	−6.00%	−2.40%	4.50%	6.40%
	2.0 ± 0.5 N	SD of diff	25.00%	25.40%	24.70%	24.40%	24.80%
|Mean| horizontal GRF ML		Diff	5.80%	−11.60%	−1.40%	3.70%	11.80%
	2.6 ± 1.0 N	SD of diff	35.00%	33.10%	33.10%	32.90%	31.90%
Mean| ANKLE angular velocity RES		Diff	9.10%	−4.30%	−9.90%	4.20%	−1.80%
	8.9 ± 4.1 deg s^{-1}	SD of diff	26.20%	28.00%	25.10%	26.80%	27.90%
|Mean| ANKLE angular velocity F/E		Diff	11.30%	−8.70%	−14.20%	1.50%	−2.50%
	2.3 ± 0.7 deg s^{-1}	SD of diff	36.50%	38.40%	33.80%	36.80%	36.90%
|Mean| ANKLE angular velocity Ab/Ad		Diff	8.40%	−4.30%	−14.10%	5.00%	−8.10%
	5.1 ± 2.9 deg s^{-1}	SD of diff	37.70%	38.60%	33.50%	36.10%	36.40%
|Mean| ANKLE angular velocity End/Exo		Diff	9.10%	−1.80%	−5.20%	4.20%	2.30%
	5.8 ± 3.0 deg s^{-1}	SD of diff	29.10%	31.80%	30.40%	30.50%	31.70%
|Mean| HIP angular velocity RES		Diff	12.20%	−10.30%	−10.50%	3.00%	2,2%
	5.6 ± 2.9 deg s^{-1}	SD of diff	29.10%	31.00%	34.20%	32.20%	33.80%
|Mean| HIP angular velocity F/E		Diff	11.40%	−9.90%	−6.10%	1.70%	0.40%
	2.0 ± 1.2 deg s^{-1}	SD of diff	37.00%	36.00%	40.20%	40.60%	40.40%
|Mean| HIP angular velocity Ab/Ad		Diff	12.50%	−18.40%	−12.90%	5.70%	7.90%
	2.0 ± 1.1 deg s^{-1}	SD of diff	41.40%	39.60%	40.10%	41.90%	42.40%
|Mean| HIP angular velocity End/Exo		Diff	14.00%	−6.90%	−10.20%	3.20%	0.60%
	4.2 ± 2.1 deg s^{-1}	SD of diff	31.70%	35.60%	32.40%	34.10%	34.60%

Mean ± SD: mean outcome ± standard deviation concerning all legs, after averaging over 3 trials per leg; CoP: center of pressure; GRF: ground reaction force; |Mean|: mean of the absolute; RES: resultant vector; ML: mediolateral direction; AP: anteroposterior direction; F/E: flexion/extension; Ab/Ad: abduction/adduction; End/Exo: endorotation/exorotation; Diff: difference between preferred and non-preferred legs (preferred minus non-preferred leg) as % of the mean value; SD of diff: standard deviation of differences between both legs; *n*: number of participants, which vary across preference tasks due to 'mixed' outcomes; *P*-value applies to the *t*-test comparison between the outcome of postural stability parameter on the preferred and non-preferred legs.

[a] Secondary outcome measures all revealed a *P*-value > 0.100.

4. Discussion

The main finding of the present study is that we did not find an effect of leg preference on postural stability in healthy field hockey athletes, regardless of the applied leg preference task. Additionally, the outcomes on the preference tasks (Table 1) suggest that leg preference is task dependent and there is no such thing as 'the preferred' or 'the dominant' leg. The common right limb preference outcome (88%) on the ball kick task, and a marked decrease of right limb preference (to 69%) when the non-mobilizing preference tasks were taken into account, are in agreement with previous research (Armitage and Larkin, 1993; Hart and Gabbard, 1998). The same applies to the higher consistency of preference outcomes in right-footed individuals compared to left-footed individuals (Hart and Gabbard, 1998). Therefore, the present sample can be seen as a valid representation of leg preference distribution throughout the population.

The novelty of the present study is that a variety of preference tasks were taken into account, and that the leg preference effect on postural stability was assessed by use of both force plate and kinematics parameters. Concerning the absence of an effect of leg preference on single-leg stance stability, our findings are in accordance with previous studies that have focused on the ball kick task (Gstöttner et al., 2009; Harrison et al., 1994; Holder-Powell and Rutherford, 2000; McCurdy and Langford, 2006), and on the combination of the ball kick, step up, and balance recovery task (Verhagen et al., 2003; Hoffman et al., 1998; Lin et al., 2011). Only one study reported a significant effect of leg preference on single-leg stance stability: a lower CoP velocity in AP direction for the non-preferred leg on the ball kick task in physically active

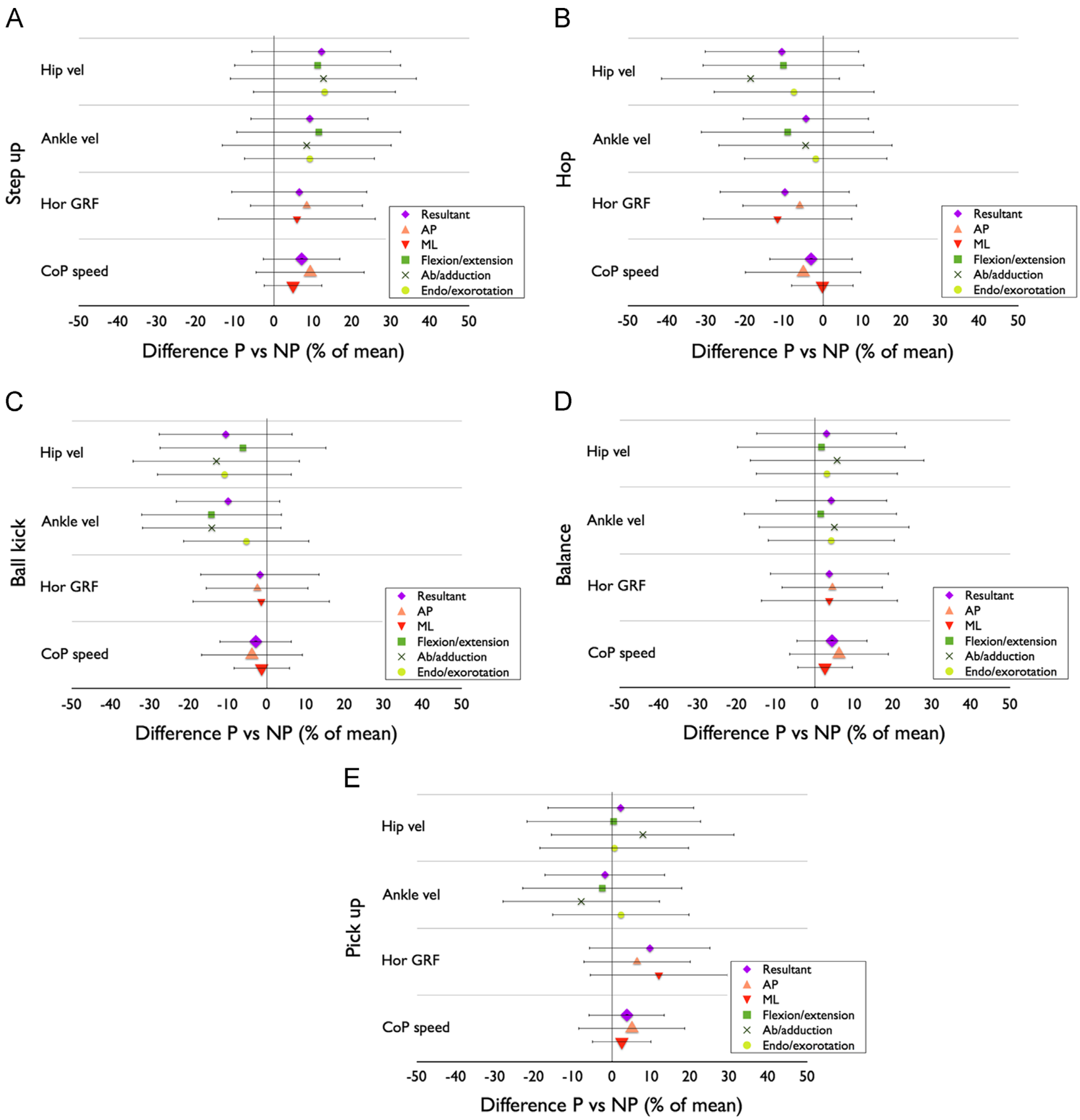

Fig. 2. Differences (as % of the mean outcome) between preferred (P) and non-preferred (NP) legs in static single-leg postural stability, whereas a positive difference indicates higher postural stability outcome in the preferred legs. The legs are categorized in P and NP based on leg preference tasks: step up (2A), hop (2B), ball kick (2C), balance (2D), and pick up (2E). The error bars illustrate the 95% confidence intervals of the difference (as % of the mean outcome). 'Hip vel/Ankle vel': mean absolute hip/ankle angular velocity; 'Hor GRF': mean absolute horizontal ground reaction force; 'CoP speed': mean center of pressure speed.

individuals (Ross et al., 2004). Our findings further strengthen the idea of Hoffman et al. (1998) that little rationale exists for the incorporation of any kind of leg preference testing in postural stability research with regard to sports or sports medicine. However, it should be noted that the present findings are most applicable to field hockey athletes. The findings may be generalized to other sports without obvious asymmetric proficiency of single-leg standing (e.g., tennis, volleyball, basketball, and rugby), but it is well possible that findings would be different in sports like soccer (Teixeira et al., 2011, Guillou et al., 2007, Grouios et al., 2009). Additionally, the level of sports participation of the present participants was moderate, i.e. on average 6 h per week. It has been suggested that athletes possess less asymmetrical skills, due to motor skill training of both legs (Grouios et al., 2009). Therefore, the present findings are likely to hold for elite athletes, but might not be generalized to untrained individuals. However, these suggestions should be verified in future research.

In view of the substantial inter-limb variances, it is important to realize that we cannot rule out the existence of small effects of leg preference due to the possibility of type II errors. However, our primary outcome measure, resultant 'CoP speed', showed differences between legs of −3.0% to 7.1% depending on leg preference task categorization. Fig. 2 illustrates that the 95% confidence interval of the resultant 'CoP speed' was approximately ±10% of the mean outcome, which is considerably smaller than the variance between subjects and effect sizes with respect to injuries such as ankle sprains or anterior cruciate ligament ruptures (Witchalls et al., 2012; Ross et al., 2009; Wikstrom et al., 2010; Negahban et al., 2013). Moreover, if small effects are considered to be of importance in the context of a specific research question, the inconsistency between leg preference task outcome may hinder the usability of a 'preferred leg' construct as a control variable. For the joint angular velocities it is difficult to interpret the 'random' variance between legs, as to our knowledge, this is the first study to employ those measures for single-leg stance, hence the variance cannot be related to previous effect sizes of injuries or impairments. More research is needed to evaluate the sensitivity of those measures in sports medicine. Additionally, in spite of our careful selection of relevant postural stability parameters, we cannot rule out that other parameters of postural stability might differ between the preferred and non-preferred legs.

In conclusion, the present findings suggest that the possible effect of leg preference on postural stability in healthy field hockey athletes is, irrespective of leg preference task, absent or small, and that inter-limb variance is largely independent of leg preference. Furthermore, leg preference tasks are inconsistent in characterizing 'the preferred leg'. Therefore, it is difficult to control for leg preference, and, at least in field hockey athletes, not controlling for leg preference is unlikely to significantly bias static postural stability outcomes.

Conflict of interest statement

None.

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