# Preferred leg and strength asymmetries

## A cross sectional study comparing perceived and measured laterality

Kung Emelie Persson

THE SWEDISH SCHOOL OF SPORT AND HEALTH SCIENCES

Master's degree project: 85:2021
Teacher education programme: 2017-2021
Supervisor: Toni Arndt & Manne Godhe
Examiner: Kerstin Hamrin

## List of tests and abbreviations

| Abbreviation | Test | Apparatus | Parameters | Category |
|---|---|---|---|---|
| LP-C | Concentric multi joint leg press | IsoMed2000 | Peak force, N·kg−1 in the left and right leg. | Strength |
| LP-E | Eccentric multi joint leg press | Isomed2000 | Peak force, N·kg−1, in the left and right leg. | Strength |
| CMJ | Countermovement jump | Kiesler force plates | Peak force, N·kg−1, in the left and right leg. | Explosive strength |
| RCMJ:<br>a) RCMJ-B (beginning)<br>b) RCMJ-E (end) | 60 s repeated countermovement jump | Kiesler force plates | Peak force, N·kg−1, in the left and right leg, pre and post fatigue. | Strength endurance |
| GQ | General questions | Pen and paper | Gender, age, weight, injury history in lower limbs. | Questionnaire |
| WFQ | Waterloo Footedness Questionnaire, revised. | Pen and paper | Preferred for skills and preferred leg for stabilizing | Questionnaire |
| PL | Perceived laterality, VASscale. | Pen and paper | Preferred leg for; landing, strength, and balance. | Questionnaire |

## Abstract

**Aim**: The aim of this study was to examine the relationship between the degree of self-perceived leg preference and the degree of strength asymmetries in well-trained adults.

**Method:** All tests took place during two separate days at the Swedish School of Sport and Health Sciences. Preferred and non-preferred leg was examined via questionnaires. Concentric and eccentric strength measurements were executed in an isokinetic dynamometer in both right and left leg. Left and right leg peak force when performing CMJ's, RCMJ-B and RCMJ-B was collected via floor fit force plates. Degree of self-perceived laterality was then compared with the degree of strength asymmetries using Spearman's rho and strength asymmetries was compared using Pearson's correlation.

**Results:** Self-perceived laterality and degree of strength asymmetries showed a significant correlation in three of the measured variables: LP-C300 and self-perceived stronger leg (=0.74), CMJ and self-perceived preferred leg for landing (=0.67), RCMJ-B and the self-perceived leg for balancing (=0.65). Strength asymmetries that were significantly correlated: LP-C10 and LP-E300 (=0.78), LP-C10 and RCMJ-B (=0.63), LP-E50 and LP-E100 (=0.91), LP-E50 and LP-E300 (=0.62), LP-E50 and RCMJ-E (=-0.73), LP-E100 and LP-E300 (=0.62), LP-E100 and RCMJ-E (=-0.70).

**Conclusion:** In conclusion, three of the self-perceived laterality results were significantly positively correlated to strength asymmetries; the self-perceived stronger leg and the LP-C300test, the self-perceived preferred leg for landing and the CMJ -test, and the self-perceived preferred leg for balancing and the RCMJ-B-test. Strength asymmetries correlated, showing that there are in fact significant correlations between strength asymmetries in eccentric leg presses in different speeds as well as in slow concentric movements and the first RCMJ-jump.

# Vilket ben som föredras och styrkeasymmetrier

## En tvärsnittsstudie som jämför självupplevd och uppmätt lateralitet

Kung Emelie Persson

GYMNASTIK- OCH IDROTTSHÖGSKOLAN
Magisteruppsats: 85:2021
Ämneslärarprogrammet: 2017–2021
Handledare: Toni Arndt & Manne Godhe
Examinator: Kerstin Hamrin

## Sammanfattning

**Syfte:** Syftet med denna studie var att undersöka relationen mellan graden av självupplevd lateralitet och graden av styrkeassymetrier hos vältränade vuxna individer.

**Metod:** Testerna i denna studie genomfördes under två, på varandra efterföljande dagar, vid Gymnastik- och idrottshögskolan i Stockholm. Vilket som ben som var det föredragna och vilket ben som var det icke- föredragna hos deltagarna undersöktes via enkäter. Den koncentriska och excentriska styrkan i respektive ben undersöktes i en isokinetisk dynamometer. Den maximala kraften I höger respektive vänster ben under utförandet av CMJ's, RCMJ-B och RCMJ-E insamlades genom golvmonterade kraftplattor. Graden av självupplevd lateralitet jämfördes med graden av styrkeassymetrier med hjälp av spearman's rho. Styrkeassymetrierna i respektive test jämfördes med hjälp av Pearson's korrelation.

**Resultat:** Den självupplevda lateraliteten och graden av stryrkeassymetrier uppvisade en signifikant korrelation inom tre av de uppmätta variablerna: LP-C300 och det självupplevt starkare benet (=0.74), CMJ och det självupplevt föredragna benet för att landa (=0.67), RCMJ-B och det självupplevt föredragna benet för att balansera (=0.65). Sex av testerna som, gjordes för att mäta styrkeassymetrier uppvisade positiva eller negativa signifikanta korrelationer: LP-C10 och LP-E300 (=0.78), LP-C10 och RCMJ-B (=0.63), LP-E50 och LP-E100 (=0.91), LP-E50 och LP-E300 (=0.62), LP-E50 och RCMJ-E (=-0.73), LP-E100 och LP-E300 (=0.62), LP-E100 och RCMJ-E (=-0.70).

**Slutsats:** Sammanfattningsvis så var tre av resultaten gällande självupplevd lateralitet positivt signifikant korrelerade med stryrkeasymetrier; det självupplevt starkare benet och LP-C300testet, det självupplevt föredragna benet att landa på och CMJ -testet, samt det självupplevt föredragna benet för att balansera och RCMJ-B -testet. Det fanns också signifikanta korrelationer mellan styrkeassimetrier mellan olika styrketest, vilket innebär att det finns en korrelation mellan styrkeassymetrier i excentriska benpressar i olika hastigheter, samt mellan koncentriska benpressar i långsam hastighet det första hoppet i RCMJ.

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# 1. Introduction

Can you imagine being an elite alpine skier, throwing yourself into a turn in, in a steep icy slope at a speed of 90 km·h-1? (Hydren et al., 2013)

Are you then confident enough to do it knowing that you will face ground reaction forces off up to four times your body weight? (Klous, Müller & Schwameder., 2014; Supej & Holmberg., 2010).

Would your confidence, or lack of, be dependent upon the direction of the turn? A left turn means that your right leg is your outer leg, and a right turn means that your left leg is your outer leg (Vogt & Hoppeler., 2014).

Stop reading here, and really, really imagine yourself doing these two different turns, one left and one right turn.

You probably felt quite uncomfortable in both turns considering the speed, the icy slope and the ground reaction forces, but if you had to choose, you probably had one turn that felt a little less frightening than the other one, right? That has to do with your lateral preference. Lateral preference can, according to Porac & Coren (1981), be defined as the "priority in the choice and usage of paired limbs of the human body in specific activities". Another, kindred definition is leg dominance. A dominant leg is, according to van Melick et al (2017), "used in order to manipulate an object", who further states that "this automatically leads to the definition of the non-dominant leg: 'the leg which performs the stabilizing or supporting role'" (Melick et al., 2017).

Sports research are unfortunately inconsistent regarding the usage of these two definitions, so try to remember both while reading this paper.

With that said, wouldn't it be interesting to find out whether the preferred or dominant leg is stronger than the non-preferred or non-dominant leg? Or how the self-perceived laterality affects sports performance in different sports?

And it is important to find out whether leg dominance is leading to injuries, right? The answers to these questions are to be found in the following part of this paper.

Some answers are however yet to be found out in this field. One of these questions are if there is a relationship between the degree of self-perceived laterality and the degree of strength asymmetries, and the aim of this study is to examine if such a relationship does exist.

## *1.1 Physical effects of having a preferred or dominant leg*

According to research by Lanshammar & Ribom (2011), there is a significant asymmetry in leg muscle strength favoring the non-dominant leg in flexion (the dominant leg was in of average 8.6% ($p < 0.001$) weaker) and dominant leg, being 5.3% ($p < 0.009$) stronger, in extension. Therewith results showed that the ratio between hamstrings and quadriceps strength, (H: Q), was substantially lower in the dominant leg than the non-dominant leg. To find out these asymmetries, maximum isokinetic contractions were made at an angular velocity of 90°/s. Only women participated in this Uppsala (Sweden) based, cross-sectional, randomly selected and population-based cohort, and the 157 participants were non-athletes, aged between 20 and 39 years (Lanshammar & Ribom., 2011).

Interestingly, Lanshammar & Ribom (2011) used handedness as a predictor of footedness; "If the subjects had (..) right-handed dominance they were regarded as having right leg dominance as well and vice versa" (Lanshammar & Ribom., 2011). This stands in contradiction to research by Bryden & Bulman-Fleming (1998) who insists that it is in fact possible to be left-handed and right-footed and vice versa. More precisely, between 1.5 and 6 % of right-handed adults prefer their left foot and between 20 and 50 % of left -handed adults have a crossed lateral preference, i.e., being right-footed (Bryden & Bulman-Fleming., 1998).

Previous research has also been investigating leg preference in relation to energy expenditure, muscle activation and muscle efficiency (Carpes et al., 2010). The aim of this research was to verify if performance differed between the preferred and non-preferred leg in cyclists and noncyclists, doing one legged pedaling, at the same relative workload.

The results showed that "regardless of cycling experience, unilateral performance of preferred and non-preferred leg did not differ based on whole body oxygen uptake, muscle efficiency and magnitude of muscle activation" (Carpes et al., 2010), indicating that degree of sports experience is not affecting the effects of self-perceived laterality, at least not when participating in bipedal sports.

How leg dominance is affecting balance has been evaluated, in a systematic review and metaanalysis, by Schorderet, Hilfiker & Allet (2021). The reason for the implementation of the research was the missing information regarding how balance performance differs between the dominant and non-dominant leg. Despite this information gap, the balance performance of the injured leg is often, by physiotherapists, compared with the performance of the non-injured leg, for example when determining degree of recovery after injury according to Schorderet, Hilfiker

& Allet (2021). The results of this meta-analysis, where most included studies defined leg dominance as the leg used to kick a ball, showed that significant differences between the dominant and non-dominant leg regarding balance were not to be found. In conclusion, Schorderet, Hilfiker & Allet (2021), stated that their results indicate that balance performance is not influenced by leg dominance.

## *1.2 Self-perceived laterality and the effect on sports performance*

Does having a preferred or dominant leg, or the degree of this laterality affect sports performance? This is of course hard to answer for all sports. Research presented below displays laterality in relation to aspects of performance in three sports, alpine skiing, soccer, and dance. In the research about alpine skiing by Vaverka & Vodičková (2010) the aim was to discover whether lateral preference of the legs influenced the execution of successive carving turns. Six skilled, male skiers executed 30 symmetrical carving turns and the kinetic analysis provided information about the time of the initiation and steering phase of the turn, as well as maximum force, average force, and force impulse.

The research by Vaverka & Vodičková (2010), showed that the turns where the outer leg is the preferred leg one is also the turns in which the speed is regulated. These turns did have a longer duration, had higher level of force produced, higher force impulse, a shorter initiation and a longer steering phase than the turns where the non-preferred leg was the outer leg. In conclusion, authors stated that "lateral preference of lower extremities influences the execution of the turn", even when performed by experts (Vaverka & Vodičková., 2010).

In conformity with the results in the research by Vaverka & Vodičková (2010), Mertz & Docherty (2012) expected dancers self-perceived stronger leg to demonstrate superior strength by absorbing ground force reactions over a longer period of time compared to the non-selfperceived stronger leg. The purpose of the research by Mertz & Docherty (2012) was to examine the relationship between, (1) the postural stability and ground reaction forces in fifth position when landing from dance-specific jumps on one hand, and (2), the dancers preferred leg for landing, their self-identified stronger leg, and their self-identified leg with better balance, on the other hand. Results did however not show any difference between the self-perceived stronger leg and the other leg in time to maximal ground reaction force, (GRF). Mertz & Docherty (2012) are emphasizing that this information can be useful for the clinical dance medicine because:

"When a patient states that his or her currently injured leg "is weaker than the other one," this observation has little to do with the GRFs associated with landing from vertical jumps or with single-leg balance capabilities, two factors often credited with heightening injury risk" Mertz & Docherty (2012)

Furthermore, results showed that the preferred landing leg did not demonstrate different balance capabilities than the non-preferred landing leg, indicating that landing leg preference does not translate to actual balance ability on that leg (Mertz & Docherty.,2012).

Lastly, results showed that dancer's self-identified leg for better balance failed to demonstrate superior balance abilities compared to the other leg, both when landing in a two-legged stance with one foot in front of the other and when landing in a one-legged stance.

In summary, differences between the preferred and the non-preferred leg were not found for any of the tasks analyzed in the research by Mertz & Docherty (2012). However, the lack of difference can be explained by the fact that the participating dancers were highly skilled. Skilled dancers are, according to Mertz & Docherty (2012), successful as dancers, partly because of their symmetry. Another reason for the lack of results in the research by Mertz & Docherty (2012), was the fact that the dancers performed relatively simple ballet jumps, in fact Mertz & Docherty (2012) are discussing the fact that more complex and/or physically demanding jumps could have led to different types of results. Mertz & Docherty (2012) are also questioning the use for the label "dominant leg" in sports like dance, which in fact are lacking a dominant leg, especially when the definition of dominant leg is "their preferred leg for kicking a ball". The label is however useful when examining single leg tasks, and since most tasks in life require the use of two limbs in different capacities, it's expected that the limbs are used and developed in different directions. This is for example often the fact when being left or right footed, which is the case among most soccer players (DeLang., 2021). But how does this laterality affect soccer players? This was examined in the research about bilateral leg differences in soccer kinematics following exhaustive funning fatigue by Katis et al (2017). The purpose of this research was to examine if fatigue effects on the soccer kick would differ between the preferred and non-preferred leg. The participants performed kicks with their preferred and non-preferred leg after running, to exhaustion, on a treadmill and three-dimensional kinematics were collected pre and post fatigue. The conclusion of the results is that the post fatigue soccer kick performance declined more for the non-preferred leg compared to the preferred leg (Katis et al., 2017).

## *1.3 Is laterality a predictor of injury in sports?*

Research from different sports have investigated the relation between limb preference or dominance and injuries. Below, examples from three different sports; dance, alpine skiing, and soccer are presented and compared.

The research about dancers, by McMahon, Pope & Freire (2021), was examining the relationships between lateral leg bias and lower limb injury history among pre-professional ballet dancers.

By lateral leg bias the authors meant the participants self-perceived dominant leg, and preferences for working and supporting leg. The working leg was described to be the moving leg when dancing, the supporting leg was described to be the stance-leg. The self-perceived dominant leg was described to be the leg which participants would use to kick a ball or initiate stepping with.

The result of this research showed that most of the 32 participants had the same leg, the right, as the self-perceived dominant leg (67%). Furthermore, the right leg was also the preferred leg for supporting (86.7%) and working (60%). Results also show that previous injury (the last 12month period) was significantly correlated to participants' dominant leg, where the majority of injuries affecting the preferred supporting and working leg ($RS = 0.595$, $p = 0.012$). Lastly, authors concluded that, in the pre-professional dancers participating in this study, the right leg, which also was the dominant, preferred supporting and preferred working leg, was the leg with the greatest risk of injury (McMahon, Pope & Freire., 2021).

In conformity with the research by McMahon, Pope & Freire (2021), research about alpine skiing by Ruedl et al, (2012) also shows right leg dominance. More specifically, 87.4 % of the youth skiers, 86,9% of the adolescent- and 88,2% of the elite athlete skiers are favoring their right leg.

This comprehensive research, had multiple aims, which was:

> "To assess differences of limb symmetry index (LSI) in strength- and coordination-related tasks between high-level, competitive, noninjured ski racers of different age-related performance levels and to prospectively assess limb differences as a possible risk factor for traumatic and overuse injury in youth ski racers". Ruedl et al, (2012)

In this research, the dominant leg was defined as (1) the preferred leg when stepping on a platform and (2) as the preferred leg when kicking a ball. If participants were differing preferred leg in these two situations, participants were asked to fall forward. The leg that then took the whole-body weight was defined as the subjective dominant leg.

Except for information regarding leg dominance, all participants did physical tests and data from two consecutive seasons (2015/2016 and 2016/2017) from an injury database was collected. One of the strength tests made was the one-leg isometric/isokinetic press strength, (OL-ILS) test. If the differences in strength (left and right leg) exceeded 10% it was considered to be an asymmetry, and the result of the OL-ILS showed that the greater asymmetry, the greater the risk was to sustain traumatic injury among youth ski racers (Wald = 7.08; $p < 0.01$). Results also showed a significant difference in the abnormal lower limb symmetry index, (LSI) between athletes with traumatic injuries and non-injured athletes ($z = 2.645$; $p = 0.008$). LSI are in fact, even in previous injury, considered a strong predictor of injuries in sports (McGrath et al., 2016). Authors are in the discussion, with the new information from the test results concluding that:

> "Younger athletes display slightly greater LSI values only in the strength-related tests. The cut-off value of limb differences of <10% for return to sport decisions seems to be appropriate for elite athletes, but for youth and adolescent athletes it has to be critically discussed" (Ruedl et al.,2012)

So, in both dancing and alpine skiing, the right leg seemed to be the self-perceived dominant one, but what about in soccer?

DeLang et al (2021) describes that the dominant limb of a soccer player accounted for 82-84% of all ball touches on average in the world's most elite international competition, the World Cup. Of all soccer players, in the 17 articles included in the review research by DeLang et al (2021), 84% were right footed and 16% were left footed.

Another thing is similar between the alpine skiing- and the soccer research results, namely the relation between bilateral strength asymmetries and sports related injuries.

The research by Izovska et al (2019), is about pre-seasonal bilateral strength asymmetries of professional soccer players and relationships with non-contact injury of lower limb in the season. The participants in their research were 227 soccer players, playing in the highest league of competition in the Czech Republic. Knee flexors and extensors was measured using a Cubex dynamometer and then bilateral asymmetries between the dominant and non-dominant limb was compared. Injuries during season was then, retrospectively, compared to pre-seasonal bilateral strength imbalances and the results showed that "65.9% of players who suffered non-contact leg injuries in the season had imbalances in knee extensors between preferred and non-preferred lover limb ≥10% difference before the season. (Izovska et al., 2019)

Injuries connected to the dominant and non-dominant leg, in the soccer context, has also been evaluated in a review article by DeLang et al (2021) and in research where data was collected in the Swedish first league by Svensson et al (2018).

In the review article by DeLang (2021), in which 74 articles were included, results showed that soccer players had a 1.6 times greater risk of injury on the dominant limb. Further, both males (RR 1.5 [95% CI 1.33–1.68) and females (RR 1.5 [95% CI 1.14–1.89]) were more likely to sustain injuries to the dominant leg according to DeLang (2021).

Lastly, the research by Svensson et al (2018), with data collected between 2007 and 2013, included data from 54 soccer players. They had 105 injuries and out of these, 53% affected the dominant leg, i.e., the leg with which they kicked the ball. The only significant value was that greater extent of injury was found in the dominant leg when compared with the non-dominant leg with regard to structural injuries of the hamstrings. (Svensson et al., 2018)

### *1.4 Description of the problem area*

To summarize the research presented above, it can be stated that there are no significant differences between the dominant and non-dominant leg regarding oxygen uptake, muscle efficiency, magnitude of muscle activation (Carpes et al., 2010) and balance (Schorderet, Hilfiker & Allet., 2021). However, the non-dominant leg is characterized by having higher H: Q ratio, by being stronger in leg flexion (Lanshammar & Ribom, 2011) and by having a bigger decline in performance post fatigue than the dominant leg (Katis, Kellis & Lees., 2017). At the same time the dominant leg is characterized by being stronger in leg extension and by having a lower H: Q ratio than the non-dominant leg (Lanshammar & Ribom, 2011). Furthermore, 87.4 % of the youth-, 86.9% of the adolescent- and 88.2% of the elite ski athletes are favoring their right leg (Ruedl et al 2012) and this is affecting the left turns, where the right leg is the outer ski, by being, inter alia, the turn in which the speed is regulated (Vaverka & Vodičková 2010). In conformity with alpine skiers, most soccer players, 84% (DeLang et al 2021), and dancers, 67% (McMahon, Pope & Freire., 2021) are favoring their right foot. Leg dominance is also connected to injury, where in dancing it's correlated to previous injury (the last 12-month period) (McMahon, Pope & Freire 2021), while in soccer, players have a 1.6 times greater risk of injury in the dominant leg (DeLang., 2021). Further, pre-season strength asymmetries of ≥10% between the dominant and non-dominant limb is shown to be related to in-season injuries in male soccer players (Izovska et al., 2019). Significant differences have also been displayed in abnormal LSI, between athletes with traumatic injuries and non-injured athletes (Ruedl et al.,2012) and this is in line with previous research which states that LSI are in fact a strong predictor of injuries in sports (McGrath et al., 2016). Interestingly, research has also shown that the greater asymmetry, the greater risk to sustain traumatic injury, though in a youth, ski racing, population (Ruedl et al., 2012).

It is interesting to find out whether, in a well-trained adult population, the degree of selfperceived leg preference for different tasks are related to their degree of strength asymmetry. If these two variables are shown to be related, this information can help to prevent future injuries, by minimizing strength asymmetries. Instead of doing expensive physical tests to find out limb strength asymmetries, easily accessible questionnaires could be done to determine the degree of leg preference and strength asymmetries.

## *1.5 Aim*

The aim of this study was to examine the relationship between the degree of self-perceived leg preference and the degree of strength asymmetries in well-trained adults by answering the following research questions.

### 1.5.1 Research questions

1. What's the relationship between the degree of self-perceived leg preference and:
    - 1.1 Closed chain multi joint peak eccentric and concentric strength asymmetries?
    - 1.2 Lateral differences peak force during countermovement jump?
    - 1.3 Lateral differences in peak force prior to and during fatigue when performing 60 second repeated countermovement jump?
2. What's the relationship between peak force strength asymmetries in multi joint eccentric and concentric leg press, countermovement jump and 60 second repeated countermovement jump?

### 1.5.2 Hypothesis

The null hypothesis, which needs to be rejected for results not to be coincidences, is that a significant relationship between the self-perceived leg preference and peak force strength in the eccentric and concentric leg press, the CMJ and the RCMJ-tests are non-existent. Further the null hypothesis is that no relation is found between peak force strength asymmetries among the strength tests.

# 2. Method

## *2.1 Study design*

This is a quantitative, cross-sectional study examining the relationship between the degree of self-perceived leg preference and the degree of strength asymmetries in well-trained adults. Participants, inquisitive to find out whether they had strength asymmetries visited the lab at two different occasions, early winter 2021.

## *2.2 Participants*

Eleven well trained participants, nine men, (M); age: 27.3 ± 3.0 and two women, (W); age: 27.0 ±4.2; height: 185.1 ± 8.8 cm (M), height: 166.5 ± 2.1 cm (W); weight: 83.2 ± 9.0 kg (M), weight: 62.0 ± 4.2kg (W) (see table 1). volunteered to participate in this study. No potential participants were disqualified due to pre-existing conditions or injuries that would interfere with jumping or ability to perform leg press. The amount of training experience among the participants ranged from 2 to 23 years (average 13,1 ± 6 years), where some were at top national level, and some doing only strength training. All the participants met the inclusion criteria of being between 18 and 35 years old, injury free the last six months, currently participating in a sport at national or just below national level or working out regularly for at least four times a week.

## *2.3 Procedure*

Prior to participation, all participants read and signed an informed consent form. Thereafter general warm up was made using an ergometer (Monark 829, Varberg, Sweden). The warm-up procedure consisted of 10 minutes of cycling at 1.5 watts per kg body weight. The warm-up was the same during both testing days. During the warm-up participants were instructed, and had the opportunity to ask questions, about the upcoming tests. The first day of testing consisted of concentric and eccentric leg presses and the second testing day consisted of CMJ, RCMJ and a questionnaire to measure self-perceived preferred and supportive leg. The participants were informed not to do heavy lower limb training the day prior to the testing days and they were also told to eat a proper breakfast and sleep well before the tests. All tests, on both testing occasions, were executed before lunch.

### 2.3.1 The leg press test

The eccentric and concentric multi joint strength test, where the criterion of maximum strength was peak force (N·kg−1), was made using an isokinetic dynamometer (IsoMed 2000-system, D&R Ferstl GmbH, Hemau, Germany). Peak force was detected for the right and left foot separately in each of the three different concentric and eccentric speeds. In order to perform the leg press test, the isokinetic dynamometer was converted into a motor driven leg press via an additional linear adapter.  This setup is shown in figure 1.

**FIGURE 1.** "Structure of the IsoMed 2000 leg press system. e: selectable gears; f: drive shaft; g: carbon toothed belt; h: bearing sled and footrest; i: force sensors (only left side shown here)". (Dirnberger et al., 2013)

The participants were seated in the dynamometer chair in an upright position, with a 75° angle of the backrest. Their feet were placed at the bottom frame of the footrest, which was located 10 cm above chair height. The footrest had an inclination of 15° plantar flexion. The participants were instructed to keep their feet within a rectangular area of 12x30 cm which was marked by tactile tape, to ensure minimal risk for over extension of the knees. During repetitions, when the participants applied pressure against the left and right footrest, the force was detected through the force plates placed directly at the backside of the footrests. Force data was collected with the IsoMed2000 Leg press Athletic module (D. & R. Ferstl GmbH, Germany) as analogue signals which were continuously converted to digital signals with the A/D converter Micro1401-3 (Cambridge Electronic Design Ltd [CED], UK), and thereafter being filtered with NL126 filter module NL900D NeuroLog System (Digitimer Ltd., UK).
After fastening the participants properly with seat belt straps over the waist, shoulders and chest to ensure a desirable position, range of motion (ROM) throughout the leg press movement was established at 50-90° hip flexion using a handheld mechanical goniometer.

Before the start of the tests and prior to every change of speed, participants performed a familiarization procedure containing as many repetitions as they wanted to excel the movement as well as possible. This was followed by 90 seconds of rest before the test started. The test consisted of two concentric repetitions with the speed of 10mm/s, four concentric repetitions at 50mm/s and four concentric repetitions at 300mm/s. Thereafter the participants had the possibility to stand up and rest for 90 seconds, before being fastened again. The final, eccentric leg press repetitions consisted of four repetitions at each of the following speeds: 50mm/s, 100mm/s, and 300mm/s. During every test repetition the participants initiated the movement by concentrically pushing the footrest, which released the 200N trigger, which started the movement. Test leaders gave verbal encouragement during all the test repetitions. The filtered force data collected from each test was manually analyzed with the Spike2 software (version 7, CED, UK), by visually detecting the beginning and end of each repetition. This was determined to be when the adapter changed direction.

### 2.3.2 Jump tests

After being instructed how to perform countermovement jump, (CMJ) during warm up the second testing day, participants could practice CMJ's as part of their specific warm up. In these instructions' participants were required to perform CMJ's with hands held in place on the hips, which is in line with previous research (Cormack et al., 2008). Participants were also instructed to jump as high as possible, and to use a self-selected depth during the movement. After the specific warm up, three maximal jumps, with 90 seconds of rest between were conducted on the two floor fit force plates. If the participants failed to land properly on the force plates, additionally repetitions were made to collect three approved repetitions.

After finishing the three CMJ's and resting for 90 seconds, during which instructions for RCMJ were made, the RCMJ test was made. The instructions given for RCMJ were similar to the instructions for CMJ; hands on the hips, self-selected depth, and as high jumps as possible without pause between jumps for 60 seconds (Cormack et al., 2008). Only one trial was made, and verbal encouragement was given, as well as information about remaining time every 10 seconds. The jump tests force data was collected via floor fit force plates (600 x 400 mm, Kistler, Switzerland) and Qualisys Track Manager [QTM] software (version 2021.1, Qualisys AB, Sweden). The collected force data was exported to .3cd-format for further analysis in Visual3D software (version 2021.11.3, C-Motion Inc., USA).

The maximum peak force in each leg was the measured value among the three trials of CMJ. Out of these three trials, the highest peak force for each leg was chosen for further analysis. All CMJ jumps were analyzed in the Visual3D software (version 2021.11.3, C-Motion Inc., USA) by manually determining the start of the jump and when the participants were leaving the ground. These parts of the CMJs are demonstrated in figure 2, by Moir (2008).

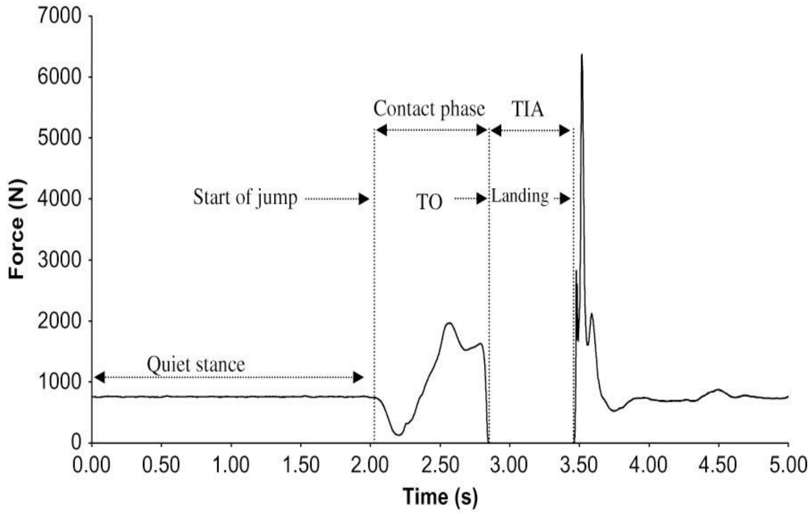


**FIGURE 2.** “The vertical force trace from a subject performing a countermovement vertical jump. Note. TIA = time in air; TO = take-off” (Moir., 2008).

For RCMJ the first and last approved jump was analyzed by manually detecting the beginning and end of the concentric phase, which can be seen in figure 3, by Cormack et al. (2008).

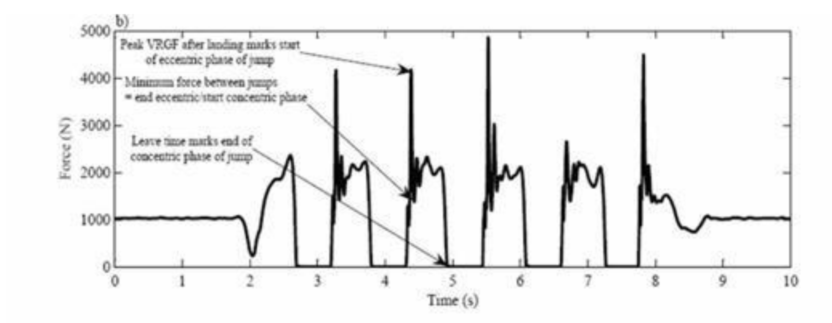


**FIGURE 3.** The vertical force trace from a subject performing repeated countermovement vertical jump.

Between beginning and end of the concentric phase the maximum peak force for each leg was measured, both for the first and the last approved jump. This was done with the Visual3D software (version 2021.11.3, C-Motion Inc., USA).

To be approved, jumps and landings had to be on the force plates, hands had to remain on hips and no rest was allowed between the jumps.

### 2.3.3 Questionnaire

Prior to the leg press test participants answered a questionnaire consisting of general questions, such as gender, height, and weight. This general, first testing day questionnaire, and the second testing day questionnaire, can be seen in full in appendix 6.3.

After the jump tests the second testing day participants were instructed to fill in the laterality questionnaire. This questionnaire consisted of a revised form of Waterloo footedness questionnaire, which had been translated to Swedish and pilot tested on five master's degree sport science students at the Swedish school of health and sport sciences. The questions were either assessing foot preference for the foot manipulating an object or assessing foot preference for providing support during an activity, (Bryden & Bulman-Fleming., 1998) and answers were ranging from LA (left always) to RA (right always) with LU (left usually), RU (right usually) and EQ (equally often) being alternatives in the middle. The questionnaire included questions such as "Which foot would you use to smooth sand at the beach?" and "If you had to step up onto a chair, which foot would you place on the chair first?"

The second part of the laterality questionnaire was a questionnaire, originally created for dancers by Mertz & Docherty (2012). This revised, more general version was, for this study, translated to Swedish and remade so that the questions became statements that could be answered by doing a mark on a 10 cm long VAS-scale line, with left at the left end and right at the right end. This measured the self-perceived laterality in each of the three statements; "When I make a high jump, I prefer to land on this foot", "I feel that this leg is stronger than the other one" and "I feel that I balance better on this leg compared to the other one.". Comparatively, in the original version by Mertz & Docherty (2012), the first statement was "Which leg do you prefer to use when landing from a jump in ballet?".

The Waterloo footedness questionnaire was analyzed by transforming the scale on which the answers were given from LA, LU, EQ, RU and RA (letters) to -2, -1,0,1 and 2 (numbers). Then the numeric answers to question 1,3,5,7 and 9 were added together, as well as the numeric answers to question 2,4,6,8 and 10. The questions with odd numbers assessed foot preference for manipulating an object and the questions with even numbers assessed foot preference for the foot providing support during an activity (Elias et al.,1998). The total sum of the answers with odd numbers determined the degree of left (negative values) or right (positive values) preference for the foot manipulating an object, such as picking up a marble and the total sum of the even questions provided information of degree of laterality regarding preferred foot for providing support during an activity.

The last part, the revised version of the questionnaire by Mertz & Docherty (2012), consisted of three statements, where participants in their answers had to grade themselves on a 10 cm line, on each statement, from left to right. In the analysis the very left end was translated to -50, the middle to zero and the very right end to 50.

## *2.4 Ethics*

Ethical aspects have been taken into consideration throughout the planning, implementation, and presentation of this very paper. Four of these aspects are the information-, consent-, confidentiality- and utilization requirement presented by Vetenskapsrådet (2002).

Participants became interested in participating after reading online and in-school (at the Swedish school of sport and health sciences) advertisement. After showing interest, participants had the possibility to ask question and visit the laboratory in which the test were to be held. Thereafter they received an email with further information, partly regarding their rights if they decided to participate. On the first testing day, participants were again, in writing by the informed consent form, informed about their rights. All participants signed this form, shown in appendix 6.2, which implies that the information and consent requirements are met (Vetenskapsrådet, 2002).

To meet confidentiality requirements, participants names was never used when collecting, analyzing, or presenting data and results. Instead, each participant was given a number during the first testing day, which only the test leader could de-code if needed. The de-coding document, as well as informed consent documents were stored in a, for others than the test leader, unobtainable way.

The data collected for the present paper meet the utilization requirement (Vetenskapsrådet, 2002). Though, if curious or interested, participants could receive and email with their individual test results after the two testing days.

## *2.5 Validity and reliability*

Before the start of the tests, to ensure standardization, a test protocol was developed.  To do this, the test leader was first familiarized with the testing equipment. Thereafter pilot tests were made, both in the physical tests and questionnaires. These pilot tests were made to ensure that measuring devices worked in accordance with the study's purpose, to ensure that the test protocol was satisfactory, and to rehearse test leaders standardized prior to and during test-instructions. During the tests these test leaders knew both how and what to do in every different situation, and could therefore, in a relaxed manner, focus on following the standardized test protocol in a systematic manner and focus on the test person in front of them.

Regarding the specific tests, decisions were made to ensure high validity and reliability.

The IsoMed 2000-leg press system has been previously used in research by Dirnberger et al (2013), who found a moderate to strong reproducibility (intraclass correlation coefficient (ICC: 0,82-0,95) for leg press in a test-retest comparison of peak force during three identical test sessions. Interestingly though, the participants in the research by Dirnberger et al (2013) showed significantly ($p = <0,05$) higher peak force values the second than the first testing day, which indicates a practice-based improvement. To avoid practice-based improvements in this study, participants had the possibility to do as many familiarization repetitions as they wanted on each speed before the test started, which can be compared with the participants in the research by Dirnberger et al (2013), who only got four warm-up repetitions.

The reliability of jump tests has been examined in previous research by Cormack et al (2008) who concluded that a self-detected knee angle provides higher reliability than a minimum of 90° knee angle during each countermovement, and that's the reason for the self-detected knee angle used for CMJ and RCMJ in this paper. Furthermore, Cormack et al (2008) found that peak force in CMJ was highly reliable (CV 2.8%), as well as peak power in RCMJ, demonstrating good overall reliability (CV 5.3%). However, the RCMJ in the research by Cormack et al (2008) was done with five maximal jumps compared to the 60 second repeated countermovement jumps in this study, previous reliability (Cormack et al., 2008) is not applicable in this study. The instructions regarding the jumps and the way peak force for CMJ and RCMJs were analyzed in the previous research (Cormack et al., 2008) were however helpful when developing the test protocol and during the analysis leading to the result in this paper.

In the strive for high validity and reliability for the questionnaires, two previously used questionnaires were chosen, translated and pilot tested for this paper. In the first one, the Waterloo Footedness Questionnaire have, in previous research by Elias et al (1998), showed that participants score for the skilled unipedal activities (such as picking up a marble) correlated significantly ($r = -0.492$, $P = 0.004$) with their score at an index created by Bryden & Sprott

(1981). The participants' scores for the questions identifying the stabilizing and balancing limb however did not correlate significantly.

The second one, the reversed version of Mertz & Dochert's (2012) questionnaire, originally created for dancers was chosen and remade by the same reason, namely because it could be remade to fit other populations than dancers. To cite the authors:

> "Identifying the preferred leg for a given ballet-specific task may be more useful to the researcher than determining the dominant limb. This should afford the researcher a more complete look at the dancer's "laterality profile," ideally providing insight into the complexity of lateral bias in ballet. "(Mertz & Dochert., 2012)

In this study, it's revised to fit the current population, but it can easily be revised again to fit another population. It's important though, which has been considered in this study, to make a pilot questionnaire to ensure good validity when remaking a questionnaire to fit a specific population.

### *2.6 Statistics*

To determine the lower limb strength asymmetry, a calculation as suggested by Impellizzeri et al (2007), (stronger-weaker)/stronger x 100, was made to compare the left and right leg test results in each of the tests. If the left leg was the strongest, this was shown with a negative value, and if the right leg was stronger, it was shown by a positive value.

To answer the research questions, correlations between different variables were calculated, using SPSS V.27.0 (SPSS Inc., Chicago, Illinois, USA) and Microsoft Excel 2021 (Microsoft Corp., Redmond, Washington, USA).

Correlations between strength asymmetries in concentric and eccentric leg press, CMJ and RCMJ was calculated using two tailed Pearson's correlation and non-parametric correlations between questionnaire answers and strength asymmetries was calculated using two tailed Spearman's rho.

Statistical level of significance was set at $\alpha < 0.05$ and the following scale of magnitudes was used to interpret correlation coefficients: < 0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; > 0.9, nearly perfect. (Impellizzeri et al., 2007)

# 3. Results

## *3.1 Descriptive statistics*

### 3.1.1 Anthropometrics

**TABLE 1.** In this table mean values and standard deviation, (mean + SD) are presented for age, height, weight, and sports experience.

| Gender | Age, years. | Height, cm. | Weight, kg. | Sports experience, years. |
|---|---|---|---|---|
| **All (N=11)** | 27.3 ± 2.9 | 181.7 ± 10.4 | 79.4 ± 11.3 | 13.1 ± 5.7 |
| **Female (N=2)** | 27.0 ± 4.2 | 166.5 ± 2.1 | 62.0 ± 4.2 | 16.5 ± 9.1 |
| **Male (N=9)** | 27.3 ± 3.0 | 185.1 ± 8.8 | 83.2 ± 9.0 | 12.3 ± 5.6 |

### 3.1.2 Questionnaire- and strength test statistics

The results from the revised version of the questionnaire by Mertz & Docherty (2012), which can be seen in full in appendix 6.3.3, table 2, showed that the majority, 54,5%, of the participants were perceiving that they would rather land on their left foot when landing after a high jump, while 45,4 % are perceiving that they would rather land on their right foot.

Regarding which leg participants believed to be stronger than the other one ,72,7% of the participants were answering the right leg and 27,3% the left leg. One of the participants did not have a perceived preferred leg for balancing, leaving the rest of the participants with 50% preferring the left leg and 50% preferring the right leg.

Further, results, presented in appendix 6.3.3, table 3, showed that the majority, 90.9%, of the participants perceived their right leg to be the preferred one for skills. Only one person perceived the left leg to be the preferred one for skills. Regarding preferred limb for stabilizing, 63,6% of the participants perceived their right leg to be the preferred one, while 36,6% of participants preferred the left one.

Regarding leg press test results, which can be seen in detail in appendix 6.3.3, table 4, where both the max peak force among all participants in each leg press test and the mean peak force for all participants in each leg press test, showed that only one result displayed higher force values for the right than the left leg, indicating an overall left leg strength dominance. The same pattern was seen among jump test results, which in conformity with leg press results showed higher force values for the left leg than the right in five of the six test results. A detailed table of these results can be seen in appendix 6.3.3, table 5.

Results in table 6 shows that the left leg was the strongest in 66 of the 99 tests, which indicates an overall left leg strength dominance.  In C10 and RCMJ-B 54,5% of the tests displayed a stronger left leg, whereas 63,6% of the tests in C50 and C300 showed a left leg strength dominance. The E100-tests showed a 72,7% left leg dominance and the E50, E300 and RCMJ-E tests showed 81,8% left leg dominance. Only one test, the CMJ, showed a small right leg dominance 54,5%. Table 5 also shows that the percentage of leg strength asymmetries are ranging from below one percent to over 30 %, indicating a wide range of degree of leg strength asymmetries, both within each participant and among participants.

**TABLE 6.** Degree of strength asymmetries in all the participants. Percentage and letter (L=left and R=right) demonstrate how many percent stronger the given leg is in a given test.

| Participant | C10 % | | C50% | | C300 % | | E50 % | | E100 % | | E300 % | | CMJ % | | RCMJ, B % | | RCMJ, E % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8.39 | L | 3.38 | L | 11.64 | L | 6.40 | L | 13.23 | L | 12.55 | L | 4.59 | L | 11.77 | L | 10.55 | L |
| 2 | 2.36 | R | 7.54 | L | 10.38 | L | 10.92 | L | 10.47 | L | 2.88 | L | 0.44 | L | 1.51 | L | 2.22 | L |
| 3 | 6.47 | L | 7.13 | L | 6.00 | L | 7.10 | L | 9.30 | L | 12.80 | L | 1.12 | R | 3.32 | R | 5.51 | L |
| 4 | 7.39 | L | 8.21 | L | 3.64 | R | 12.73 | L | 14.60 | L | 9.36 | L | 14.45 | L | 14.6 | L | 8.33 | L |
| 5 | 9.51 | R | 4.35 | R | 5.48 | R | 4.21 | R | 0.51 | R | 6.40 | R | 9.28 | R | 2.44 | L | 9.60 | L |
| 6 | 3.70 | L | 5.76 | L | 0.52 | R | 33.20 | L | 27.65 | L | 18.45 | L | 4.79 | R | 4.50 | R | 8.20 | R |
| 7 | 5.41 | R | 0.60 | L | 2.51 | R | 1.48 | L | 4.86 | R | 4.19 | R | 2.45 | R | 13.25 | R | 8.86 | L |
| 8 | 1.95 | R | 5.60 | R | 0.21 | L | 8.17 | L | 13.78 | L | 0.10 | L | 1.71 | R | 3.10 | R | 6.20 | R |
| 9 | 6.54 | R | 9.95 | L | 7.80 | L | 5.84 | L | 6.30 | L | 4.95 | L | 10.85 | L | 7.38 | R | 1.40 | L |
| 10 | 6.14 | L | 1.67 | R | 0.33 | L | 10.54 | L | 8.30 | L | 3.57 | L | 4.46 | R | 4.28 | L | 2.40 | L |
| 11 | 6.54 | L | 3.14 | R | 1.10 | L | 3.50 | R | 5.11 | R | 10.51 | L | 12.28 | L | 11.77 | L | 10.55 | L |

### *3.2 Relationship between leg preference and leg press strength asymmetries*

**TABLE 7**. Spearman's rho, correlation coefficient between degree of strength asymmetries in concentric leg press tests (C10, C50 and C300), the eccentric leg press tests (E50, E100 and E300) and the degree of laterality in the skilled (self-perceived preferred leg for skills), stabilizing (self-perceived preferred stabilizing leg), landing (self-perceived preferred leg for landing), stronger (self-perceived stronger leg) and balancing (self-perceived preferred leg for balancing) leg.

| | **C10** | **C50** | **C300** | **E50** | **E100** | **E300** |
|---|---|---|---|---|---|---|
| **Skilled** | - 0.32 | 0.03 | 0.22 | -0.20 | -0.32 | 0.07 |
| **Stabilizing** | 0.11 | 0.27 | 0.01 | 0.25 | 0.21 | -0.29 |
| **Landing** | 0.31 | 0.52 | 0.23 | 0.20 | 0.24 | 0.18 |
| **Stronger** | 0.07 | -0.15 | 0.74** | -0.31 | -0.27 | -0.08 |
| **Balancing** | 0.51 | 0.35 | 0.34 | 0.09 | -0.03 | 0.11 |

* Correlation is significant at the 0.05 level (2-tailed) **
Correlation is significant at the 0.01 level (2-tailed)

### *3.3 Relationship between leg preference and jumps test strength asymmetries*

**TABLE 8**. Spearman's rho, correlation coefficient between degree of strength asymmetries in jump tests (CMJ, RCMJ-B and RCMJ-E) and the degree of laterality in the skilled (selfperceived preferred leg for skills), stabilizing (self-perceived preferred stabilizing leg), landing (self-perceived preferred leg for landing), stronger (self-perceived stronger leg) and balancing (self-perceived preferred leg for balancing) leg.

| | **CMJ** | **RCMJ-B** | **RCMJ-E** |
|---|---|---|---|
| **Skilled** | 0.02 | -0.49 | -0.22 |
| **Stabilizing** | 0.29 | 0.37 | 0.21 |
| **Landing** | 0.67* | 0.24 | 0.28 |
| **Stronger** | 0.33 | 0.19 | 0.29 |
| **Balancing** | 0.59 | 0.65* | 0.53 |

* Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed)

### *3.4 Relationship between strength tests*

Table 9 shows that there are, in fact, significant correlations between the strength asymmetries in many of the strength tests performed in this study. These tests and correlations are C10 and E300 (=0.777), C10 and RCMJ-B (=0.628), E50 and E300 (=0.907), E50 and E300 (=0.617), E50 and RCMJ-E (=-0.729), E100 and E300 (=0.615). Further, E100 strength asymmetries have significant, negative correlation to RCMJ-E (=-0.691). Among jump tests only, none of the tests had a significant correlation.

**TABLE 9.** Pearson's, correlation, showing relation between degree of strength asymmetries in strength tests; both leg press (C10, C50, C300, E50, E100 and E300) and jump tests (CMJ, RCMJ-B and RCMJ-E).

| | C10 | C50 | C300 | E50 | E100 | E300 | CMJ | RCMJ-B | RCMJ-E |
|---|---|---|---|---|---|---|---|---|---|
| **C10** | 1 | 0.21 | 0.33 | 0.33 | 0.37 | 0.78* | 0.37 | 0.63* | 0.11 |
| **C50** | | 1 | 0.51 | 0.45 | 0.42 | 0.51 | 0.42 | -0.05 | -0.08 |
| **C300** | | | 1 | 0.05 | 0.19 | 0.36 | 0.25 | 0.05 | -0.02 |
| **E50** | | | | 1 | 0.91** | 0.62* | -0.13 | -0.11 | -0.73* |
| **E100** | | | | | 1 | 0.62* | -0.10 | 0.07 | -0.70* |
| **E300** | | | | | | 1 | 0.37 | 0.34 | -0.20 |
| **CMJ** | | | | | | | 1 | 0.74 | 0.31 |
| **RCMJ-B** | | | | | | | | 1 | 0.44 |
| **RCMJ-E** | | | | | | | | | 1 |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

## *3.5 Relationship between laterality questionnaires*

Results in table 10, see appendix 6.3.3, shows that significant correlations can be found between (1) the self-perceived preferred leg for stabilizing and the self-perceived preferred leg for landing (=0.719) and (2) the self-perceived preferred leg for stabilizing and the self-perceived preferred leg for balancing (=0.766). In table 12 (appendix 6.3.3), showing correlations between the three measured variables in the revised questionnaire by Mertz & Dochert's (2012), significant correlations were found between the self-perceived leg for balancing and landing (=0.684).

# 4. Discussion

The aim of this research was to explore the relationship between the degree of self-perceived laterality and the degree of lower limb strength asymmetries. If existing, such a relationship would mean that a questionnaire could predict strength asymmetries, which in turn would mean that by detecting self-perceived laterality and thereby detecting strength asymmetries, both athletes and recreational sports participants could in fact avoid lower limb injuries generated by lower limb strength asymmetries (McGrath et al., 2016). If a relationship between the degree of self-perceived laterality and the degree of lower limb strength asymmetries exists, the information could be of good use for sports participants, elite athletes, coaches, P.E teachers and physiotherapists.

The following sections will discuss the significant results in this study regarding the relationship between the degree of self-perceived leg preference and the degree of strength asymmetries seen in the concentric and eccentric leg press-, the CMJ-, RCMJ-B- and RCMJ-E-tests, as well as the relationship between the tests made in this study. The significant results of this study are also being compared and discussed in relation to previous research within the field of leg preference, strength asymmetries and injuries. Lastly, the limitations of this study are being presented, as well as the conclusion.

## *4.1 Relationship between preferred leg and strength asymmetries*

### 4.1.1 Self-perceived preferred leg for skills and stabilizing

When comparing the results from this study with previous research regarding the relationship between leg preference and strength asymmetries, one must first know what to compare.

In previous research the dominant leg was determined to be the leg used when kicking a ball or manipulating an object (DeLang., 2021; Ruedl et al.,2012), while in this study almost the same definition,” foot preference for manipulating an object” (Elias, Bryden & Bulman-Fleming., 1998) was used to determine self-perceived preferred leg for skills. Therefore, the results regarding self-perceived preferred leg for skills in this study are being compared with the results from previous research regarding dominant leg.

In this study the self-perceived preferred leg for skills did not have significant correlation to strength asymmetries in any of the strength tests. Neither did the self-perceived preferred leg for stabilizing, which can be compared with the non-dominant leg from previous research (DeLang., 2021; Ruedl et al.,2012). In summary, from the results in this study it can be stated that the Waterloo Footedness Questionnaire (Elias, Bryden & Bulman-Fleming., 1998) failed to predict degree of strength asymmetries in the strength tests made by the 11 participants in this study. Previous research, determining laterality by using handedness as a predictor of footedness, has in contrast to this study shown significant results then comparing the leg preference and strength results (Lanshammar & Ribom., 2011). More specifically the research by Lanshammar & Ribom (2011) displayed that the non-dominant leg was stronger in flexion, while the dominant leg was stronger in extension.

A reason for the difference in results between the research by Lanshammar & Ribom (2011) and this study can, except for the different ways to determine self-perceived laterality, also be the difference in strength tests and participants. The participants in the research by Lanshammar & Ribom (2011) performed open chain isokinetic contractions, while the participants in this study performed closed chain, multi joint leg presses. Another big difference between this study and the research by Lanshammar & Ribom (2011) was the number of-, and training experience among participants, where Lanshammar & Ribom (2011) had 157 untrained participants and this study had eleven well trained participants.

### 4.1.2 Self-perceived preferred leg for landing, balancing and strength

Significant correlations in this study were however found among the questions in the part of the laterality questionnaire, seen in appendix 6.3.2, regarding self-perceived preferred leg for landing, the self-perceived stronger leg, and the self-perceived preferred leg for balancing, and some of the strength asymmetry variables.

More precisely the self-perceived stronger leg was significantly correlated (=0.74) to strength asymmetries in the concentric leg press at the speed of 300mm/s, (LP-C300).

This can be compared to previous research by Mertz & Docherty (2012), who indeed used a different strength measurement, but they were at the same time using a similar tool to find out the self-identified stronger leg. The results in the research by Mertz & Docherty (2012) showed no difference between the self-perceived stronger leg and the other leg in time to maximal ground reaction force (GRF) of any of the other center of pressure-, (COP), measures. This result was found to be helpful in the clinical medicine for dancers according to Mertz & Docherty (2012) who concluded that the result meant that when a patient states that the currently injured leg “is weaker than the other one”, that has little to do with the GRF associated with landing from a vertical jump, a factor which is credited for heightening the injury risk. (Mertz & Docherty., 2012)

In this study, the significant result regarding the self-perceived stronger leg showed the opposite result compared to the research by Mertz & Docherty (2012); the higher degree of self-perceived laterality (stronger leg), the more strength asymmetries in that limb. A reason for this difference in results could be the different ways to measure strength, with landing from ballet jumps in the research by Mertz & Docherty (2012) and leg presses in this study.

Even though it seems like strength asymmetries in leg presses can be predicted by perceiving oneself to be stronger in that leg, this information is only applicable in one of the concentric leg press speeds performed in this study. None of the other concentric or eccentric leg press strength asymmetry results correlated to participants’ self-perceived stronger leg. This means that, even though one significant correlation is found between “stronger leg” and strength asymmetries in leg presses, it is still hard to draw any conclusions.

It would however be interesting to see whether correlations between self-perceived laterality (strength, landing and balance) and strength asymmetries in various strength tests exist in bigger populations in future research.

Two other significant findings in this study were (1), the fact that the self-perceived preferred landing leg was correlated to strength asymmetries in CMJ and (2), that the self-perceived preferred leg for balancing was correlated to the first RCMJ-jump, (RCMJ-B).

These results can be compared to the results in from the research by Mertz & Docherty (2012) which shows that (1), landing preference neither translates to landing “skills”, nor to balance ability and (2), that the preferred leg for balancing fails to demonstrate superior balance ability compared to the other leg. Furthermore, the self-identified “leg with better balance” is not absorbing GRF when landing better than the other leg (Mertz & Docherty., 2012).

So, if combining the findings from this study with findings from previous research it seems like if perceiving one leg to be preferred for landing, that leg also generates a higher peak force in the concentric part of the jump in a CMJ-jump. Furthermore, that preferred landing leg is neither better, nor worse than the other leg when landing from the jump or when balancing (Mertz & Docherty., 2012).

Lastly, the self-perceived preferred leg for balancing is also the leg with the highest peak force in the concentric phase in the first jump of many in repeated countermovement jump. This “better balancing leg” does however not have better balance compared to the other leg and it does not absorb GRF better when landing from a jump either (Mertz & Docherty., 2012). These current and previous findings can also be compared with the results from a recently published meta-analysis which was evaluating how balance performance differs between the dominant and non-dominant leg. The results of this meta-analysis showed that significant differences regarding balance ability are missing, indicating that balance performance is not influenced by leg dominance. (Schorderet et al., 2021).

### *4.2 Relationship between tests*

Interestingly, there were significant correlations between many of the strength asymmetry test results in different tests in this study. Not surprisingly there were significant correlations between three of the eccentric leg presses. More surprisingly however, is the both positive and negative correlations, between the more anomalistic movements or muscle activities, like: C10 and E300 (=0.78), C10 and RCMJ-B (0.628), E50 and RCMJ-E (=-0.73) and E100 and RCMJ-E (=-0.69).

Among jump tests only, none of the tests had a significant correlation. Furthermore, significant correlations were also found between the variables of the questionnaires. When comparing the variables of the Waterloo Footedness Questionnaire with the revised questionnaire by Mertz & Dochert's (2012), the self-perceived preferred leg for stabilizing correlated both to the self-perceived preferred leg for landing and the self-perceived preferred leg for balancing. When comparing only the variables of the revised version of the questionnaire by Mertz & Dochert's (2012), a significant correlation was found between the selfperceived leg for balancing and landing.

### *4.3 Additional interesting findings*

In line with previous research, participants in this research had the right leg as their selfperceived stronger leg (72,7%), as their self-perceived preferred leg for: skills (90.0%), stabilizing (63,6%), and balancing (50%), in other words - most of the self-perceived laterality variables. Only in one, which leg they preferred to use when landing from a high jump, the answers was favoring the left leg (54.5%). The previous research shows similar results, where out of 32 dancers 67% had a right leg dominance and 86.7% preferred their right foot as the stabilizing one (McMahon, Pope & Freire., 2021) while in alpine skiing 87.4 % of the youth, 86,9% of the adolescents and 88,2% of the elite athletes are favoring their right leg according to Ruedl et al, (2012). In soccer the right leg dominance is 84% (DeLang et al., 2021). When looking into the fact that 72,7% of the participants in this research were perceiving themselves to be stronger in the right than in the left foot, it's interesting to see the massive left leg dominance in the strength tests made. In 66 of the 99 tests displayed in appendix 6.3.3, table 5**,** the left legs were stronger. More exactly, in LP-C10 and RCMJ-B 54,5% of the tests made displayed a stronger left leg, whereas 63,6% of the tests in LP-C50 and LP-C300 showed a left leg strength dominance. The LP-E100-tests showed a 72,7% left leg dominance and the LP-E50, LP-E300 and RCMJ-E tests showed 81,8% left leg dominance.

Seeing this, one thought is inevitable. If the participants were so unlucky in their estimations about which of the legs to be the strongest, were they equally unlucky with their other estimations? Or is it just hard to estimate leg strength?

Another interesting finding, standing in contrast with previous research, is the fact that only one of the participants had a previous injury on the preferred leg for skills (dominant leg). The research in fact describes (1) that previous injury (the last 12-month period) is significantly correlated to participants' dominant leg (McMahon, Pope & Freire., 2021) and that (2), soccer players had a 1.6 times greater risk of injury on the dominant limb (DeLang et al., 2021).

Lastly, interesting findings concerning participants' degree of strength asymmetries were also found. To see a detailed table about this, see table 6. The table shows that there's a big difference both between and within participants when looking at the strength asymmetry percentage, favoring the strongest of the legs in each of the tests. Based on the asymmetry percentage results from this research, showing that ten out of eleven participants had a more than a 10% strength asymmetry, in at least one of their tests, the participants could in fact be in risk of future injury according to research by (McGrath et al., (2016); Ruedl et al, (2012); Izovska et al., (2019). This, however, is if they are doing sports regularly (McGrath et al., 2016), if they are elite alpine skiers (Ruedl et al, 2012) or if they are elite soccer players (Izovska et al., 2019).

### *4.4 Limitations*

The obvious limitation in this research is the relatively low number of participants. The low number of participants could be the reason why many of the results in this research are differing from results in the previous studies presented. Another reason for the inconsistent results in the current research in relation to previous research could also be the lack of consensus in the research field regarding how to determine the preferred or dominant foot.

Furthermore, literature does “not recommend that large numbers of comparisons are performed” (Altman., 2020), which is the case in this study, and that is a limitation too. The reason why this is not recommended is because it is suggesting poorly specified research objectives according to Altman (2020). Instead of comparing large numbers of variables Altman (2020) suggests the strategy of deciding in advance which groups that is particularly interesting for comparison, and the fewer groups, the better. Another strategy is to “perform modified t tests to compare the pairs of groups of interest, using the Bonferroni method to adjust the p values” (Altman, 2020). However, due to the large numbers of comparisons in this study, the Bonferroni method was considered to be too conservative.

Lastly, this research has a difference in comparison to the previous research presented, namely the fact that the group of participants in this research are a heterogeneous group, with both male and female participants, with participants competing or training different sports and with participants having various training experience. Even though previous research stated that degree of sports experience is not affecting the self-perceived laterality, that is a fact only for bipedal sports (Carpes et al., 2010), and there were not only participants from bipedal sports in this research. Thus, the combination of the low number of participants and the differences among the participants regarding both uni- and bipedal sports and sports experience in this research, was limiting factors. However, with the limited amount of time to accomplish this study, there were unfortunately no time for testing more participants.

### *4.5 Conclusions*

In conclusion, three of the self-perceived laterality results were significantly correlated to strength asymmetries; the self-perceived stronger leg and the LP-C300-test, the self-perceived preferred leg for landing and the CMJ -test, and the self-perceived preferred leg for balancing and the RCMJ-B-test. None of the self-perceived degree of laterality for skill or stabilizing were significantly correlated to any of the strength asymmetry tests. Significant correlations were found between strength asymmetries in eccentric leg presses at different speeds as well as slow concentric movement and also the first RCMJ-jump.

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# 6. Appendices

## *6.1 Literature search*

**Purpose and research questions**

The aim of this study is therefore to examine the relationship between the degree of selfperceived of leg preference and the degree of strength asymmetries in well-trained adults by answering the following research questions.

1. What's the relationship between the degree of self-perceived leg preference and:
    1.1 Closed chain multi joint peak eccentric and concentric strength asymmetries?
    1.2 Lateral differences peak force during countermovement jump?
    1.3 Lateral differences in peak force prior to and during fatigue when performing 60 second repeated countermovement jump?
2. What's the relationship between peak force strength asymmetries in multi joint eccentric and concentric leg press, countermovement jump and 60 second repeated countermovement jump?

**Keywords**

Preferred leg, dominant leg, eccentric strength, concentric strength, less press, CMJ, RCMJ, Waterloo Footedness Questionnaire, asymmetry

**Where did you search?**

PubMed, Discovery, Sports Discus, Google Scholar

**Which combinations did you use?**

Preferred OR dominant

Leg OR limb

Asymmetries OR LSI

Injuries

Isomed2000

CMJ OR countermovement jump

RCMJ or repeated countermovement jump

### *6.2 Informed consent*

## Samtyckesblankett

Syftet med denna undersökning är att ta reda på om det finns något samband mellan styrkeskillnader i höger respektive vänster ben och vilket ben som en föredrar att använda.

För att ta reda på detta så kommer mätningar av styrka att utföras. I Isomed 2000 utförs koncentrisk och excentrisk benpress och på kraftplattor görs countermovement jump och 60 sekunders repeated countermovement jump.

Dessutom kommer en enkät att utföras som syftar till att bestämma vilket ben som är det föredragna eller dominanta i olika lägen.

### *Samtycke till att delta i studien:*

Jag har skriftligen informerats om studien och samtycker till att delta.

Jag är medveten om att mitt deltagande är helt frivilligt och att jag kan avbryta mitt deltagande i studien utan att ange något skäl.

### Om du använder pappersenkät:

Min underskrift nedan betyder att jag väljer att delta i studien och godkänner att Gymnastik- och idrottshögskolan, GIH behandlar mina personuppgifter i enlighet med gällande dataskyddslagstiftning och lämnad information.

…………………………………
Underskrift

………………………………… …………………………………………………
Namnförtydligande Ort och datum

**Student: Emelie Mimmi Persson**

**Mail:XXX**

**Telefon: XXX**

**Handledare: Manne Godhe & Toni Arndt**

**Mail: XXX & XXX**

## *6.3 Questionnaires*

### 6.3.1 Part one

**Tillfälle 1.**

Försöksperson 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐

# Generella frågor

Könsidentitet Man ☐ Kvinna ☐

Ålder ____________________________________________

Längd ____________________________________________

Vikt ____________________________________________

Nuvarande idrott Gym, minst 4 ggr/vecka ☐ Annan sport:______________________

År av erfarenhet inom sin idrott ______________________________

Skadehistorik på
underkroppen*________________________________________

________________________________________________

* Skriv i vilken kroppsdel, vilken typ av skada och vilket år skadan inträffade. Ta endast med allvarliga skador, som har tvingat dig att avstå från ditt ordinarie idrottande under minst en månad.

### 6.3.2 Part two

## Tillfälle 2.

Försöksperson 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

## Lateralitet, del 1.

Instruktioner: Besvara var och en av de följande frågorna så noggrant som du kan. Om du *alltid* använder använder en fot när du gör den beskrivna aktiviteten, gör en då cirkel runt Va (vänster alltid) eller Ha (höger alltid). Om du *oftast* använder en fot när du gör den beskrivna aktiviteten, gör en cirkel runt Vo (vänster oftast) eller Ho (höger oftast). Om du använder båda fötterna *lika ofta*, gör en cirkel runt L (lika).

Gör inte en cirkel på samma svar på samtliga frågor. Tänk istället efter och försök se dig själv göra aktiviteten som beskrivs, och ringa sedan in ditt svar. Om det behövs, stanna gärna upp och gör rörelsen i luften.

1. Vilken fot skulle du använda för att sparka en boll mot ett mål som är rakt framför dig?

Va Vo L Ho Ha

2. Om du fick lov att stå på *en* fot, vilken skulle du välja?

Va Vo L Ho Ha

3. Vilken fot hade du använt för att släta ut sanden på stranden?

Va Vo L Ho Ha

4. Om du skulle kliva upp på en stol, vilken fot hade du placerat på stolen först?

Va Vo L Ho Ha

5. Vilken fot skulle du använda om du skulle stampa på ett snabbt springande småkryp?

Va Vo L Ho Ha

6. Om du skulle balansera med *ena* foten på en upp och nedvänd bänk, vilken fot skulle du balansera på?

   Va Vo L Ho Ha

7. Om du skulle plocka upp en spelkula med dina tår, vilken fot hade du använt?

   Va Vo L Ho Ha

8. Om du skulle hoppa på *ett* ben, vilket ben hade du använt?

   Va Vo L Ho Ha

9. Vilken fot hade du använt för att hjälpa till att trycka ner en spade i marken?

   Va Vo L Ho Ha

10. Folk brukar automatiskt placera mer vikt på ena foten när de står vanligt (avslappnat), vilket innebär att andra benet blir lätt böjt. Vilken fot har du mest tyngd på när du står vanligt (avslappnat)?

    Va Vo L Ho Ha

11. Finns det en anledning (t.ex en skada) till att du har ändrat din/dina fotpreferens/er på någon av frågorna ovan?

    Ja ☐ Nej ☐

12. Har du någonsin tränat eller tränats till att använda en viss fot för en viss aktivitet?

    Ja ☐ Nej ☐

13. Om du har svarat JA på antingen fråga 11 eller fråga 12, förklara gärna.

    ______________________________________________________________

## Lateralitet, del 2.

Denna enkät innehåller tre påståenden där vart och ett följs av ett streck.

Strecket representerar grad av hur mycket du föredrar ett visst ben eller en viss fot, där ändarna på strecket innebär maximala värden av det ena eller det andra benet eller foten. Om du sätter ett streck i mitten så betyder det "ingen skillnad mellan fötterna eller benen".

1. När jag hoppar från en stol så föredrar jag att landa på denna fot.

   Vänster__________________________________________________________Höger

2. Jag känner att det här benet är starkare än det andra.

   Vänster__________________________________________________________Höger

3. Jag känner att jag har bättre balans på den här foten än på den andra.

   Vänster__________________________________________________________Höger

### 6.3.3 Result tables

**TABLE 2.** Individual responses to the laterality questionnaire, presented in both self-perceived limb in left or right and degree of self-perceived leg in percentage for landing, strength, and balance.

| Participant | Landing | Degree of laterality (%) | Stronger | Degree of laterality (%) | Balance | Degree of laterality (%) |
|---|---|---|---|---|---|---|
| 1 | L | 80 | L | 100 | L | 100 |
| 2 | L | 70 | L | 90 | L | 90 |
| 3 | R | 80 | R | 90 | R | 90 |
| 4 | L | 90 | R | 100 | L | 100 |
| 5 | R | 80 | R | 80 | R | 90 |
| 6 | R | 40 | R | 100 | R | 100 |
| 7 | L | 50 | R | 50 | L/R | 0 |
| 8 | R | 70 | R | 30 | R | 40 |
| 9 | L | 30 | R | 30 | R | 40 |
| 10 | R | 80 | R | 40 | L | 30 |
| 11 | L | 10 | L | 50 | L | 10 |

**TABLE 3.** Individual responses to Waterloo Footedness Questionnaire, presented in both self-perceived limb in left or right and degree of self-perceived leg in percentage for preferred leg for skills and stabilizing.

| Participant | Preferred leg for skills. | Degree of laterality (%) | Preferred leg for stabilizing. | Degree of laterality (%) |
|---|---|---|---|---|
| 1 | R | 70 | L | 20 |
| 2 | R | 70 | L | 50 |
| 3 | R | 100 | R | 100 |
| 4 | R | 100 | L | 100 |
| 5 | R | 80 | R | 30 |
| 6 | R | 60 | R | 50 |
| 7 | R | 60 | L | 10 |
| 8 | R | 70 | R | 30 |
| 9 | L | 30 | R | 30 |
| 10 | R | 70 | R | 10 |
| 11 | R | 60 | R | 50 |

**TABLE 4.** Table of multi joint concentric and eccentric leg press results. Peak force (N) is showing the highest peak force among all participants. Mean peak force's showing mean force for all the participants.

| Test | Max peak force (N) | Mean peak force, N (N=11) |
|---|---|---|
| LP, C10, L | 3718.6 | 2187.1 ± 701.3 |
| LP, C10, R | 3978.9 | 2177.7 ± 767.3 |
| LP, C50, L | 3735,0 | 2376.3 ± 564.2 |
| LP, C50, R | 3363.3 | 2311.7 ± 512.7 |
| LP, C300, L | 2488,0 | 1892.3 ± 401.1 |
| LP, C300, R | 2479.9 | 1846.2 ± 394.3 |
| LP, E50, L | 4119.9 | 2668.3 ± 661.6 |
| LP, E50, R | 3879.4 | 2446.8 ± 654.4 |
| LP, E100, L | 3463.4 | 2286.0 ± 566.9 |
| LP, E100, R | 3254.7 | 2096,0 ± 573.0 |
| LP, E300, L | 2612.6 | 1832.8 ± 391.5 |
| LP, E300, R | 2483.2 | 1771.0 ± 431.7 |

**TABLE 5.** Table of CMJ and RCMJ results. Peak force (N) is showing the highest peak force among all participants. Mean peak force's showing mean force for all the participants.

| Test | Max peak force (N) | Mean peak force, N (N=11) |
|---|---|---|
| CMJ, L | 1085.1 | 915.0 ± 110.3 |
| CMJ, R | 1079.4 | 897.5 ± 106.9 |
| RCMJ, Beginning, L | 1065.4 | 892.1 ± 113.8 |
| RCMJ, Beginning, R | 1141.9 | 882.5 ± 137.3 |
| RCMJ, End, L | 762.2 | 661.0 ± 71.0 |
| RCMJ, End, R | 793.5 | 647.4 ± 87.2 |

**TABLE 10.** Spearman's rho, correlation coefficient between the degree of laterality in the skilled and supporting leg and the degree of laterality in self-perceived preferred landing-, stronger- and balancing leg.

| | Degree of laterality for self-perceived preferred leg for skills | Degree of laterality for self-perceived preferred supporting leg |
|---|---|---|
| Degree of laterality for self-perceived preferred landing leg | 0.143 | 0.719* |
| Degree of laterality for self-perceived stronger leg | 0.326 | 0.238 |
| Degree of laterality for self-perceived preferred leg for balancing | -0.185 | 0.766** |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

**TABLE 11.** Spearman's rho, correlation coefficient between the degree of laterality in self-perceived preferred landing-, stronger- and balancing leg.

| | Degree of laterality for self-perceived preferred landing leg | Degree of laterality for self-perceived stronger leg | Degree of laterality for self-perceived preferred leg for balancing |
|---|---|---|---|
| Degree of laterality for self-perceived preferred landing leg | 1,0 | 0.281 | 0.684* |
| Degree of laterality for self-perceived stronger leg | 0.281 | 1,0 | 0.384 |
| Degree of laterality for self-perceived preferred leg for balancing | 0.684* | 0.384 | 1,0 |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)