

THE ASYMMETRY OF LOWER LIMB LOAD IN BALANCE BEAM ROUTINES

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Abstract

The asymmetry of use of lower limbs may influence balance beam results and injury risk. This research was performed to study how many elements which asymmetrically load lower extremities are included in balance beam routines of professional female gymnasts. We video-recorded all exercises of qualification round on balance beam at an international competition B World Cup in Ljubljana 2014. We analysed take-offs and landings to define the actions done by left leg, both legs simultaneously, or right leg. A delay of at least 0.01 second in recruitment of one of the lower limbs defined the action as being from a single leg. In the routines of 19 included gymnasts we found significant asymmetry of load: right leg initiated 42.87% of actions (on average 12.47±3.32 per routine), while left leg and both legs initiated 29.08 and 28.05 % of actions (on average 8.58±2.97 and 8.21±3.07 per routine, respectively). The load on right leg was significantly larger compared to left leg and both legs ($p=0.002$ and 0.003). Only 4 gymnasts (20.8%) loaded left leg more than right leg. Additional review of code of points revealed that it mostly contains elements (in 60% of cases) where a single leg at take-off or at landing is loaded. We conclude that asymmetric lower limb loading is present at balance beam routines in elite gymnasts. We hypothesize that the unilateral distribution of load may be associated with the unilateral predominance of injuries and this should be analysed in further research.

Keywords: *female, artistic gymnastic, injuries, lateralization.*

INTRODUCTION

It was already in 1926 when body symmetry was recognised as a component of beauty and ideal body was supposed to always be symmetrical regarding the ratio of its parts as well as its physical abilities (Tyrš, 1926). In the Sokol gymnastic organization (one of the main middle Europe's gymnastic societies in the first half of 20th century) special emphasis was laid

on equal involvement of musculoskeletal apparatus through distributed employment of exercises for various body parts (Fikar, 1947). Gymnastic exercises require coordination of muscle activities in space and time and this may be influenced by morphological or functional asymmetry (Sovak, 1962). Regarding the fact that motor abilities are a direct limiting factor of

performance, the level of lateral asymmetry of extremities may determine the gymnast's performance as well.

Strešková (2006) claimed that somatic and functional asymmetries are constantly influenced by the character of sport activity in a dynamic process independently of the dominance of lower and upper limbs. As stated by Marchetti (2009) and Bernaciková, Kapounkova, & Novotny (2011), preferential use of one of the lower limbs leads to adaptations at morphological, structural and functional levels. This may result in a functional specialization of the limbs such that one is more skilled in strength performance, such as bouncing, whereas the contralateral one is more skilled in performances requiring accuracy and in the art of swipe (Drnková & Syllabová, 1983; Sadeghi, Prince, Sadeghi, & Labelle, 2000). Niu, Wang, He, Fan, & Zhao (2011) examined biomechanical differences between the dominant and non-dominant limb during double-leg landing. They concluded that the non-dominant ankle has a more effective protective mechanism regarding excessive joint motion and that the dominant ankle joint is at a greater injury risk during drop landing.

By repeating asymmetrical physical activities the difference in somatic structure becomes evident: in athletes, the non-dominant leg showed greater cortical bone mineral density (BMD) than the dominant leg which is used for mobility or manipulation whereas the non-dominant leg lends support during the actions of the dominant leg (Sone, Imai, Joo, Onodera, Tomomitsu, & Fukunaga, 2006). Achilles tendon (AT) properties were also examined with regard to symmetry between legs in male healthy adults who were physically active (Bohm, Mersmann, Marzilger, Schroll, & Arampatzis, 2015). The AT of the dominant leg featured a significant higher Young's modulus and length but a tendency toward lower maximum strain compared with the non-dominant leg.

In artistic gymnastics, specifically in balance beam exercises, the differences between activities of the lower extremities

are minimal; therefore the significant influence of asymmetry of lower limbs can be expected. When creating balance beam routine, which is the area of this study, athlete can choose from six groups of elements: 1. mounts, 2. gymnastic leaps, jumps and hops, 3. gymnastic turns, 4. holds and acrobatic non-flight, 5. acrobatic flight, 6. dismounts. The maximum of 8 highest difficulties including the dismount are counted for difficulty value (DV) score (maximum 5 acrobatic elements, minimum 3 dance elements) (FIG, 2013). Regarding the fact that landings and dismounts are the most common causes of injuries in artistic gymnastics (Marshall, Covassin, Dick, Nassar, & Agel, 2007; Lund & Myklebust, 2011), we are mainly interested in jumping elements. Here, the asymmetric reactions of the lower limbs when landing on a single leg were found, particularly in the size of the reaction forces (Chavet, Lafortune, & Gray, 1997). Čuk and Marinšek (2013) highlighted the asymmetric activity of the lower limbs when the jump element execution was not technically perfect. In such cases landing on both legs was associated with uneven load distribution. It is worth to note, that even elements which are supposed to be performed with both legs simultaneously, can have a significant asymmetrical load on lower limbs. This often happens in elements with turns (Čuk and Marinšek, 2013) and on balance beam we can find a lot of elements with turns in each element group.

There is a lack of data on association of asymmetries in artistic gymnastics and injury risk. There is some scarce data showing that increased lateral trunk sway (denoting asymmetric posture) is associated with knee ACL ligament injury (Hewett, Torg, & Boden, 2009) and asymmetry in functional movement screen score is a predictor of injury risk (Mokha, Sprague, & Gatens, 2016). However, none of these studies were performed in artistic gymnastics. Currently a theoretical hypothesis about asymmetry influence on injury risk states that asymmetries can influence muscle-skeletal relations such as

force-length relationship, alter the distribution of forces between the two legs, place the inert structures of joints under greater load, and put disproportionate demands on the musculature of one extremity. Asymmetries during bilateral tasks are surrogates of motor coordination and, therefore less coordinated athletes (who also exhibit greater asymmetries) are at a higher risk of injuries. Asymmetries in bilateral tasks may mean that excessive load is placed for example on one leg while the other leg is protected (and possibly de-trained) from successfully decelerating the body during landing. This may lead to increased risk of injury for both legs.

In the present study we were interested in the asymmetry of use of lower limbs due to its potential influence on balance beam results and injury risk. This research was aimed to find out how many elements which asymmetrically load lower extremities are included in balance beam routines of professional female gymnasts.

METHODS

At an international competition B World Cup in Ljubljana 2014 we video-recorded all exercises of qualification round on balance beam. Video-recording was done with Go Pro camera®, which was set to record 100 frames per second. Camera was placed in a proper position to capture mount, all actions on the balance beam and dismount. The position of the camera was perpendicular to the long axis of the beam as close to the middle point of the beam as possible. Taped material was retrieved with Kinovea® software to determine time codes at take-off and landings in 10 milliseconds time-marks.

On the balance beam we included into analysis all elements which are defined by the Code of Points (COP), simple steps and choreography were not taken into account. We analysed take-offs and landings (whether they were done with left leg, both legs simultaneously, or right leg). When a delay of at least 0.01 second of one of the lower limbs was noticed, we counted the

action as being from a single leg. When there was recruitment of both legs in action in a shorter time interval we considered the action as being initiated by both legs. The time interval of delay between the legs was defined as a difference in time between the departure of first and last foot from the ground (or the time interval in the first ground contact in landing). The leg which left support last, was considered as the take-off leg and the leg which was first in support at landing was considered as the landing leg.

The reliability and validity in recognising left/right body side from the video-recorded routines in similar previous researches was high (Kovač, 2012). Two gymnastics experts (B.P.M. and H.P.) evaluated the taped routines, designated and counted the leg actions.

We calculated a sum of all take-offs and landings with left, right and both legs and a pairwise t-test between the number of left/right/both leg actions. As the number of take offs and landings were different by gymnasts we calculated also percentage of actions on left/right/both legs and again calculated a pairwise t-test between each left/right/both legs. Statistical analyses were done by using Microsoft Excel®.

This research was performed in accordance with the Declaration of Helsinki. The identity of all participants was blinded during evaluation process. Informed approval to study participation was given from all participants.

RESULTS

We included 19 exercises in the analysis. The scores of included 19 competitors are given in the Table 1. Competitors originated from 12 different countries and their average age was 19.1 ± 3.3 years.

Main results (Table 2) show that gymnasts have a predominance of asymmetrical load. Gymnasts on average performed 12.47 actions with right leg, 8.58 with left leg and 8.21 actions with both legs. Right leg initiated 42.87% of actions, while

left leg and both legs initiated 29.08 and 28.05 % of actions. A large difference was found between the number of right and left leg initiated actions (the average of 5.05). Among all 19 gymnasts only one gymnast (5,2%, number 13) had a balanced load on left and right leg and almost an equal use of right (9)/left (9) or both legs (8) (Figure 1).

On other side the most unbalanced gymnast (number 18) had the scores of right (16)/left (4)/both legs (11), which means 60% larger load on the right leg compared to the left (Figure 2). Only 4 gymnasts (20.8%) loaded left leg more than right leg.

Table 1

Difficulty (D), execution (E) and final score of competitors at balance beam routine (N=19).

Score	Mean	SD	Min	Max
Difficulty	4.71	0.5	3.5	5.5
Execution	6.79	0.72	5.4	7.9
Final	11.46	1	9.7	12.9

Table 2

Descriptive statistics.

Gymnast	Right leg	Left leg	Both legs	% Right leg	% Left leg	% Both legs	Abs.	%
							Difference R-L leg	Difference R-L leg
1	17	11	5	51.52	33.33	15.15	6	21.43
2	11	8	12	35.48	25.81	38.71	3	15.79
3	13	7	3	56.52	30.43	13.04	6	30.00
4	15	11	9	42.86	31.43	25.71	4	15.38
5	14	11	7	43.75	34.38	21.88	3	12.00
6	15	9	10	44.12	26.47	29.41	6	25.00
7	19	8	5	59.38	25.00	15.63	11	40.74
8	12	4	13	41.38	13.79	44.83	8	50.00
9	12	4	5	57.14	19.05	23.81	8	50.00
10	16	10	2	57.14	35.71	7.14	6	23.08
11	10	8	7	40.00	32.00	28.00	2	11.11
12	9	12	8	31.03	41.38	27.59	3	14.29
13	9	9	8	34.62	34.62	30.77	0	0.00
14	11	12	10	33.33	36.36	30.30	1	4.35
15	7	9	10	26.92	34.62	38.46	2	12.50
16	12	11	10	36.36	33.33	30.30	1	4.35
17	12	3	10	48.00	12.00	40.00	9	60.00
18	16	4	11	51.61	12.90	35.48	12	60.00
19	7	12	11	23.33	40.00	36.67	5	26.32
XA	12.47	8.58	8.21	42.87	29.08	28.05	5.05	25.07
SD	3.32	2.97	3.07	10.77	8.92	10.11	3.42	18.68
SE	0.10	0.09	0.09	0.17	0.16	0.17	0.10	0.23

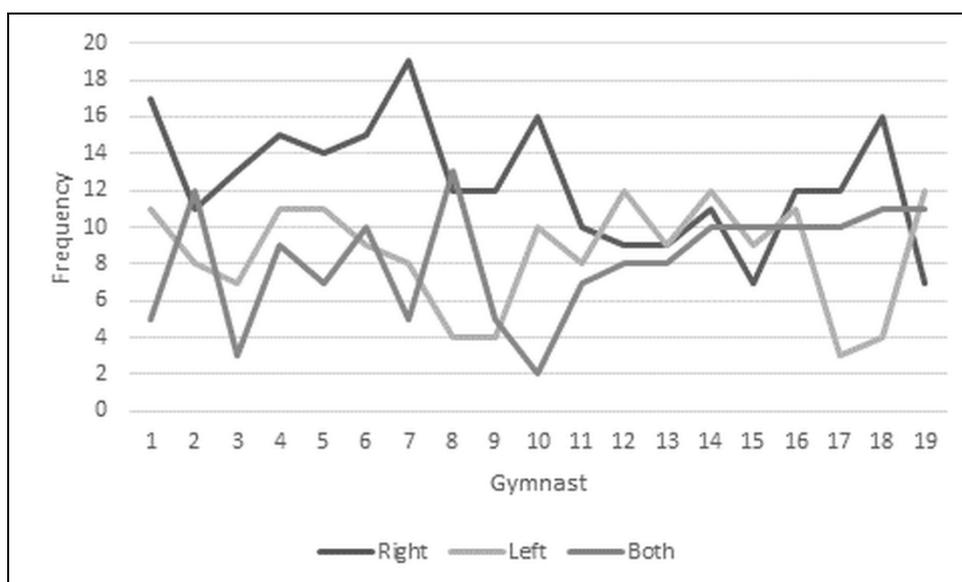


Figure 1. Load on legs by each gymnast (gymnasts are numbered by sequential numbers).

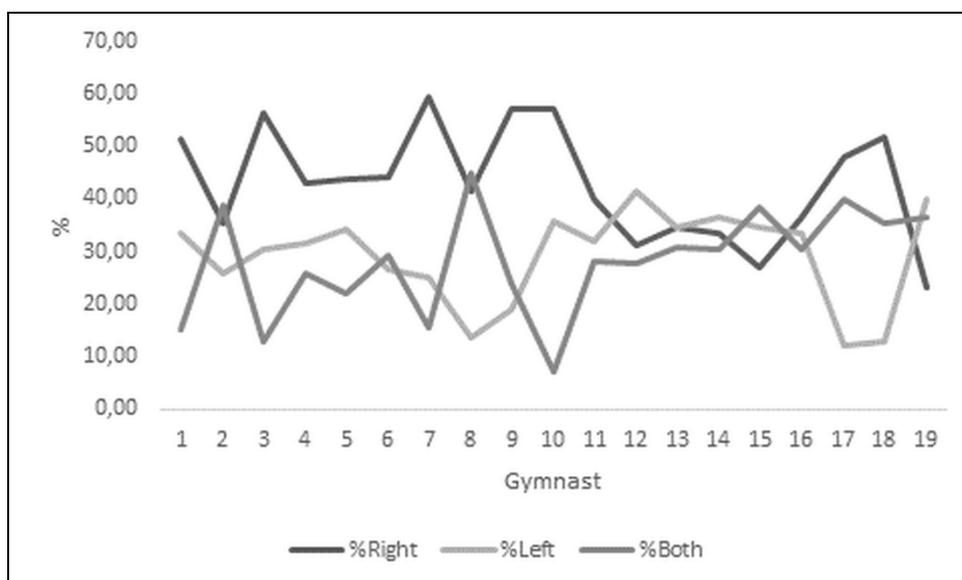


Figure 2. Load on legs in percentage according to all take offs and landings by each gymnast (gymnasts are numbered by sequential numbers).

Table 3

Probability (*p*) of pairwise *t*-test for significance of differences in the number and percentage of usage between pairs of variables.

Variable (absolute number of actions)	Left leg	Both legs
Right leg	0.002	0.002
Left leg	N/A	0.725
Variable (relative number of actions)	% Left leg	% Both legs
% Right leg	0.002	0.003
% Left leg	N/A	0.776

N/A – not applicable

Pairwise t-test (Table 3) showed a significant difference between the load on the right leg and left leg, right leg and both legs both for absolute values and relative values.

DISCUSSION

In the present study we analysed the asymmetry of usage of lower limbs in the take-off and landing phases of balance-beam gymnastic elements. We found a high and statistically significant predominance of unilateral (right leg) usage. From our results a critical question arises whether asymmetrical load of such a magnitude is acceptable not only for adults, but also children and youngsters. This asymmetrical load may have significant anthropometric, structural and safety impact.

The influence of long-term training on anthropometric parameters of rhythmic sports and artistic gymnasts was investigated by Douda, Laparidis, & Tokmakidis (2002) and they found significant differences in circumferences between the right and left legs, but surprisingly only in rhythmic gymnasts, not in artistic gymnasts. Another study assessed the position of the anterior and posterior iliac spinae (Barakatt, Smidt, Dawson, Wei, & Heiss, 1996). Gymnasts as a group were found to have asymmetrically positioned innominate bones as opposed to non-gymnasts representing the control group. By repeating asymmetrical physical activities bilateral differences between extremities and bones are expected to enlarge with time.

In regard to injuries, we know that elite female gymnasts may train on average 5.4 days a week and 5 hours a day (Caine, Cochrane, Caine, & Zemper, 1989), which exposes them to a high risk of serious injury. According to Purnell, Shirley, Nicholson, & Adams (2010) risk factors for injury are being older than 13 years and training for more than 8 h per week at the age of 11 years. In most of the surveys of injury locations, types and causative factors, two thirds of injuries were located in the lower extremities: 62 % percent of the

injuries in the Swedish gymnastics team (Harringe, Renström, & Werner, 2007) and 69% in the study of Marshall, Covassin, Dick, Nassar, L, & Agel (2007). The most common acutely injured body parts were foot (21.0 %), ankle (19.3 %) and knee (14.0 %) (O'Kane et al, 2011). The most common injury was ankle sprain and the most frequent mechanisms were joint compression and joint rotation (Harringe et al., 2007). Concerning injury causes Lund and Myklebust found that 84 % of the injuries occurred in the landing phase of the gymnastic skills and most frequently the ankle was injured (Lund & Myklebust, 2011). The majority of competition injuries (approximately 70 %) resulted also from either landings or dismounts (Marshall et al, 2007). Other above-mentioned authors reported the same causes without percentages. Most injuries occurred on floor exercise (32.1 %), beam (20.7 %), and bars (17.0) (O'Kane, Levy, Pietila, Caine, & Schiff, 2011). These studies do not, however, evaluate which side of body was affected, whether it was an injury that occurred during performing symmetrical or asymmetrical elements and whether the dominant or non-dominant limb was injured. Kimmerle points out a similar problem in dancers, when he states that injury histories, injury reports, and surgical procedures could be a rich source of laterality data if they included the subjects' leg preferences for performing different dance skills and injured leg occurrences (Kimmerle, 2010). He stresses that it is important to include data on take-off and landing legs in jumps, range of motion and flexibility of the gesturing leg, and strength of the supporting leg when a balance task is difficult or the gesturing leg has to be held in the air for a long time.

Available literature mentions several cases of artistic gymnastics injuries where there was a bilateral injury of extremities, however such injuries are mostly reported as isolated cases (Syed & O'Flanagan, 1999; Fujioka et al, 2014; Oda, Fujiwara, Ichimaru, Morihara, Ikeda, & Kubo, 2015). Authors agree on the fact that these bilateral

injuries are rather exceptional, and predominantly we meet with unilateral injuries. Niu et al, (2011) examined biomechanical differences between the dominant and non-dominant limb during double-leg landing. They concluded that the non-dominant ankle has a more effective protective mechanism regarding excessive joint motion and that the dominant ankle joint is in at a greater injury of risk during drop landing. As we have already mentioned above, this fact can not be verified statistically because injury records do not provide sufficient information. As a result of the unilateral injuries further lateral differences can arise (Nadler, Malanga, DePrince, Stitik, & Feinberg, 2000): a significant difference in side-to-side symmetry of maximum hip extension strength was observed in female subjects who reported lower extremity injury or low back pain as compared to those who did not. Forkm, Koczur, Battle, & Newton (1996) compared ability to detect passive plantar flexion of the ankle in gymnasts with unilateral, multiple ankle sprains. For the injured ankle decreased level of the ability was found. Chilvers, Donahue, Nassar, & Manoli (2007) stated that if gymnast sustained serious injury of the lower limb requiring surgery, in most cases it led to career-ending (Chilvers et al, 2007).

On the basis of these reports we may infer that our data showing predominant unilateral load in the phases of routines strongly associated with injuries confirms a possible link between asymmetry of load and injuries and this hypothesis should be further explored in future studies.

Further important issue regarding the impact of asymmetry in load is the general structure of balance beam routines as defined by the COP (FIG, 2013). Elements are divided into following groups (added number of elements with difficulty, take offs and landing are counted for each figure within difficulty box):

- Mounts – 45 elements – take off with one leg 7, landing with one leg 6;

- Gymnastics leaps, jumps and hops – 35 elements, take off with one leg 17, landing with one leg 22;

- Gymnastics turns – 22 elements, take off (start of turn) with one leg 22, landing (end of turn) with one leg 22;

- Holds and acrobatic non –flight – 18 elements, take off with one leg 18, landing with one leg 12;

- Acrobatic flight - 34 elements, take off with one leg 15, landing with one leg 14;

- Dismounts - 29 elements, take off with one leg 16, landing with one leg 0;

It is evident that a vast number of elements are proposed as one leg take off or one leg landing. As can be seen in contemporary rules of artistic gymnastic, at any level of competition in gymnastics the symmetry of exercises is not emphasized neither in children, nor in adults (FIG, 2013). Furthermore, in COP there is no rule or statement on the symmetrical load. So it is evident that current COP and rules do not favour or acknowledge the symmetry of load.

The drawbacks of our study are a relative low number of included subjects and the absence of dominance definition of lower extremities. The dominant leg may be defined as the leg which a person uses for object manipulation and non-dominant leg maintains standing position (Gabbard & Iteya, 1996). However, a question arises what is the correct definition of dominant and non-dominant leg for gymnasts. Although the general consent is that the mobilising limb is considered the dominant leg, and the posture stabilizing leg is the non-dominant for practicing gymnasts perhaps predominant load-bearing extremity may be defined as the dominant one.

CONCLUSIONS

From our robust investigation on the symmetry of load we can conclude that asymmetric lower limb loading is present in balance beam routines in elite gymnasts. Asymmetrical load distribution is facilitated by the COP on balance beam, which mostly contains elements (in 60% of cases) where a

single leg at take-off or at landing is loaded. From the previous research and experience we can hypothesise that the unilateral distribution of load may be associated with the unilateral predominance of injuries with possible significant consequences. Further research should explore the impact and associations of the unilateral predominance of lower extremity load which was established in the present study and this would support coaches and gymnasts to construct their exercises with a higher symmetry of load.

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