THE INFLUENCE OF DIFFERENT TWISTS IN THE FORWARD AND BACKWARD SOMERSAULT ON INCREASED LANDING ASYMMETRIES

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Abstract:

The aim of this research was to determine if additional twists in the forward and backward somersaults increase landing asymmetries. Twelve gymnasts from the Slovenian national artistic gymnastics team took part in the research. Each gymnast performed various stretched forward and backward somersaults with or without a twist. We used several dynamic and kinematic variables to assess landing asymmetry. Reaction forces and pressure values under each foot were collected with the Parotec insole pressure measurement system. The data was normalized by the gymnast's body mass. *Ariel Performance Analysis System* was used to calculate the kinematic variables. Our results showed that most of the forward and backward somersaults with twists on the floor landed asymmetrically (17–50%). Somersaults with 1/2 twist landed 50−58% asymmetrically, somersaults with 1/1 twist 67–75% and somersaults with 3/2 twist 58−83%. The asymmetries on landing rose with the task complexity. The asymmetries were displayed in the time of landing, vertical hip velocity at touchdown, maximum force and pressure distribution. The landing time differences between the legs were up to -13.09±12.98 ms and up to 4.08±7.61 ms for the forward and backward somersaults, respectively. The hip velocity at touchdown differed between the hips up to 0.71 m/s for forward and 0.54 m/s for the backward somersaults. Maximal force difference between the feet normalized by body mass ranged from 0.98 to 1.03 times body weight. The forward landings showed a bigger pressure on the heels at the moment of the biggest ground reaction force in comparison to the backward landings.

Key words: *acrobatics, mistakes, somersaults, twists, leading leg*

Introduction

The landing performance is one of the most important factors that influence the gymnast's final score (Leskosek, Cuk, Karacsony, Pajek, & Bucar, 2010; Zivcic, Breslauer, & Stibilj-Batinic, 2008). Landing asymmetry directly affects a gymnast's balance and therefore the probability that such a landing will be completed in a standstill position. According to the Code of Points (COP), for men's artistic gymnastics competitions, every acrobatic skill has to be finished in a standstill position with feet together (FIG, 2009). Even more, COP article 20 states: the gymnast must include in his exercise only elements that he can perform with complete safety and with a high degree of aesthetic and technical mastery; the responsibility for his safety rests entirely with him. Landing is the most risky part of gymnastics and most injuries are related to the landing (Panzer, 1987; Lindner & Caine, 1990; Meeusen & Borms, 1992; McNitt-Gray, Munkasy, Welch, & Heino, 1994; Nigg, & Herzog, 1998; Kirialanis, et al., 2002; Verhagen, Mechelen, Baxter-Jones, & Maffulli, 2000).

Researchers have found many reasons that affect the landings. The magnitude of impact forces during landings tends to increase with the increase of falling height and also with the skill complexity (Panzer, 1987; McNitt-Gray, et al., 1994; Karacsony & Cuk, 2005; Marinsek, 2010). One of the variables that can change skill complexity on the floor in artistic gymnastics is the number of twists in the somersault. Frolich (1980) stated that any body movement that causes the gymnast's somersaulting axis to move away from the direction of the total angular momentum vector will produce twisting around his/her longitudinal axis. Yaedon (1993) used the angle of tilt between the longitudinal axis and the plane perpendicular to the angular momentum vector as a measure of the twisting potential. The bigger angle of tilt means a higher twisting potential. To maximize the twisting rate the gymnast has to maximize the angle of the tilt. Therefore, more twists do not imply just a more complex skill that needs higher height, but also a bigger chance to land asymmetrically because of the nature of how the twist is initiated.

The greatest dynamic loads on the lower extremities occur for the asymmetrical landings rather than for unsuccessful landings as typically assumed (Panzer, 1987). The asymmetrical, yet reasonably successful landings appear to represent the greatest injury potential for the Achilles tendon, knee joint and spine (Panzer, 1987). If asymmetrical landings appear to represent the greatest injury potential, it would be interesting to find out to what extent different twists increase landing asymmetries.

The only study considering the differences of injury rate between the genders at an intercollegiate sports level was made by Lanese, Strauss, Leizman and Rotondi (1990). The authors found out that female ymnasts were injured more than male gymnasts (273 versus 217 per 1,000 persons, respectively) and sustained more injuries in terms of exposure time than male gymnasts (0.82 versus 0.21 injuries per 100 persons-hours of exposure, respectively). Women had also a higher rate of disability training days in comparison to men (7.44 versus 1.15 days per 100 persons-hours of exposure, respectively). The authors noted that the difference in higher injury rate is rather a consequence of the different types of events and apparatus than of gender.

A compilation of twenty gymnastics injury rate studies has shown a large range of rates being 5.3 to 200 injuries per 100 gymnasts and 0.44 to 22.7 injuries per 1,000 hours of participation (Dowdell, 2011). Within artistic gymnastics, the floor apparatus is associated with the highest injury risk (Lindner & Caine, 1990; Meeusen & Borms, 1992; Kirialanis, et al., 2002). Most of the injuries on the floor (40% of acute injuries) occur during landing (Pettrone & Ricciardelli, 1987; Hudash & Albright, 1993; Gervais, 1997; Kirialanis, Malliou, Beneka & Giannakopoulos, 2003).

Gymnastics skills are very diverse; they can be technically very difficult and demand a great deal of physical fitness but are executed in a stable and predictable environment. A stable and predictable environment allows the anticipation of hazardous outcomes of skill performance and the ability to control these outcomes (Dowdell, 2011).

The question that arises is what happens on landing when the number of the twists rises. The aim of this research was to determine if additional twists in the forward and backward somersaults increase landing asymmetries.

Methods

Subjects

Twelve male gymnasts from the Slovenian national artistic gymnastics team took part in the research. Informed consent was obtained from each gymnast (from parents/guardians for minors) according to the Declaration of Helsinki. The Ethics Committee of the Faculty for Sport at the University of Ljubljana approved the conduct of the investigation. On the day of the measurements the participants' average age was 18.75±2.63 years, their average height was 168.85±6.41 cm and the average weight 67.48±10.16 kg.

Experimental procedure

Every gymnast had to demonstrate the proficiency in performing the acrobatic skills of interest. Each gymnast performed the following somersaults once:

- stretched forward and backward somersault
- stretched forward and backward somersault with 1/2 twist
- stretched forward and backward somersault with 1/1 twist
- stretched forward and backward somersault with 3/2 twist

All the somersaults were performed on the competition floor Spieth after a warm-up. The difficulty of the somersault was increased in half-twist intervals. Because the gymnasts did not twist in the same direction, the leading and non-leading limb were defined according to the direction of the twist. The limb corresponding to the direction of the gymnast's twist was assigned as the leading limb. In that sense the gymnast who twisted to the left had his left leg as his leading leg and his right leg as his non-leading leg.

Instruments

The participants had to wear gymnastics shoes in order to keep the insole pressure device (Parotec, Paromed GmbH) in place. Participants were used to wearing gymnastics shoes for performing acrobatic skills on the floor. None of them argued that wearing an insole pressure device affected their landing performance (Figure 1).

Figure 1. Parotec system

The Parotec system was found to be an effective tool for assessing pressure under each foot in dynamic situations. Parotec insoles are equipped with 24 discrete hydro cell pressure sensors for each foot. Both insoles are triggered at the same time. Hydro cell technology enables one to measure compressive force and shear force but does not discriminate between them. Sensors have shown less than 2% measurement error in the range of 0-400 kPa and provided highly consistent data (Zequera, Stephan, & Paul, 2006) which was deemed acceptable for our study.

All somersaults were recorded with three video cameras with the frequency of 50 frames per second. The recording ran according to the standard method, required by the Ariel Performance Analysis System (APAS). The landing area was defined with a square the size of 3x2x1 metre. The sample of independent variables is represented with a group of kinematic variables, which have been calculated from the 7-segment model of the gymnast. We used manual digitization. The objective was to determine the movement of the lower limbs. Thus the following segments were used: right/left foot, right/left shank, right/left thigh and the segment that connects left and right hip. With the help of the 7-segment model we were able to calculate the following kinematic variables: vertical right/left hip velocity, angle in the right/left ankle in the sagittal plane, angle in the right/left knee in the sagittal plane, left/right hip displacement and contact time for right/left leg. Mean linear error estimates obtained with the APAS for a length of 50 cm are less than 3 mm and angular error estimates for angles between 10° and 170° are less than 0.3° (Klein & DeHavenb, 1995). As angles approach 180° the size of the error is bigger but still less than 2°. Parotec and APAS were synchronized by the first change of the ground reaction force and the moment of the first contact with the floor, respectively. The kinematics was extrapolated to 300 frames per second.

Statistical analysis

We used the contact time difference between the legs [ms], the vertical velocity for leading and non-leading leg [m/s], normalized maximal reaction force difference between the legs [times body weight] and pressure distribution under each foot [N/cm^2] to assess the landing asymmetry.

The contact time difference between the leading and non-leading leg was determined from the insole pressure measurement system with the precision of 3ms. The contact time difference was calculated using the following equation:

$$dt\ [\mathrm{ms}] = t_L\ [\mathrm{ms}] - t_{NL}\ [\mathrm{ms}] \quad (1)$$

In the equation (1) *dt* is represented as the contact time difference, t_L as the contact time of the leading leg and t_{NL} as the contact time of the non-leading leg. The contact time for the single leg is defined as the time frame from the point of ground contact to the point when the reaction force reaches the body mass after the maximal reaction force. With regard to the equation (1), the positive result shows that the gymnast touched the ground with his non-leading leg first and vice versa. The zero contact time difference shows the landing on both feet at the same time.

Reaction forces and pressure under each foot were sampled at 300 Hz using the insole pressure measurement system. The data was processed in the Excel worksheet and normalized by the gymnast's body mass. To assess the pressure distribution, three areas under each foot were determined as shown in Figure 2.

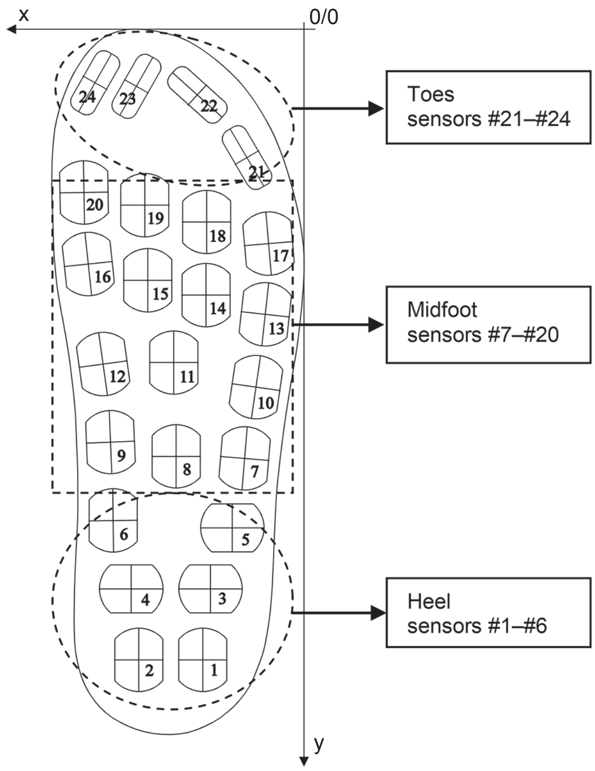

Figure 2. Areas on the insole pressure measurment system (Parotec, Paromed GmbH).

The differences between somersault variations were tested with a one-way analysis of variance (ANOVA) and Bonferroni *post-hoc* test. The differences in variables between the leading and non-leading leg were tested with the paired *t*-test.

Results

Most of the landings (42–50%) after the forward and backward somersaults without a twist and with a half twist were performed on both feet at the same time (Table 1). Only 17–42% of the forward and backward somersaults with more than a half twist were executed on both feet at the same time. The percentage of the symmetrical landings of the forward somersaults with more a than half twist (25% and 17%, respectively) is lower in comparison to the backward somersaults (33% and 42%, respectively). Most of the somersaults with 1/1 or 3/2 twist (irrespective of the somersault direction) which ended in the forward landing were performed on the non-leading foot first (58% and 50%, respectively). The same group of somersaults which ended in the backward landing were performed on the leading foot first (42% and 75%, respectively).

The average contact time difference between the legs rose with the difficulty of the somersault (Table 1). The gymnasts landed on average first on their leading leg only when they performed forward somersault with 3/2 twist. The most consistent landings were the forward and backward somersaults with no twist (1.25±3.57 ms and 0.33±2.18 ms, respectively). The least consistent landings were the forward and backward somersaults with 3/2 twist (-13.09±12.98 ms and 4.08±7.61 ms, respectively) and 1/2 twist (2.25±6.05 ms and 1.58±8.47 ms, respectively).

The one-way ANOVA test showed a statistically significant difference between the four forward somersault skills ($F=11.63$; $p<.01$). The Bonferroni *post-hoc* test revealed that a difference existed between the forward somersault with 3/2 twist and all the other somersault variations ($p<.01$).

Paired *t*-test revealed statistically significant differences between the vertical velocity of leading and non-leading hip for the forward somersault with 1/1 twist, forward somersault with 3/2 twist and backward somersault with 3/2 twist (Table 2). The leading hip dropped on average faster than the non-leading hip for the forward somersault with 1/1 twist and backward somersault with 3/2 twist. For the forward somersault with 3/2 twist the non-leading hip dropped on average faster than the leading hip. The differences diminished from the point when the gymnasts touched the ground. The differences between the vertical velocity of the hips for the forward somersaults were however higher and lasted longer than for the backward somersaults.

Table 1. Contact time difference [ms] between leading and non-leading leg for forward and backward somersault variations

Somersault type	Mean±SD	MAX	ν (%)	ν_{NL} (%)	ν_{LL} (%)
Forward somersault	1.25±3.57	10	50%	33%	17%
Backward somersault	0.33±2.81	-6	50%	33%	17%
Forward somersault 1/2	2.25±6.05	14	50%	42%	8%
Backward somersault 1/2	1.58±8.47	23	42%	33%	25%
Forward somersault 1/1	3.67±5.26	14	25%	58%	17%
Backward somersault 1/1	1.00±5.98	17	33%	25%	42%
Forward somersault 3/2[a]	-13.09±12.98	-37	17%	8%	75%
Backward somersault 3/2	4.08±7.61	23	42%	50%	8%

Legend: ν – frequency of the symmetrical landings, ν_{NL} – frequency of the asymmetrical landings on the non-leading leg, ν_{LL} – frequency of the asymmetrical landings on the leading leg. [a] – statistically significant mean difference between groups p<.01

Table 2. Vertical velocity [m/s] for leading and non-leading hip

Landing time	Forward somersault 1/1		Forward somersault 3/2		Backward somersault 3/2	
	non-leading	leading	non-leading	leading	non-leading	leading
- 0.10 s	-3.22±0.46	[b] -3.71±0.68	-2.87±0.71	-2.58±0.85	-3.56±0.55	[a]-4.14±0.66
- 0.08 s	-3.35±0.53	[b] -3.89±0.71	-3.20±0.61	-2.67±0.56	-3.69±0.64	[a]-4.28±0.67
- 0.06 s	-3.62±0.66	[b] -4.20±0.72	-3.68±0.53	[b] -3.08±0.55	-3.96±0.71	[a]-4.54±0.68
- 0.04 s	-4.00±0.77	[b] -4.58±0.71	-4.28±0.49	[b] -3.64±0.75	-4.30±0.75	[a]-4.84±0.68
- 0.02 s	-4.28±0.82	[b] -4.77±0.68	-4.70±0.50	[b] -3.99±0.78	-4.52±0.72	[a]-4.97±0.63
GC	-4.16±0.82	[a]-4.51±0.64	-4.57±0.58	[b] -3.83±0.77	-4.35±0.66	-4.68±0.58
0.02 s	-3.53±0.75	[a]-3.73±0.59	-3.72±0.67	[a]-3.06±0.88	-3.70±0.66	-3.91±0.61
0.04 s	-2.53±0.62	-2.62±0.53	-2.39±0.72	-1.93±0.92	-2.69±0.72	-2.82±0.69
0.06 s	-1.49±0.55	-1.54±0.50	-1.06±0.72	-0.81±0.84	-1.66±0.81	-1.74±0.75
0.08 s	-0.67±0.58	-0.74±0.50	-0.10±0.77	-0.02±0.79	-0.89±0.89	-0.96±0.81
0.10 s	-0.18±0.62	-0.29±0.51	0.38±0.87	0.36±0.86	-0.49±0.97	-0.58±0.88

Legend: GC – ground contact; means±standard deviation, [a] statistically significant mean difference between legs p<.05, [b] – statistically significant mean difference between legs p<.01

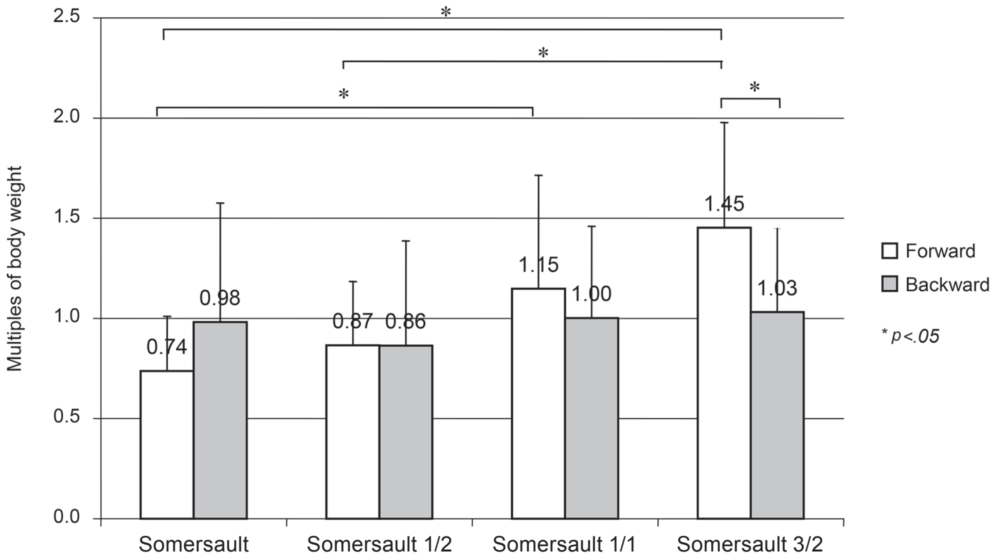

Figure 3. Average values and standard deviations of maximal force difference between the leading and non-leading foot normalized by body mass for the forward and backward somersaults variations.

Maximal force difference between the legs for the forward somersaults rose with additional twists (Figure 3). The greatest maximal force difference was calculated for the forward somersault with 3/2 twist (1.45±0.52 times body weight) and was statistically bigger (p<.05) compared to the forward somersault (0.74±0.27 times body weight) and the forward somersault with 1/2 twist (0.87±0.32 times body weight). There was also a statistically significant difference (p<.05) between the forward somersault with 1/1 twist (1.15±0.57 times body weight) and the forward somersault (0.74±0.27 times body weight).

There were no statistically significant differences between backward somersaults. The maximal force difference ranged from 0.98 to 1.03 times body weight. There was, however, a statistically significant difference in the maximal force between the forward and backward somersault. The maximal force difference for the forward somersault with 3/2 twist (1.45±0.52 times body weight) was bigger (p<.05) than for the backward somersault with 3/2 twist (1.03±0.42 times body weight).

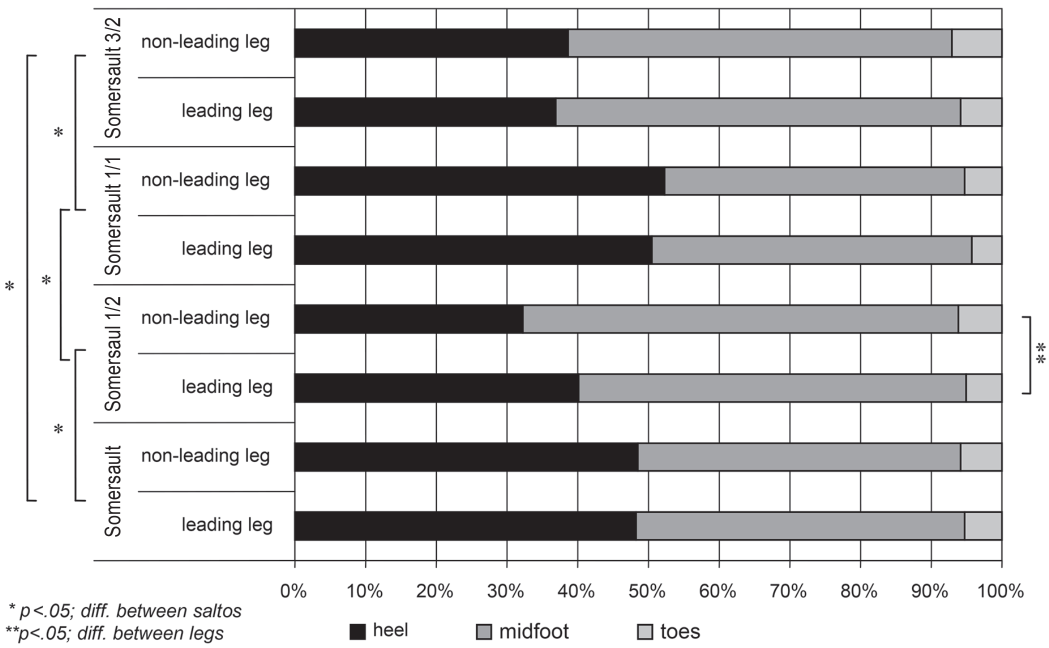

Figure 4. Pressure distribution on the leading and non-leading foot at the moment of the biggest ground reaction force for the forward somersault variations.

We found statistically significant asymmetries in pressure in the moment of the biggest ground reaction force for the forward somersault 1/2 (Figure 4). The heel of the leading leg was more loaded than the heel of the non-leading leg (32% and 40%, respectively). The midfoot area of the non-leading leg was more loaded than the midfoot area of the leading leg. The pressure on the toes did not differ between the legs.

landings could have been the lack of angular momentum around the longitudinal axis. The hips dropped with a different vertical velocity in the last 0.10 seconds before ground contact (Table 2). Different vertical velocities of the hips can be seen when the body is still twisting. The last 0.10 seconds before ground contact are intended for the preparation with an aligned body for the landing and not for twisting. The tilt from the direction of the

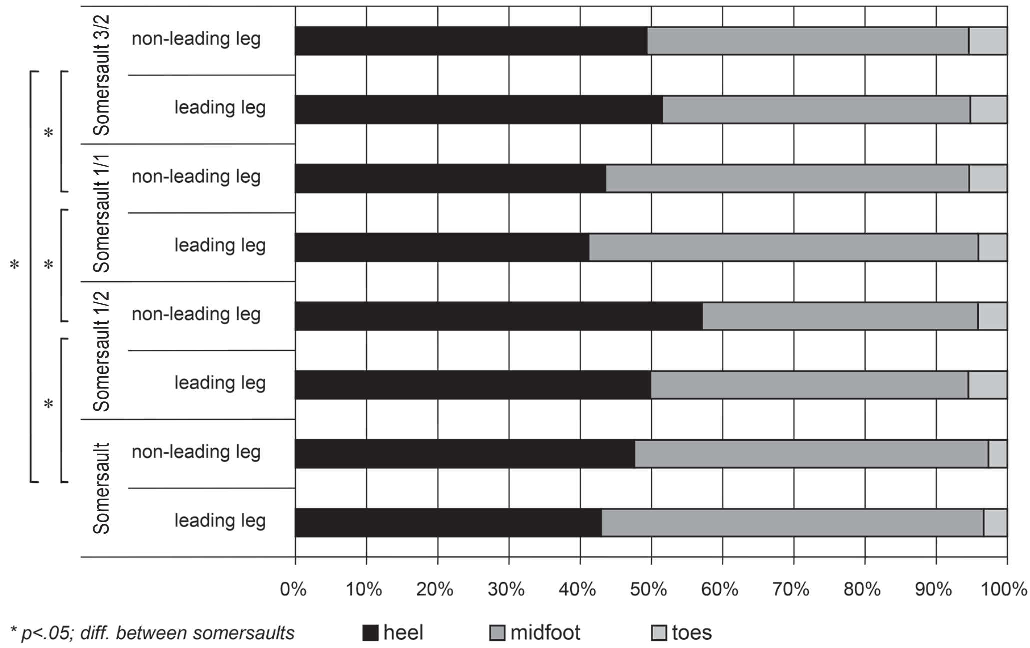

Figure 5. Pressure distribution on the leading and non-leading foot at the moment of the biggest ground reaction force for the backward somersault variations.

Results showed statistically significant differences between different types of the forward and backward somersaults (Figures 4 and 5) (p<.05). The forward somersault, forward somersault 1/1, backward somersault 1/2 and backward somersault 3/2 were characterized by a bigger load on the heels in comparison to the rest of the somersaults. The pressure on the toes was consistent between different types of either forward or backward somersaults in the moment of the biggest ground reaction force.

Discussion and conclusions

Our results showed that most of the forward and backward somersaults on the floor were performed with an asymmetrical landing. Any body movement that causes the gymnast's somersaulting axis to tilt away from the direction of the total angular momentum vector will produce twisting around his longitudinal axis (Frolich, 1980). Differences between leading and non-leading vertical hip velocities for somersaults with more than a half twist revealed that the reason for asymmetrical total angular momentum vector that produces twisting has to diminish prior to landing to stop the twisting and to make a symmetrical landing possible (Yeadon, 1993). Twisting late in the aerial phase of the somersault or even twisting during the landing phase can lead to landing asymmetries. The problem enhances with the number of twists. The frequencies of asymmetrical landings and contact time difference between the legs in our research suggest that the asymmetries at landings rise with the number of twists.

The maximal height enables gymnasts to finish the defined number of twists (Frolich, 1980; Yeadon, 1993; Karacsony & Cuk, 2005). With a lower maximal height it is more difficult to diminish twisting and prepare for a symmetrical landing. The forward somersaults are in general executed with a lower maximal height in comparison to the backward somersaults (Karacsony & Cuk, 2005). Consequently, it is more difficult to land symmetrically when performing forward somersaults which can be also seen from the results shown in our research. The average maximal force difference between the leading and non-leading leg for the forward somersaults got bigger with adding twists. The statistically significant differences occurred when gymnasts performed one or more twists. However, the average maximal force difference between the leading and non-leading leg did not change statistically significantly with adding twists for the backward somersaults. Between the forward and backward somersaults statistically significant differences were obtained in the average maximal force between the legs when the gymnasts performed a somersault with 3/2 twist.

The results in our research showed that regardless of the different vertical hip velocities, contact time difference between the legs and the average maximal force difference between the legs, the pressure distribution on the feet did not differ within the somersault variations. The only statistically significant difference between the legs was found in the forward somersault with 1/2 twist. However, there were several statistically significant differences in the pressure distribution found between the somersault variations. The results indicate that pressure distribution was generally affected by the direction of the landing and not by the asymmetries that emerged on landing.

The landing direction is one of the factors that influence the position of the feet on landing and is closely linked with the somersaults twisting (Cortes, et al., 2006; Kovacs, et al., 1999). Half twist intervals determine the landing direction (Karacsony & Cuk, 2005). The present research showed that the forward landings were performed with a bigger load on the heels in comparison to the backward landings. Landing with a bigger load on the heels changes the kinematic and dynamic parameters during landing, which can cause serious damage to the gymnast's body. This kind of landing results in a higher vertical ground reaction force, smaller contraction at the knees and knee valgus compared to the landings where gymnasts first place their toes on the ground (Cortes, et al., 2006; Kovacs, et al., 1999). We believe the reason for landing on the heels was the distance between the heels and the ground at ground contact. In order to gain the best starting-point for landing in a standstill position (kinetic energy is zero), gymnasts have to under-rotate the somersaults irrespective of the landing direction. The under-rotation results in a smaller distance between the heels and the ground for the forward landings in comparison to the backward landings. The smaller distance between the heels and the ground gives the gymnasts a smaller chance of stopping the heels from hitting against the ground. The smaller distance between the heels and the ground was probably the reason that the heels were more loaded when the gymnasts completed their somersaults with a forward landing.

As the frequency and magnitude of impacts increase, there is a greater need to implement and follow a detailed training programme (Lauren, Geraldine, Dean, & Raul, 2010). Kirialanis, et al. (2003) warned that coaches and sports medicine personnel should develop and implement prevention programmes especially for the landing phase of acrobatic elements on the floor. Most of the injuries on the floor occur during landing (Pettrone & Ricciardelli, 1987; Hudash & Albright, 1993; Gervais, 1997; Kirialanis, et al., 2003). Coaches have to be very careful when they instruct gymnasts to add twists to their somersaults. According to Zivcic, Breslauer, and Stibilj-Batinic (2008), the most important factors when choosing new gymnastics skills are a gymnast's physical fitness, a gymnast's motor proficiency, a gymnast's psychological preparedness and a coach's expert competences.

Gymnasts have to be physically prepared to such an extent that they are capable of producing enough power at take-off before starting to add twists to the somersaults. For the first trials it is recommendable to use a foam pit. The twisting somersaults with not enough height and angular momentum can result in landing asymmetry. Landing asymmetry can lead to a poor landing performance or even acute or overuse injuries (Panzer, 1987). When performing forward landings, the gymnast's body is most likely exposed to more severe loading. It is of great importance to take loadings measured in the research into consideration when planning and monitoring the training sessions in order to minimize the injury risk.

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UTJECAJ RAZLIČITIH ROTACIJA OKO UZDUŽNE OSI U IZVEDBAMA SALTA NAPRIJED I NATRAG NA POVEĆANU ASIMETRIJU DOSKOKA

Cilj je ovog istraživanja bio utvrditi povećavaju li dodatne rotacije oko uzdužne osi asimetričnost doskoka prilikom izvedbe salta naprijed i natrag. U istraživanje je bilo uključeno dvanaest slovenskih reprezentativaca u sportskoj gimnastici. Svaki je gimnastičar izveo različite inačice opruženih salta s rotacijom oko uzdužne osi ili bez nje. U analizi je korišteno nekoliko dinamičkih i kinematičkih varijabla da bi se utvrdila asimetričnost doskoka. Vrijednosti reaktivnih sila i sila opterećenja ispod svakog stopala prikupljene su sustavom *Parotec Insole Pressure Measurement*. Podaci su normalizirani za tjelesnu masu gimnastičara. *Ariel Performance Analysis System* je korišten za izračunavanje kinematičkih varijabla. Rezultati su pokazali da većina izvedenih salta naprijed i natrag s rotacijom oko uzdužne osi završava asimetričnim doskokom (17–50%). Salta sa 1/2 rotacije oko uzdužne osi završavaju sa 50–58% asimetričnim doskokom, salta sa 1/1 rotacije sa 67–75% asimetričnosti te salta sa 3/2 rotacije sa 58–83% asimetričnosti. Asimetričnost doskoka povećavala se s povećanjem složenosti zadatka. Asimetričnost se očitovala u vremenu doskoka, okomitoj brzini kukova pri kontaktu s podlogom te u distribuciji maksimalne sile i pritiska. Razlike u vremenima doskoka između nogu bile su do -13,09±12,98 ms kod salta naprijed, odnosno do 4,08±7,61 ms kod salta natrag. Brzina kukova pri doskoku razlikovala se između kukova do 0,71 m/s za salto naprijed odnosno 0,54m/s za salto natrag. Razlika u maksimalnoj sili između stopala, normaliziranoj za tjelesnu masu gimnastičara, kretala se u rasponu od 0,98 do 1,03 tjelesne težine. Pri doskocima u saltu naprijed manifestirali su se veći pritisci na pete u trenutku najveće sile reakcije podloge nego li u doskocima pri izvedbi salta natrag.

Ključne riječi: *akrobatika, pogreške, salta, rotacije, doskočna noga*