

AN INVESTIGATION OF THE INFLUENCE OF BILATERAL DEFICIT ON THE COUNTER-MOVEMENT JUMP PERFORMANCE IN ELITE SPRINTERS

Mitja Bračić¹, Matej Supej¹, Stanislav Peharec², Petar Bačić² and Milan Čoh¹

¹University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

²Peharec Polyclinic for Physical Medicine and Rehabilitation, Pula, Croatia

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Abstract:

The purpose of the present study was to investigate the bilateral deficit (BLD) in elite sprinters and examine the relationship between the BLD and sprint start performance. Twelve male elite sprinters (age: 22.41±3.39 years, 100m personal best: 10.82±.25s) performed sprint starts, two- and one-leg counter-movement jumps (CMJ). A system of eight CCD cameras with a frequency of 200 Hz was used for the 3D kinematic measurements of CMJ. The ground reaction forces of sprint starts and vertical jumps were measured unilaterally and bilaterally by means of two independent and synchronized force platforms. Significantly lower values of force production of the front leg in the double start compared to the force production in the single start indicated the existence of a phenomenon similar to the bilateral deficit (BLD). The main findings of the present study were that: 1) lower values of BLD in the CMJ are related to higher peak force production of the rear leg in the double start of the sprint start ($r=-.630$; $p=.000$), 2) lower BLD in the CMJ is also related to higher total impulse of force on the blocks ($r=-.550$; $p=.000$) and 3) BLD values in CMJ are higher in elite sprinters compared to team sport athletes examined in the previous studies. The BLD measured in CMJ is a good indicator of a lower performance in the sprint start. As a consequence, the sprinters with higher BLD produced a lower total impulse of force on the blocks and lower block velocity, which are related to the overall 60m and 100m sprint performance.

Key words: *biomechanics, kinematics, dynamics, sprint start*

Introduction

The phenomenon known as the bilateral deficit (BLD) is manifested by the maximum voluntary force of a bilaterally performed task being smaller than the sum of the maximum voluntary force of the unilaterally performed tasks (for review see Jakobi & Chilibeck, 2001). Previous studies have shown the existence of a bilateral deficit (BLD) in both simple (Howard & Enoka, 1991; Owings & Grabiner, 1998) and complex motor tasks (Taniguchi, 1997; Hay, De Souza, & Fukashiro, 2006; Rejc, Lazzar, Antonutto, Isola, & di Prampero, 2010). A number of factors has been proposed to explain the existence of the BLD, including a selective restriction of high threshold motor units (Koh, Grabiner, & Clough, 1993; Owings & Grabiner, 1998), the force-velocity relationship (Bobbert, de Graaf, Jonk, & Casius, 2006), neural mechanisms (Howard & Enoka, 1991), training (Oda & Moritani, 1995), age (Häkkinen,

Pastinen, Karsikas, & Linnamo, 1995; Häkkinen, et al., 1996), motor disorders (Secher, Rube, & Ellers, 1988), the right-left dominance (Herbert & Gandevia, 1996), and different muscle coordination (Rejc, et al., 2010).

Studies that have used measures such as force and power developed during the jump task, have reported strong correlations between the vertical counter-movement jump (CMJ) and sprint performance (Liebermann & Katz, 2003), block velocity (Mero, Luhtanen, & Komi, 1983), and the acceleration phase of sprinting (Mero, et al., 1983; Bret, Rahmani, Dofour, Mesonnier, & Lacour, 2002). Maulder, Bradshaw, & Keogh (2006) have reported a strong correlation between the peak force of CMJ and 10m sprint time from a block start and concluded that CMJ is a good indicator for predicting the sprint start performance. In several studies it has been reported that in a two-leg vertical

jump humans achieve less than twice the jump height they are able to reach in a one-leg vertical jump (van Soest, Roebroek, Bobbert, Huijing, & van Ingen Schenau, 1985; Challis, 1998; Bobbert, et al., 2006). Some of them established the existence of BLD, using a sample of team sport athletes such as volleyball (Van Soest, et al., 1985; Bobbert, et al., 2006) and basketball (Challis, 1998). The results and findings of these studies using heterogeneous samples are unsuitable for scientific research of monostructural sports such as athletic sprinting, because they fail to reflect the athletes' actual state in a specific sport. In basketball, for example, the playing positions of guard, wing and centre differ considerably in terms of morphological aspects and motor abilities (Dežman, Trninić, & Dizdar, 2001; Erčulj, Blas, Čoh, & Bračić, 2009); therefore, players in different playing positions cannot be used in the same experimental procedure to determine the differences between one-leg and two-leg jump or to establish a BLD.

Sprinting is a complex cyclic human movement defined by stride frequency and stride length (Mann, 1981; Mero & Komi, 1994). Delecluse, et al., (1995) divided the 100m sprint into three specific performance phases. The first phase generates high acceleration over the initial 10m, the second phase continues this acceleration up to the attainment of maximal running speed (10 to 36m) and the third phase sees the maintenance of this maximal speed over the remaining distance (36 to 100m). The sprint start executed by a two-leg and one-leg push-off from a rear and front block, and block acceleration are two extremely important phases in the 60m and 100m sprints (Mero, 1988). In previous studies it has been reported that elite sprinters produce greater forces during the last contact moment in the blocks (Mero, Komi, & Gregor, 1992; Harland & Steele, 1997). However, in the beginning of the sprint start push-off action sprinters have both legs on the starting blocks, which can be defined as a bilateral movement, then the rear leg leaves the block and a push-off action is executed only with the front leg, which can be defined as a unilateral movement. Therefore it is expected that at the beginning of the sprint start BLD may play an important role in force production and sprint start performance.

The purpose of the present study was to investigate the bilateral deficit (BLD) in elite sprinters and examine the relationship between the BLD and sprint start performance. The hypotheses of the study were that: H1) lower values of BLD in a counter-movement jump will be related to a higher peak force production of the rear leg in the beginning of the sprint start, H2) lower BLD will be related to a higher total impulse of force on the blocks and H3) BLD values in vertical jumping will be higher in elite sprinters compared to team sport athletes examined in the previous studies.

Methods

Participants

Twelve elite sprinters participated in the experimental protocol (mean±SD: age: 22.41±3.39 years, body height: 177.58±6.86cm, body mass 74.92±5.23 kg, personal best time averages at 60m 6.93±.12 s (best time 6.65s), personal best time averages at 100m 10.82±.25s (best time 10.39s). All participants gave their informed consent. The study was approved by the Ethics Committee of the Faculty of Sport, University of Ljubljana.

Study design

Each subject performed five sprint starts, five two-leg counter-movement jumps (CMJ), and five one-leg counter-movement jumps with the dominant leg (CMJ_D) and the non-dominant leg (CMJ_ND) to push-off, while keeping their hands on their hips throughout the activity and during one-leg jumps to keep their free leg position fixed. The starts were performed with the starting blocks set in the medium position. The horizontal distance from the front block to the starting line was .75±.05m, and the horizontal distance between the blocks was .25±.06m. This position provided optimal conditions for the development of the force and force impulse on the rear and front blocks, as well as the rapid clearing of the blocks (Mero & Komi, 1990). Before the trials, participants performed light aerobic movements to warm up, followed by several practice jumps. Once the participants were comfortable with the jumping tasks, they were asked to perform randomized maximal jumps and sprint starts, with 90s of rest between jumps and 3min between sprint starts.

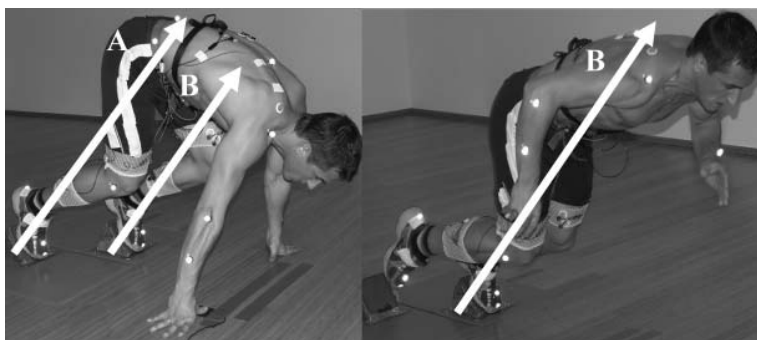
Experimental procedures

Kinematics. A system of eight CCD cameras with a frequency of 200 Hz and an image resolution of 768x576 pixels (BTS Smart-D, BTS Bio-engineering, Padua, Italy) was used for the 3D kinematic measurements of vertical jumps. For the link segment analysis, we defined an anatomical model with a system of 17 passive, (semi)spherical retro-reflective markers attached to: apex of the head, shoulders, torso, the joint centres of the wrists, elbows, hips, knees, ankles and the metatarsal-phalangeal joints (Vaughan, Davis, & Connor, 1999). The markers attached on the joints were automatically recognized by the system's BTS SMART Analyser computer software. The accuracy of the system was <0.2 mm on a volume of 4 x 2 x 2 m. The space calibration was performed using the THOR2 calibration system (BTS Smart-D, BTS Bioengineering, Padua Italy) (Pribanić, Peharec, & Medved, 2009). To process the kinematic variables, we used BTS SMART Analyser computer software. The angles of the ankle, knee and hip of both lower

extremities were measured. The knee and hip angle at full extension was 0° ; the ankle angle in standing position (neutral position) was 0° (Vaughan, et al., 1999).

Force measurements. The dynamic variables of sprint starts and vertical jumps were measured by means of two independent and synchronized force platforms (600x400, Type 9286A, Kistler Instrumente AG, Winterthur, Switzerland). The ground reaction forces measured unilaterally and bilaterally with forceplates were recorded at an 800 Hz sampling rate. Measurement error of the force measurements was ± 2 full scale output. During the measurements of vertical jumps the subject placed his left leg on the left platform and his right leg on the right platform. When executing the sprint start, the subject placed his dominant leg in the front starting block and his non-dominant leg in the rear starting block. The starting blocks were positioned on the two independent force platforms; therefore the developments of the forces were measured at the rear and front blocks (Figure 1).

The analysis of jump data was performed in accordance with the procedures of Caserotti, Aagaard, Simonsen, & Puggaard (2001). The maximal jump height of the centre of body's mass (H_{CM}) was determined for two-leg and one-leg jumps by the time integration (t_{fl}) of the vertical force (F_v) signal: $H_{CM} = t_{fl}^2 \cdot g \cdot 8^{-1}$ [m], where g stands for gravity ($9.81 \text{ m}\cdot\text{s}^{-2}$). In vertical jumps the curve of the ground reaction force was used to determine the onset of the GRF change by 1% of its value at rest; the same method was used to determine the end of the generation of GRF. The definition of the onset and the end of the force production also served as a basis for the synchronization of the 3D kinematics (Pribanić, et al., 2009). In the sprint start the force threshold of 10% from the maximal horizontal force was selected as a point of origin for force production (GRF) (Mero & Komi, 1990). For the sprint start and vertical jumps a peak ground reaction force (GRF_{max}) was determined and the impulse of ground reaction force (GRF_{imp}) was calculated as a time-dependent integral under the force curve. We also



Legend: A – rear block force; B – front block force.

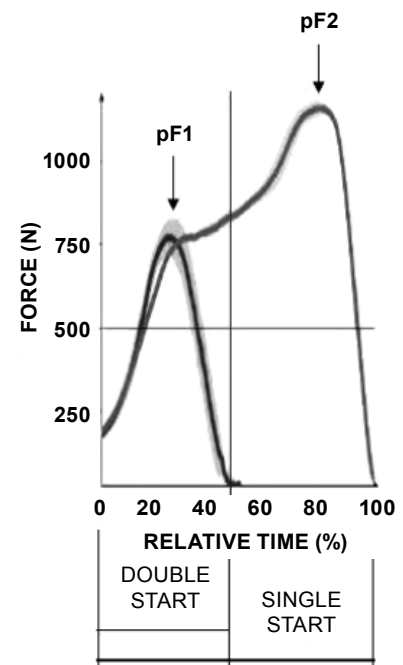
Figure 1. The double (left) and single start (right) of the sprint start.

normalized the values to the subject's body mass: GRF / BM [$\text{N}\cdot\text{kg}^{-1}$]. During the take-off phase, the velocity of the centre of body's mass (V_{VJ} – vertical jump; V_{BL} – block velocity) was determined by the integration of the acceleration, which in turn was calculated from the ground reaction force (GRF) signal. Block velocity (V_{BL}) is the resultant velocity of the sprinter at loss of foot contact with the front block (Harland & Steele, 1997). The position of the centre of body mass (CM) was determined by the time integration of the velocity. The starting block phase refers to the time when the subject is in contact with the blocks. The first phase is a double start, where the subject produces the force on the blocks with both legs (Figure 1 and 2). The second phase is a single start, where the subject produces the force with the front (dominant) leg (Figure 2).

The *bilateral index* was calculated using the (Howard & Enoka, 1991) method:

$$BI\% = 100 [(BL_{tot} / (UL_{dom} + UL_{ndom})) - 100],$$

in which BI denotes bilateral index, BL_{tot} denotes total bilateral force, while UL_{dom} and UL_{ndom} denote the dominant and non-dominant unilateral forces. A BI value deviation from zero indicates the difference between unilateral and bilateral jumps. $BI > 0$ indicates that the value of the two-leg jump variable is greater than the sum of the dominant and non-dominant leg variables in the one-leg jump. $BI < 0$ indicates that the value of the two-leg variable



Legend: pF1 – peak ground reaction force of rear block; pF2 – peak ground reaction force of front block.

Figure 2. Dynamic parameters in the double and single start of the sprint start.

is smaller than the sum of the dominant and non-dominant leg variables in one-leg jumping. Negative BI indicates a bilateral deficit (BLD), while positive BI indicates bilateral facilitation (BFC).

Statistical analysis

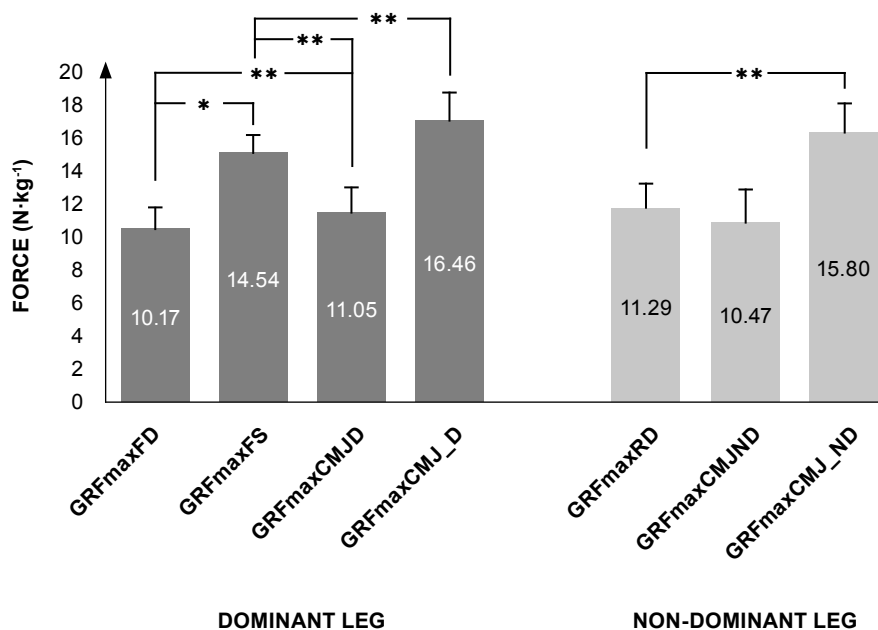
The three best performances for each type of jump were chosen for statistical processing. For the statistical analysis of results we used the SPSS 15.0 for Windows (Chicago, IL, USA) software. Data were presented as mean±standard deviation. Pearson correlation coefficients were used to determine the interrelationships among a vertical counter-movement jump and the sprint start variables. To determine the differences between force production in a sprint start and vertical jump and between two- and one-leg jump variables, we used the ANOVA for repeated measures (Bonferroni correction). The differences were confirmed at a 1% risk level ($p < .01$). Student *t*-tests were used to determine if the bilateral index was different from zero. The differences (BLD) were confirmed at a 5% risk level ($p < .05$).

Results

Figure 3 illustrates the comparison between the relative values of force production in a sprint start and vertical jumps. Maximum force production of the front (dominant) leg in the double start ($GRF_{max}FD$) ranged from $8.03 \text{ N}\cdot\text{kg}^{-1}$ to $13.02 \text{ N}\cdot\text{kg}^{-1}$

and was statistically lower than the maximum force production of the front (dominant) leg in the single start ($GRF_{max}FS$), which ranged from $12.61 \text{ N}\cdot\text{kg}^{-1}$ to $16.51 \text{ N}\cdot\text{kg}^{-1}$ ($p < .05$). $GRF_{max}FD$ was significantly lower than the maximum ground reaction force of the dominant leg in the two-leg jump ($GRF_{max}CMJD$), which ranged from $8.79 \text{ N}\cdot\text{kg}^{-1}$ to $16.15 \text{ N}\cdot\text{kg}^{-1}$ ($p < .01$). Maximum force production of the front leg in the single start ($GRF_{max}FS$) was significantly greater than the maximum force production of the dominant leg in the two-leg jump ($GRF_{max}CMJD$) ($p < .01$) and significantly lower than the maximum force production of the one-leg jump with the dominant leg ($GRF_{max}CMJ_D$), which ranged from $14.29 \text{ N}\cdot\text{kg}^{-1}$ to $20.06 \text{ N}\cdot\text{kg}^{-1}$ ($p < .01$). Maximum force production of the rear (non-dominant) leg in the double start ($GRF_{max}RD$) ranged from $8.58 \text{ N}\cdot\text{kg}^{-1}$ to $14.26 \text{ N}\cdot\text{kg}^{-1}$ and was significantly lower than the maximum force production in the one-leg jump with the non-dominant leg ($GRF_{max}CMJ_ND$), which ranged from $12.79 \text{ N}\cdot\text{kg}^{-1}$ to $20.42 \text{ N}\cdot\text{kg}^{-1}$ ($p < .01$).

Table 1 illustrates the values of selected kinematic and dynamic parameters of two- and one-leg counter movement jumping. The value of the jump height (H_{CM}) in the one-leg vertical jump with the dominant leg (CMJ_D) was 63.5% of the two-leg jump height while the value of the one-leg vertical jump with the non-dominant leg (CMJ_ND) was 67.7% of the two-leg jump height ($p < .01$). The value of both the one-leg jump heights (H_{CM}) was 126.2%



Legend: $GRF_{max}FD$ – ground reaction force of front (dominant) leg in the double start; $GRF_{max}FS$ – ground reaction force of front (dominant) leg in the single start; $GRF_{max}CMJD$ – ground reaction force of dominant leg in the two-leg jump; $GRF_{max}CMJ_D$ – ground reaction force of dominant leg in the one-leg jump; $GRF_{max}RD$ – ground reaction force of rear (non-dominant) leg in the double start; $GRF_{max}CMJND$ – ground reaction force of non-dominant leg in the two-leg jump; $GRF_{max}CMJ_ND$ – ground reaction force of non-dominant leg in the one-leg jump; ** $p < .01$, * $p < .05$.

Figure 3. Comparison of force production between the sprint start and vertical jumps (mean values).

Table 1. Selected kinematic and dynamic values for a two-leg and one-leg counter movement jump

PARAMETER	UNIT	CMJ_D	CMJ_ND	CMJ	
H _{CM}	cm	37.67±3.42*	38.20±3.88*	60.11±6.35	
V _{VJ}	m·s ⁻¹	2.20±.13*	2.22±.11*	3.06±.20	
Total GRF _{max} (D+ND)	N	2405.75±186.77*		1589.41±216.79	
Relative GRF _{max} (D+ND)	N·kg ⁻¹	32.22±3.11*		21.31±3.38	
Total GRF _{imp} (D+ND)	N·s	854.75±111.47*		363.66±41.88	
				DOMINANT	NON-DOMINANT
GRF _{max}	N	1182.08±98.29*	1223.66±96.83*	815.66±103.15	773.75±135.27
Relative GRF _{max}	N·kg ⁻¹	15.83±1.63*	16.38±1.55*	10.93±1.62	10.38±1.99
Total GRF _{imp}	N·s	416.75±54.32*	438.00±62.17*	173.58±21.82	190.08±32.02
Joint angle					
Ankle	°	27.33±3.11	27.66±3.74	28.16±4.34	29.41±3.75
Knee	°	78.83±6.05*	79.00±7.89*	96.91±10.32	96.33±10.78
Hip	°	70.16±14.25*	71.91±13.25*	81.25±10.21	79.50±8.86

Legend: CMJ_D – one-leg jump with dominant leg, CMJ_ND – one-leg jump with non-dominant leg, CMJ – two-leg jump; H_{CM} – jump height of the centre of body's mass; V_{VJ} – vertical jump take-off velocity; GRF_{max} – peak ground reaction force; D+ND – sum total values of one-leg jumps with dominant and non-dominant leg; GRF_{imp} – impulse of ground reaction force; GRF_{imp} (ecc + con) – sum total of eccentric and concentric force impulses.

* The difference between dominant and non-dominant legs during a two - and one-leg vertical jump is statistically significant (p<.01).

of the height of the two-leg jumps. The comparison of values of both the one- and two-leg jumps showed that the bilateral index in two-leg jumping ranged from -29.4% to -4.6% (-19.1±7.36%; p<.05), which indicated the BLD. The take-off velocity (V_{VJ}) values of one-leg jumps were significantly lower than the take-off velocity of two-leg jumps (p<.01). The difference was 28.1% for CMJ_D (p<.01) and 27.4% for CMJ_ND (p<.01).

To establish the range of movement in individual jumps, we analysed the angles at the ankle, knee and hip joints at the lowest point of the jumps. A comparison of angle values at the ankle joint showed no statistically significant differences. However, the differences became noticeable when we compared the values at the knee and hip joints. On average, the angle value of the knee joint on the dominant leg during one-leg jumping (CMJ_D) was significantly lower by 18.6%, which is about 18° less than the angle value at the knee joint during two-leg jumping (p<.01). The angle value at the knee joint of the non-dominant leg in one-leg jumping (CMJ_ND) was significantly smaller by 18.0%, which is about 17.3° less than the angle value at the knee joint in two-leg jumping (p<.01). On average, the angle value at the hip joint of the dominant leg in one-leg jumping (CMJ_D) was significantly smaller by 13.6%, which is about 11° less than the angle value at the hip joint in two-leg jumping (p<.01). The angle value at the hip joint of the non-dominant leg in one-leg jumping (CMJ_ND) was significantly smaller by 9.5%, which is about 7.6° less than the angle value at the hip joint in two-leg jumping (p<.01).

During a one-leg jump with the dominant leg (CMJ_D) the GRF_{max} (absolute and normalized) was 31.0% greater than the GRF_{max} that this leg produces during a two-leg jump (p<.01). The non-dominant leg, on average, produced 36.7% more force during a one-leg jump (CMJ_ND) than during a two-leg one (p<.01). The value of the sum of forces produced by the dominant and non-dominant legs during one-leg jumping (absolute and relative) was 33.9% higher than the value of the total force produced during two-leg jumping (p<.01). The ground reaction force (GRF_{max}) BLD in the counter movement jump ranged from -45.6% to -8.2% (-33.2±8.7%).

The value of the impulse of force (GRF_{imp}) produced by the dominant leg during a one-leg jump (CMJ_D) was 41.6% higher in comparison to the value of the GRF_{imp} produced by the same leg during a two-leg jump (p<.01). The value of the GRF_{imp} of the non-dominant leg (CMJ_ND) was 43.4% higher in comparison to the GRF_{imp} in a two-leg jump (p<.01).

The Pearson correlation coefficients showed that the force production BLD of the CMJ were significantly related to the peak force production of the rear leg in the double start (GRF_{max} RD : r=-.630; p=.000). The BLD of the CMJ were also significantly related to the total impulse of force on blocks (GRF_{imp} : r=-.550; p=.000), which ranged from 253.20 N·s to 353.80 N·s (295.66±26.63 N·s). Values of total impulse of force of rear and front blocks (GRF_{imp}) in the sprint start ranged from 253.20 N·s to 353.80 N·s (295.66±26.63 N·s) and

were significantly related to block velocity (V_{BL}) ($r=.610$; $p=.000$), which ranged from $2.90 \text{ m}\cdot\text{s}^{-1}$ to $3.70 \text{ m}\cdot\text{s}^{-1}$ ($3.28\pm.21 \text{ m}\cdot\text{s}^{-1}$).

Discussion and conclusions

In the 60m and 100m sprints, the sprint start is an important and crucial skill to be learned if a sprinter wants to maximize performance over the distance. In the double start of the sprint start BLD plays an important role in force production and sprint start performance. The main findings of the present study of twelve elite sprinters were: 1) that lower values of bilateral deficit (BLD) in the counter-movement jump (CMJ) are related to the higher peak force production of the rear leg in the double start of the sprint start ($r=-.630$; $p=.000$), 2) that lower bilateral deficit in the CMJ is also related to the higher total impulse of force on the blocks ($r=-.550$; $p=.000$) and 3) BLD values in vertical jumping are higher in elite sprinters compared to team sport athletes examined in the previous studies.

The sprint start in the present study was divided into two phases; a double start, where a sprinter produces force with both legs (rear and front block), and a single start, where the sprinter produces force with only one leg (front block) (Figure 1 and 2). Significantly lower values of force production of the front (dominant) leg in the double start (GRF_{maxFD}) compared to the force production of the front (dominant) leg in the single start (GRF_{maxFS}) indicated the existence of a phenomenon similar to the bilateral deficit (BLD), which also occurs in the CMJ (Figure 3). This is similar to what was observed in the force production of the rear leg in the sprint start, where the force production of the rear (non-dominant) leg in the double start (GRF_{maxRD}) was significantly lower than the force production in the one-leg jump with the non-dominant leg (GRF_{maxCMJ_ND}) (Figure 3). The results also showed that BLD measured in CMJ is a good indicator of a lower performance in the sprint start. When high values of BLD were present in the CMJ, the sprinters were not able to produce equally high peak forces on the blocks in the double start compared to sprinters where lower values of BLD were present. As a consequence the sprinters with higher BLD values produced a lower total impulse of force on the blocks (GRF_{imp}) and lower block velocity (V_{BL}), which are related to the overall 60m and 100m sprint performance (Harland & Steele, 1997; Mero, et al., 1992).

As expected, in the present study the height of the jump (H_{CM}) ratio between one- and two-leg jumps was much higher in sprinters than in the team sport athletes. The ratio of 58.1% was reported by Challis (1998), 58.5% by van Soest, et al., (1985) and 57.0% by Bobbert, et al., (2006). In contrast to those research papers, elite sprinters in the present study were a more homogenous sample with more simi-

lar jump strategies. Furthermore, they were also of similar abilities, so that jump height deviation was also not as high as in the previous studies (Challis, 1998; van Soest, et al., 1985; Bobbert, et al., 2006). If complex and multi-joint movements such as a vertical jump are used for research into BLD, difficulties could be encountered as there are differences in strategies between individual attempts (repetitions), as well as the subjects. The results of the study by van Soest, et al., (1985) showed -8.5% BLD in the jump height in basketball players, which is a smaller value compared to the present study.

It was discovered that the two dynamic parameters – maximum ground reaction force (GRF_{max}) and the impulse of force (GRF_{imp}) – were significantly greater in one-leg jumping (CMJ_D and CMJ_ND) compared to two-leg jumping (Table 1). This can be explained to some extent by the force/velocity ratio, which shows clearly that in a one-leg jump a higher production of the GRF is possible due to the lower velocity of movement in the take-off phase and that the impulse of force (GRF_{imp}) in a one-leg jump is higher due to the longer take-off phase. These factors also influence the ratio between the height of one-leg and two-leg jumps, which exceeded 126% in this study. The maximum ground reaction force (GRF_{max}) BLD in CMJ showed a higher value compared to the BLD of -28.0% reported by Challis (1998) and of -21.2% by Bobbert, et al., (2006).

Following Challis (1998), we attempted to keep the range of motion the same in the two-leg and one-leg jumps, but we nevertheless ended up with a smaller vertical displacement of the center of mass (H_{CM}) during the push-off (Table 1), similar to Bobbert, et al., (2006). However, the smaller range of motion in the knees (by 18%) and hips (by 10.0% to 13.0%) during the push-off in one-leg jumps was only a secondary explanation for the reduced mechanical output per leg in the two-leg jump. The primary explanation was that the GRF_{max} produced by the dominant and non-dominant legs was less in the two-leg jump compared to the one-leg jump (Table 1).

Although most track coaches and researchers agree that an efficient start is essential in winning sprint races, a problem exists if a phenomenon similar to BLD occurs in the force production on the blocks. For a fast start technique and high block velocity biomechanical variables such as bilateral force production and total impulse of force on the blocks need to be as high as possible to achieve a high performance. We suggest that sprint coaches should consider incorporating bilateral exercises in the training of power of a jumping type and also in strength and power training to improve the sprint start performance and consequently overall performance. The sprint start and 100m sprint itself is very much a power event; considerable effort should be directed towards developing concentric

and eccentric strength and power of the hip and legs extensors' muscles to enable the sprinter to apply large forces on the blocks and track to propel the body at high sprinting velocities.

The findings of the bilateral deficit in CMJ related to the sprint start performance and the differences in the mechanical output between a two-leg counter-movement jump and a one-leg jump in elite sprinters are highly important for both track-and-field theory and practice. Besides the understanding of the relationship of the BLD in

CMJ and the sprint start, relatively simple CMJ tests can be used to predict a sprint start performance and the level of an athlete's physical abilities. Future research directions should include larger samples of elite sprinters. Furthermore, they should involve the continual monitoring of the physical abilities with vertical jumps and the sprinting performance of the sprinters along with changes arising due to incorporation of bilateral exercises in training of power of a jumping type and also in strength and power training.

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Correspondence to:

Mitja Bračić, PhD

Faculty of Sport, University of Ljubljana

Gortanova 22, SI-1000 Ljubljana, Slovenia

Phone: +386 1 520 77 84

Fax: +386 1 520 77 40

E-mail: mitja.bracic@fsp.uni.lj.si

UTVRĐIVANJE UTJECAJA BILATERALNOG DEFICITA NA IZVEDBU SKOKA S PRIPREMOM KOD VRHUNSKIH SPRIINTERA

Cilj ovog istraživanja bio je utvrđivanje bilateralnog deficita (BLD) kod vrhunskih sprintera i istraživanje relacija između BLD i izvedbe niskog starta. Dvanaest vrhunskih muških sprintera (starih: 22.41 ± 3.39 godina, osobni rekord u sprintu na 100 m: $10.82 \pm .25$ s) izvodili su niski start, te jednoonožne i objenožne skokove s pripremom (CMJ). Sustav od osam CCD kamera frekvencije 220 Hz koristio se za 3D kinematičko mjerenje skokova s pripremom. Sile reakcije podloge sprinterskih startova i vertikalnih skokova mjerene su unilateralno i bilateralno pomoću dvije nezavisne i sinkronizirane tenziometrijske platforme. Statistički značajno slabije vrijednosti manifestiranja sile prednje noge kod *objenožnog* starta u usporedbi s manifestiranjem sile kod *jednoonožnog* starta uputile su na postojanje fenomena koji je sličan fenomenu bilateralnog deficita. Glavni rezultati ovog istraživanja su: 1) niže vrijednosti bilateralnog deficita kod skoka s pripremom povezane

su s očitovanjem veće vršne sile stražnje noge kod *objenožnog* starta ($r = -.630$; $p = .000$); 2) manji BLD kod skoka s pripremom je također povezan s većim ukupnim impulsom sile na startni blok ($r = -.550$; $p = .000$) i 3) vrijednosti BLD kod skoka s pripremom su veće kod vrhunskih sprintera u usporedbi sa sportašima iz sportskih igara testiranih u dosadašnjim istraživanjima. Vrijednosti BLD izmjerene pri izvedbi skoka s pripremom su vrlo dobri pokazatelji slabije izvedbe sprinterskog starta. U skladu s navedenim rezultatima provedenog istraživanja sprinteri s većim BLD proizveli su manji ukupan impuls sile na startni blok i nižu brzinu izlaska iz bloka, što je izravno povezano sa slabijim rezultatom sprinta na 60 i 100 metara.

Ključne riječi: biomehanika, kinematika, dinamika, sprinterski start