

# Changes in eccentric utilization ratio, reactive strength index and leg stiffness in highly trained sprinters between training phases

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**Purpose:** To determine changes in eccentric utilization ratio (EUR), reactive strength index (RSI), squat jump (SJ) and countermovement jump (CMJ) parameters in elite sprinters from the preparation phase to the competition (indoor) phase.

**Methods:** Ten elite-level sprinters (n=10) were examined. All sprinters performed the SJ, CMJ and 10/5 rebound jump (RJ) tests. Body composition analysis was assessed using dual X-ray absorptiometry (DXA) method. A paired t-test was performed to determine statistical significance.

**Results:** SJ height and relative peak power increased significantly from  $43.10 \pm 6.1$  cm to  $46.30 \pm 5.7$  cm ( $P = .013$ , Cohen's  $d = .98$ ) and from  $52.62 \pm 4.5$  W·kg BM<sup>-1</sup> to  $55.55 \pm 4.5$  W·kg BM<sup>-1</sup> ( $P = .017$ ,  $d = .92$ ) respectively. CMJ height and relative peak power increased significantly from  $46.78 \pm 6.1$  cm to  $49.18 \pm 5.5$  cm ( $P = .039$ ,  $d = .76$ ) and from  $55.53 \pm 4.1$  W·kg BM<sup>-1</sup> to  $57.92 \pm 4.0$  W·kg BM<sup>-1</sup> ( $P = .024$ ,  $d = .86$ ) respectively. No significant differences were observed in RJ performance parameters.

**Conclusions:** SJ and CMJ height, flight time and peak power output per body mass increased in elite sprinters from the preparation to the competition phase while RSI, EUR and leg stiffness (LS) values did not. SJ and CMJ performance can be used as markers of training phase changes in elite sprinters. EUR should be used cautiously to determine training status in elite sprinters since sprint training encompasses reactive strength training all year round. Reactive strength levels via RSI and stiffness levels should be assessed individually in each training phase to determine whether the measured value of these parameters is satisfactory to optimize competition readiness. LS levels should not be compared to general guidelines but rather individually to the athletes' sprint performance and then training should be adjusted accordingly.

**Keywords:** exercise, power, explosive, jump, performance.

## Introduction

The training and development of elite sprint performance has always been a topic of interest in sports science, improving performance and athlete training<sup>1</sup>. Many training methods and assessment methods have been proposed to better optimize and control the training process in elite sprinters<sup>1,2</sup>. Various means such as acceleration, maximum speed, speed endurance, sprint-specific endurance, resisted sprint, assisted sprint, and tempo training have been proposed to improve sprint performance<sup>1,2</sup>. Furthermore, strength, power, and plyometric training have been discussed as very important supplementary training means to further increase sprint performance<sup>1,2</sup>. It was demonstrated that greater leg stiffness (LS)<sup>3,4</sup>, power<sup>3</sup>, reactive strength and shorter ground contact times<sup>5</sup> were characteristic of sprinters compared to other athletes<sup>(6)</sup>. Testing protocols like the squat jump (SJ)<sup>7,8</sup>, countermovement jump (CMJ)<sup>8-10</sup>, drop jump (DJ)<sup>6,8</sup>, and hopping tests such as the 10/5 rebound jump (RJ)<sup>11</sup> have been proposed as a means to assess and monitor power, stretch-shortening cycle (SSC) and LS performance in sprinters throughout an annual training cycle. Training loads vary throughout the year so that more general training loads are applied earlier in the annual training cycle (in the preparation phase), and more specific training loads in the later stages (pre-competitive and competition phases)<sup>1</sup>. This ensures that athletic readiness and performance are higher closer to competition

dates since training loads around this time are the most specific to competition demands. This allows athletic performance variables most specific to the sport to be trained closest to competition and with the closest resemblance to the demands of the sport.

Kale et al.<sup>12</sup> investigated jump parameters (SJ, CMJ, depth jump) in sprinters during the preparation training phase. However, there is still a current lack of research concerning jump performance in highly trained sprinters as well as differences between these parameters in training phases of an annual training cycle. Loturco et al.<sup>13</sup> assessed SJ parameters in elite sprinters, rugby athletes and soccer players but at relative loads only and not in different phases of a training cycle. Additionally, a more commonly used parameter termed the eccentric utilization ratio (EUR), calculated by dividing CMJ height by SJ height, has been proposed as a marker of SSC performance<sup>14</sup>, especially in an annual training cycle. This parameter was proposed to be sensitive to types of training implemented in athletes and an indicator of training status<sup>14</sup>. However, except for McGuigan et al.<sup>14</sup> very few studies have measured EUR in an annual training cycle. Additionally, there is a lack of research studying EUR changes in an annual training cycle in elite sprinters. Beattie et al.<sup>10</sup> assessed CMJ characteristics of world-class elite and sub-elite sprinters but did not include a full range of jump tests and did not measure performance in separate phases of an annual training cycle. Finally, many of these parameters have not been analyzed

along with crucial body components such as lean, muscle and fat mass/content. Assessing jump parameters relative to body composition parameters could offer new parameters sensitive to training status or explosive performance in the testing of elite sprinters.

The aim of this study was to determine changes in EUR, reactive strength index (RSI), SJ and CMJ parameters in elite sprinters between the preparation phase and the competition (indoor) phase in an annual training cycle. We hypothesized that SJ, CMJ, RJ performance parameters and the EUR and RSI will increase from the preparation phase to the competition phase of an annual training cycle.

## Methods

### *Participants*

A group of elite sprinters ( $n=10$ , 7 men and 3 women) participated in the study, specialized in the 100 m (average personal best was 10.83s for men and 11.89s for women) and 200 m events (average personal best was 21.77s for men and 23.92s for women), aged  $22.00 \pm 2.7$  years, and height at the first testing session was  $178.69 \pm 7.2$  cm. Weight, BMI and total lean mass were  $74.59 \pm 11.0$  kg,  $23.17 \pm 2.3$  kg·m<sup>-2</sup> and  $60.43 \pm 11.5$  kg at the first testing session and  $74.30 \pm 11.1$  kg,  $23.23 \pm 2.20$  kg·m<sup>-2</sup> and  $60.50 \pm 11.4$  kg at the second testing session, respectively. All sprinters were part of the XXXXX National Team and regularly competed at National and International Athletics Competitions in the Indoor and Outdoor Seasons.

The project was approved by the local Ethics Committee and was performed in accordance with the ethical standards of the Declaration of Helsinki. The testing procedures, the purpose and risks of the study were explained to each participant. Each participant submitted their written consent to participate.

### *Design*

The study was adapted to the training phases of the sprinters and covered a period of 3 months. Two consecutive testing sessions were performed: the first session represented the beginning of the preparation phase, the second session represented the beginning of the competitive phase (indoor season).

All training sessions between these phases were based on general and well-known sprinter training methods<sup>1,2</sup>. Strength training was focused on general exercises with a microcycle structure aimed at increasing training load (increase in %1RM up to 90%1RM) while decreasing repetitions per set. Power exercises such as power clean, power snatches, barbell jump squats and step-up jumps were also implemented. Plyometric training consisted of various forms of drop/depth jumps, bounds, single-leg hops, and low intensity skipping exercises (an integral part of the warm-up). Speed training was progressed from training the acceleration phase early in the preparation phase (with short 10-meter sprints) to slowly progressing to maximal speed development near the competition phase (30–60m sprints indoors). Endurance training comprised of light to medium intensity interval runs, progressed to tempo runs to speed endurance and special endurance means<sup>1</sup>. Regardless of individual modifications in training load structure, all sprinters were trained in a similar fashion since they were all part of the XXXXX National Team and monitored and controlled by the XXXXX National Team sprinting Head Coach.

These two training phases were chosen to see how training means applied in the preparation phase would produce changes in jump

performance parameters. Additionally, sprinters represent a group of athletes which achieve very high results in most jump performance tests due to the explosive nature of sprint training and competing. Lastly, elite athletes already represent high-level training adaptations present due to years of systematic and rigorous training.

### *Methodology*

#### *Body composition analysis*

Participants were informed to refrain from any high-intensity or long-duration training session at least 24–48 hours before testing. Testing was performed in the morning, 3 hours after breakfast (no caffeine). Subjects were asked to eat a similar breakfast before each testing session throughout the annual training cycle. Room temperature was maintained at 20–21°C and air pressure at 1006 hPa.

A digital stadiometer (SECA 285, Hamburg, Germany) was used to measure body mass (kg) and height (cm) while body mass index (BMI) was calculated by dividing body mass by height squared (kg·m<sup>-2</sup>). Body composition analysis was performed using the Dual X-ray Absorptiometry (DXA) method with the Lunar Prodigy Pro device (GE Healthcare, Madison, Wisconsin, USA) and encore v. 16 SP1 software as described previously<sup>15</sup>. Participants were instructed to only wear their undergarments to minimize measurement error (without jewelry or metal objects).

#### *Jump Protocols*

All sprinters performed SJ, CMJ and 10/5 RJ tests. All athletes were instructed to hold their hands on their hips during all jumps to avoid upper body interference. A total of three trials were given in each test with full recovery in between trials. For the SJ, athletes were instructed to lower into a half squat position with 90° flexion in both the hip and knee joints, hold this position for 2 sec and then jump for maximum height without initiating a countermovement. Athletes were carefully monitored by the research team to ensure that the half squat position was attained, held and no countermovement was performed<sup>16</sup>. For the CMJ, athletes were instructed to stand fully upright, and then on command to drop down into a half squat position (the same depth as the SJ) and immediately without pausing to jump up for maximum height. Athletes were encouraged to perform the lowering/eccentric phase of the jump as fast as possible to maximize jump height<sup>17</sup>. To measure RSI and LS the 10/5 RJ test<sup>11</sup> was used. In the RJ test, the athletes were instructed to perform 11 maximal jumps where the first jump in each trial served as a CMJ and consequently was discounted for analysis. Athletes were instructed to maximize jump height while minimizing ground contact time<sup>18</sup>. From the 10 jumps, 5 highest jumps with ground contact times <250ms were selected and averaged for analysis of LS and the RSI. Throughout all jumps, athletes were verbally encouraged to attain their best performance during each trial. The selected jumps were chosen to be reliable in measuring leg extensor muscle mechanical power<sup>19</sup>.

All jumps were performed on a mobile contact mat (Smartjump, Fusion Sport, Australia), and data instantaneously collected via a hand-held PDA (iPAQ, Hewlett Packard, USA). The smartjump contact mat was shown to be highly reliable with intra-trial coefficients of variation for all parameters in the range of 0.72–1.44%, 1.1–2.28% and 1.86–7.32% for the SJ, CMJ, and RJ, respectively.

#### *Parameters/Variables*

Two parameters were measured during each trial:

- contact time: the time (ms) the athlete spent on the contact mat
- flight time: the time (ms) between leaving and returning to the contact mat

which allowed the calculation of the following parameters:

- jump height : in cm (Vertical jump height= $\frac{1}{4} (TOV^2) / (2 \times g) \times 100$ )
- $g$  – acceleration due to gravity (in  $9.81 \text{ m} \cdot \text{s}^{-2}$ )
- $t$  – time in air (TIA) of vertical jump
- Take-off velocity (TOV) –  $(gt)/2$
- RSI: jump height divided by contact time
- Peak Power (W) =  $60.7 \times (h) + 45.3 \times (BM) - 2055$
- BM – bodymass
- Relative peak power output: peak power output / BM
- LS:  $\frac{M \times \pi (T_f + T_o)}{T_o (\frac{T_f + T_o}{\pi} \cdot \frac{T_f}{T_o})}$
- EUR: CMJ height / SJ height

### Statistical Analysis

The results were obtained on two test dates separated by a period of 3 months. A paired t-test was performed to determine the statistical significance. Significance level was set at  $P < .05$ . Confidence intervals (CI -95%) were also calculated. Cohen's  $d$  effect sizes were calculated to examine the magnitude of differences. The magnitude of these differences were classed as follows: small (.2), medium (.5), large (.8), very large (1.3)<sup>20</sup>. Pearson correlation coefficients ( $r$ ) were used to describe the relationship between jump parameter changes and body composition changes. All statistical analyses were performed using STATISTICA 13.0 software (statsoft, Tulsa, OK). All values were presented as means  $\pm$  standard deviation (SD).

## Results

### Descriptive characteristics

Basic characteristics between groups and testing sessions are presented in Table 1. There were no statistically significant changes in height, weight, BMI, lean body mass, lean legs mass and fat mass in sprinters between training phases.

**Table 1.** Basic characteristics of the sprinter group

|                           | Preparation Phase                | Competition Phase                | Change                    | P-value | Effect Size |
|---------------------------|----------------------------------|----------------------------------|---------------------------|---------|-------------|
| Age (yr)                  | 22.0 $\pm$ 2.7<br>(20.1–23.9)    | 22.2 $\pm$ 2.5<br>(20.4–24.0)    | --                        | --      | --          |
| Height (cm)               | 178.7 $\pm$ 7.2<br>(173.6–183.8) | 178.8 $\pm$ 7.2<br>(173.6–183.8) | --                        | --      | --          |
| Weight (kg)               | 74.6 $\pm$ 11.0<br>(66.7–82.5)   | 74.3 $\pm$ 11.1<br>(66.3–82.3)   | -.29 $\pm$ .9<br>(-.43%)  | .31     | .35         |
| BMI (kg·m <sup>-2</sup> ) | 23.2 $\pm$ 2.3<br>(21.5–24.8)    | 23.2 $\pm$ 2.2<br>(21.7–24.8)    | .06 $\pm$ .3<br>(.28%)    | .53     | .20         |
| Lean Body Mass (kg)       | 60.4 $\pm$ 11.5<br>(52.0–68.7)   | 60.5 $\pm$ 11.4<br>(52.3–68.6)   | .07 $\pm$ 1.3<br>(.15%)   | .87     | .06         |
| Lean Legs Mass (kg)       | 22.0 $\pm$ 4.2<br>(19.0–25.0)    | 22.1 $\pm$ 4.3<br>(19.0–25.2)    | .1 $\pm$ .5<br>(.37%)     | .54     | .21         |
| Fat Mass (kg)             | 11.0 $\pm$ 2.0<br>(9.6–12.4)     | 10.7 $\pm$ 1.9<br>(9.4–12.0)     | -.28 $\pm$ .6<br>(-2.60%) | .19     | .46         |

Values are means  $\pm$  standard deviations (confidence intervals).

\* Significantly different between training phases

Abbreviations: BMI – body mass index

### SJ performance changes

All changes in SJ variables with standard deviation, effects sizes and confidence intervals are presented in Table 2. SJ height and flight time increased significantly ( $P < .05$ ) from  $43.10 \pm 6.1 \text{ cm}$  to  $46.30 \pm 5.7 \text{ cm}$  (.013) and from  $591.40 \pm 43.4 \text{ ms}$  to  $613.40 \pm 37.8 \text{ ms}$  (.014) respectively. Additionally, SJ peak power output per body mass increased significantly ( $P < .05$ ) from  $52.62 \pm 4.5 \text{ W} \cdot \text{kg} \text{ BM}^{-1}$  to  $55.55 \pm 4.5 \text{ W} \cdot \text{kg} \text{ BM}^{-1}$  (.017). Percentage increases for all SJ parameters are also presented in Table 2.

### CMJ performance changes

All changes in CMJ variables with standard deviation, effects sizes and confidence intervals are presented in Table 2. CMJ height and flight time increased significantly ( $P < .05$ ) from  $46.78 \pm 6.1 \text{ cm}$  to  $49.18 \pm 5.5 \text{ cm}$  (.039) and from  $616.4 \pm 40.8 \text{ ms}$  to  $632.4 \pm 35.5 \text{ ms}$  (.042) respectively. Additionally, CMJ peak power output per body mass increased significantly ( $P < .05$ ) from  $55.53 \pm 4.1 \text{ W} \cdot \text{kg} \text{ BM}^{-1}$  to  $57.92 \pm 4.0 \text{ W} \cdot \text{kg} \text{ BM}^{-1}$

(.024). Percentage changes for all CMJ parameters are also presented in Table 2.

### RJ performance changes

All changes in 10/5 RJ variables with standard deviation, effects sizes and confidence intervals are presented in Table 3. No significant differences were observed for all RJ performance parameters. A significant correlation between RSI and legs lean mass was observed ( $r = -.69$ ,  $P = .03$ ). Percentage changes for all RJ are also presented in Table 3.

## Discussion

Our main finding was that SJ and CMJ height, flight time and peak power output relative to body mass increased in elite sprinters from the preparation phase to the competition phase. In contrast, no significant changes were noted for the other

**Table 2.** Changes in squat jump, countermovement jump and eccentric utilization ratio performance parameters in elite sprinters

|                                      | Preparation phase       | Competition phase       | Change               | P-value | Effect size |
|--------------------------------------|-------------------------|-------------------------|----------------------|---------|-------------|
| Squat Jump Parameters                |                         |                         |                      |         |             |
| Jump height (cm)                     | 43.1±6.1<br>(38.7–47.5) | 46.3±5.7<br>(42.3–50.5) | 3.2±3.3<br>(6.9%)    | .01*    | .98         |
| Flight time (ms)                     | 591±43<br>(560–622)     | 613±38<br>(586–640)     | 22.0±22.9<br>(3.59%) | .01*    | .96         |
| Impulse (Ns)                         | 217±41<br>(187–246)     | 220±40<br>(192–248)     | 3.3±12.7<br>(1.54%)  | .43     | .26         |
| Peak power (W)                       | 3935±751<br>(3398–4474) | 4062±709<br>(3554–4569) | 126±186<br>(3.27%)   | .06     | .68         |
| Peak power (W·kg BM <sup>-1</sup> )  | 52.6±4.5<br>(49.4–55.8) | 55.6±4.5<br>(52.3–58.8) | 2.9±3.2<br>(5.2%)    | .02*    | .92         |
| Peak power (W·kg LBM <sup>-1</sup> ) | 65.3±5.5<br>(61.4–69.3) | 67.4±4.1<br>(64.5–70.3) | 2.1±3.7<br>(3.1%)    | .11     | .57         |
| Peak power (W·kg LLM <sup>-1</sup> ) | 187±59.3<br>(145–230)   | 193±61.9<br>(149–237)   | 6.1±10.1<br>(2.9%)   | .09     | .60         |
| Peak power (W·kg FM <sup>-1</sup> )  | 372±114<br>(290–454)    | 392±110<br>(313–471)    | 20.1±32.7<br>(5.4%)  | .08     | .61         |
| Countermovement Jump Parameters      |                         |                         |                      |         |             |
| Jump height (cm)                     | 46.8±6.1<br>(42.4–51.2) | 49.2±5.5<br>(45.3–53.1) | 2.1±3.2<br>(4.9%)    | .04*    | .76         |
| Flight time (ms)                     | 616±40.8<br>(587–645)   | 632±35.5<br>(607–658)   | 16±21.3<br>(2.5%)    | .04*    | .75         |
| Impulse (Ns)                         | 227±44.1<br>(195–258)   | 227±41.5<br>(198–257)   | .79±17.7<br>(0.35%)  | .90     | .04         |
| Peak power (W)                       | 4159±803<br>(3585–4733) | 4062±709<br>(3554–4569) | 78±290<br>(2.0%)     | .42     | .27         |
| Peak power (W·kg BM <sup>-1</sup> )  | 55.5±4.1<br>(52.6–58.4) | 57.9±4.0<br>(55.0–60.8) | 2.4±2.8<br>(4.1%)    | .02*    | .86         |
| Peak power (W·kg LBM <sup>-1</sup> ) | 68.9±4.8<br>(65.5–72.4) | 70.3±4.1<br>(67.4–73.2) | 1.4±5.3<br>(1.8%)    | .43     | .27         |
| Peak power (W·kg LLM <sup>-1</sup> ) | 198±62.2<br>(153–242)   | 203±65.9<br>(155–249)   | 4.2±12.6<br>(1.6%)   | .32     | .33         |
| Peak power (W·kg FM <sup>-1</sup> )  | 393±117<br>(308–476)    | 408±114<br>(327–490)    | 16.7±38.4<br>(4.2%)  | .20     | .42         |
| EUR                                  | 1.09±.07<br>(1.04–1.14) | 1.06±.05<br>(1.03–1.10) | -.03±.06<br>(-2.4%)  | .24     | .40         |

\*significantly different between training phases

Abbreviations: BM – body mass, FM – fat mass, LBM –Lean Body Mass, LLM – lean legs mass, EUR – eccentric utilization ratio

parameters.

**Changes in SJ and CMJ performance**

In terms of SJ and CMJ parameters, only height, flight time and peak power output per body mass increased. During the preparation phase, a large amount of time is spent on building maximal strength using exercises such as various squats (back squat, single-leg squat, split-squat), deadlifts (classical, sumo, single-leg RDL), step-ups,<sup>1,2</sup> which mainly focus on the force side of the power equation. Most strength exercises also have a greater emphasis on the concentric side of muscle contractions which could explain why SJ height and relative power increased. SJ performance also highly correlates with the starting phase of a sprint<sup>21,22</sup>, and the indoor track and field competitive phase

is an area where most sprinters compete in the 60-meter race where the block start and acceleration phases play a more important role compared to max speed and speed-endurance abilities<sup>22</sup>. SJ performance (jump height, peak power per body mass) was shown to correlate with 5-meter sprint performance<sup>23</sup>, 60-meter sprint performance<sup>22</sup> and sprinting ability<sup>7</sup>, therefore improvement in SJ performance could indicate effective training strategies in improving sprint performance in the competitive phase. The CMJ, however, has an eccentric component<sup>16</sup> and is an indicator of slow SSC performance<sup>24</sup>. In the preparation period, more training is emphasized on slow SSC plyometric exercises like vertical jumps, box jumps, split-squat jumps as well as fast SSC-type movements such as depth jumps, drop jumps, bounds, and hops. This could explain the increase in CMJ height and

**Table 3.** Changes in 10/5 rebound jump performance parameters in elite sprinters

|                                      | Preparation phase        | Competition phase        | Change                | P-value | Effect size |
|--------------------------------------|--------------------------|--------------------------|-----------------------|---------|-------------|
| Jump height (cm)                     | 40.3±5.7<br>(36.2-44.4)  | 40.4±9.2<br>(33.9-47.0)  | .14±4.8<br>(-3.0%)    | .93     | .03         |
| Contact time (ms)                    | 181±49.5<br>(145-216)    | 155±14.2<br>(145-165)    | -25.6±52<br>(-17.4%)  | .15     | .49         |
| RSI (m/ms)                           | 2.25±.5<br>(1.92-2.58)   | 2.56±.6<br>(2.13-2.99)   | .3±.6<br>(8.6%)       | .12     | .55         |
| Flight time (ms)                     | 572±42.7<br>(541-602)    | 570±71.7<br>(519-621)    | -1.6±40<br>(-1.1%)    | .90     | .04         |
| Impulse (Ns)                         | 211±42.5<br>(180-241)    | 207±50.2<br>(171-243)    | -3.64±13.1<br>(-3.3%) | .40     | .28         |
| Peak power (W)                       | 3766±804<br>(3191-4341)  | 3706±1002<br>(2990-4423) | -59.4±277<br>(-4.3%)  | .51     | .21         |
| Peak power (W·kg BM <sup>-1</sup> )  | 50.1±4.8<br>(46.7-53.5)  | 49.9±8.5<br>(43.9-56.0)  | -.16±5.1<br>(-2.2%)   | .92     | .03         |
| Peak power (W·kg LBM <sup>-1</sup> ) | 62.1±5.6<br>(58.1-66.1)  | 60.5±9.7<br>(53.5-67.4)  | -1.65±6.4<br>(-4.6%)  | .44     | .26         |
| Peak power (W·kg LLM <sup>-1</sup> ) | 180±61.1<br>(136-223)    | 178±71.5<br>(127-229)    | -1.83±13.5<br>(-4.9%) | .68     | .13         |
| Peak power (W·kg FM <sup>-1</sup> )  | 354±111<br>(275-433)     | 357±126<br>(267-446)     | 2.58±43.2<br>(-2.2%)  | .85     | .06         |
| LS (kN·m <sup>-1</sup> )             | 31.2±10.9<br>(23.5-39.0) | 37.0±8.5<br>(31.0-43.1)  | 5.79±11.7<br>(12.8%)  | .15     | .49         |

\*significantly different between training phases

Abbreviations: BM – body mass, FM – fat mass, LBM –Lean Body Mass, LLM – lean legs mass, LM – leg stiffness, RSI – reactive strength index

peak power output. CMJ parameters (jump height and peak power) have been shown to correlate to acceleration and max speed performance in sprinters<sup>12,25,26</sup> so CMJ performance should therefore be highest when sprint performance (acceleration, max speed) is maximized (in the competitive phase).

### Changes in EUR performance

EUR performance decreased only by 2.4% in this study ( $P = .24$ ). EUR is a parameter used to measure SSC performance<sup>14,25</sup>. It has been proposed that especially slow SSC performance can be measured using tests such as the CMJ<sup>24,25</sup>. There was shown to be no differences in EUR between sprinters and endurance athletes<sup>3</sup> even though sprinters obtained better results in SJ and CMJ testing. Only one study measured EUR performance in different training phases<sup>14</sup> and concluded that EUR appears to be sensitive to changes in the type of training being performed by athletes. Rugby athletes and field hockey athletes were shown to have higher EUR values in the pre-season compared to the off-season most likely due to the greater amount of power training performed by these athletes in the pre-season<sup>14</sup>. In our study, it was interesting that there were no significant differences in EUR between the preparation and competitive training phases in highly trained sprinters whereas McGuigan et al.<sup>14</sup> noted a significant increase in rugby and field hockey athletes. This can most likely be due to sprinters consistently performing plyometric (slow SSC) and power training year-round while only changing the ratio of strength and power training slightly in these training phases<sup>1,2</sup>. This could also be due to the fact that

the indoor track and field competitive phase is for most sprinters still mostly a “starting control” phase to test how the preparation phase went and in what direction should further training aim towards. This could mean that most sprinters still perform more strength-based movements during this phase compared to the second preparation phase (sometimes called the specific preparation phase) after the indoor track season<sup>1</sup>. Lastly, this could also be caused by the greater importance of effective block starting in the indoor season (60-meter sprint) which is more correlated to SJ performance<sup>7,21-23</sup>. Training that increases block start performance will most likely improve SJ performance more than CMJ performance hence the non-significant difference (slight percentage decrease) in EUR.

### Changes in RJ performance

There were no significant changes in RJ performance in this study. This is another very interesting finding since sprinters are known to have very high levels of reactive strength<sup>27</sup>. The RSI has been used in the coaching setting to better assess and quantify plyometric SSC performance<sup>24</sup>. RSI can also be defined as an individual's ability to quickly change from eccentric to concentric contractions<sup>25</sup>. It has been previously shown that sprint-trained athletes exhibit superior reactive strength than non-sprint trained participants<sup>5</sup> and team sport athletes<sup>28</sup> due to the ability to strike the ground with a stiffer leg spring, an enhanced expression of braking force, and possibly an increased utilization of elastic structures<sup>5</sup>. Additionally, reactive strength ability (via RSI) has been shown to differentiate between

sprinting levels<sup>22</sup>. It has also been shown that reactive strength level is dictated by a relative maximal strength level, especially eccentric strength<sup>29</sup>. An explanation why RSI level did not change could be because sprinters already possess such a high RSI level, that to improve significantly is very difficult. Highly trained sprinters must already possess such a high reactive level that only marginal changes can be noticed, especially in such a homogenous group. Secondly, sprinters perform more strength-based movements during the preparation phase and a lower volume of plyometrics<sup>1,2</sup>. The main focus for most sprinters in the indoor season is the 60-meter event where the importance of acceleration is much higher than maximal speed. Since reactive strength mostly correlates with the maximal speed phase of sprinting, this could explain why the increase is not large enough. A possible explanation why no significant changes were noted between training periods is because in highly-trained (stronger) athletes, higher boxes or heights would be needed to produce adequate eccentric stretch loads<sup>29</sup>. Lastly, a correlation was observed between RSI changes and legs lean mass changes ( $r = -.69$ ). Since reactive strength level is associated with increased utilization of elastic structures<sup>5</sup> and overall a greater power output relative to body mass is more favourable in sprinters<sup>27</sup> this could explain why a higher leg lean mass could be disadvantageous in highly trained sprinters.

### **Changes in LS**

There were no significant changes in LS in this study. This is another very interesting finding since sprinters are known to have very high levels of LS<sup>30</sup>. Bret et al.<sup>4</sup> tested CMJ, LS and concentric half squat force in sprinters and concluded that LS correlated the most with the last phase of the 100m sprint. Once again since sprinters focus on the 60-meter event in the indoor season, their training will most likely cause improvements in this distance rather than further events.

Taylor and Beneke<sup>31</sup> studied the stiffness characteristics of the best 100-meter sprinters in the world and concluded that although Usain Bolt achieved the highest running speed, he had lower LS than his competitors. This could mean that higher stiffness values do not necessarily indicate higher performance in sprinting. Additionally, Brughelli and Cronin<sup>32</sup> concluded that an optimal level of stiffness has yet to be discovered and current research is based on correlation analysis and thus should be considered to be speculative at best. This may also explain that for each individual athlete, the optimal stiffness level<sup>33</sup> needs to be obtained through training, but greater values may not necessarily account for better performance. It is most likely that a high level of stiffness is needed for high running speed<sup>27</sup> especially compared to team sport athletes<sup>28</sup>, but once stiffness levels are high enough, it is more likely that there are optimal values for each individual.<sup>31</sup>

### **Practical applications**

Firstly, SJ and CMJ performance (jump height and power output per body mass) can be used as markers of training phase changes and competition readiness in elite sprinters. EUR should be used cautiously to determine training status in elite sprinters since sprint training encompasses plyometric and reactive strength training all year round. Reactive strength levels via RSI and stiffness levels should be assessed individually in each training phase to determine whether sufficient performance in these parameters is satisfactory to optimize competition readiness. LS levels should not be compared to general guidelines but rather individually to the athletes sprint performance and then training

should be adjusted accordingly. Further research should be performed to assess how these values change compared to the outdoor track season.

### **Conclusions**

In conclusion, SJ and CMJ height, flight time and relative peak power output increased in elite sprinters from the preparation phase to the competition phase while RSI, EUR and LS values did not. In highly trained sprinters, changes in RJ parameters and EUR may not be sensitive to changes in training phases since most sprinters maintain a high reactive strength and LS level year-round. SJ and CMJ parameters appear to be the most sensitive to changes between the preparation phase and competitive phase due to specific training changes between these periods.

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### **Ethical Committee approval**

Uniwersytet Medyczny im. Karola Marcinkowskiego w Poznaniu (Poznań University of Medical Sciences), nr 143/15.

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Informed consent was obtained from all subjects involved in the study.

### **Topic**

Sport Performance.

### **Conflicts of interest**

The authors have no conflicts of interest to declare.

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### **Declaration if used ChatGPT**

We didn't used ChatGPT.

### **Author-s contribution**

Conceptualization, M.W, K.K and J.Z.; methodology, M.W,

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