



Dynamic Strength Index in Basketball Players: Age and Position Differences, Seasonal Variation and Association with Sprinting and Change of Direction Performance

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Abstract

The aim of the study was to investigate the differences in bilateral and unilateral dynamic strength index (DSI) between age categories (seniors and juniors), player positions (guards and forwards), its variation during the basketball season, and its association with sprint and change of direction (CoD) performance. Highly trained basketball players ($n=32$) performed bilateral and unilateral countermovement jumps (CMJ), bilateral and unilateral isometric squats, 10-m sprint, and 505 CoD test. DSI was calculated from CMJ and isometric peak force, while 10-m sprint and 505 test were used to calculate the CoD deficit. Two-way factorial analysis showed larger isometric peak force in seniors, and larger bilateral DSI in juniors, while guards had higher DSI values and larger peak force in both metrics compared to forwards. Two-way mixed model ANOVA showed a significant increase in unilateral isometric squat and CMJ peak force force ($g = -0.08$ to -0.64) and increase in bilateral DSI values. Post-hoc analysis showed that isometric squat force significantly increased only in seniors ($g=0.88$), resulting in decreased bilateral DSI values ($g=0.52$), with bilateral and unilateral DSI values increasing in juniors. Similar trends were observed in guards and forwards, with guards exhibiting a more pronounced increase in all variables compared to forwards. Furthermore, correlation analysis for in-season testing showed moderate associations between isometric squat peak force and CoD ability ($r = -0.43$ to -0.54 ; $P < 0.001$), and weak associations between DSI and CoD ability ($r = 0.36$ to 0.39 ; $P < 0.05$), while associations were not significant for sprint performance. The relationships were lower or absent during pre-season testing. Further interventional studies are needed to determine the usefulness of DSI to guide training related decision-making.

Keywords DSI · Performance · Testing · Strength · Power

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Introduction

Basketball is characterized by many high-intensity tasks such as jumping, sprinting, and changes of direction (CoD) [23]. In a recent study, professional basketball players were reported to perform more than 300 CoD maneuvers during a basketball game, indicating the importance of CoD ability for basketball performance [25]. Based on this, evaluation of athletic performance is an indispensable component of basketball training. It provides coaches and athletes with insights into an individual's neuromuscular function, weaknesses and strengths, which serve as a foundation for customized training plan [15]. CoD ability is usually assessed with different tests in the horizontal plane, while acceleration ability is assessed with sprint times on different distances [11]. The score on the CoD task relative to the acceleration

score at the same cumulative distance is referred to as the CoD deficit and is reported as a more direct measure of CoD ability [16]. Given the importance of strength and power qualities for basketball athletes [8, 19, 22], an analytical approach to biomechanical testing can provide detailed insight into the athlete's neuromuscular capacity, providing the opportunity for training optimization. Strength and power capabilities can be represented on the force-time continuum. Therefore, a thorough assessment of strength and power capabilities can be achieved by testing the athlete's qualities under different loading conditions [21].

With this in mind, the dynamic strength index (DSI) has been proposed as a promising method to gain insight into an athlete's strength and power qualities. The DSI is calculated as the ratio between force production during ballistic (e.g., vertical jumps) and isometric/quasi-isometric tasks (e.g., isometric mid-thigh pull (IMTP)) [7, 21, 29]. In other words, the DSI reflects an athlete's dynamic force production capacity relative to their maximal force capacity. It is claimed to be a useful metric to determine individual training needs [13, 21]. Specifically, a DSI < 0.60 has been suggested to be low, indicating that the athlete should focus on ballistic training to generate higher forces during the ballistic task. In contrast, a high DSI (> 0.80) suggests that the athlete should focus on maximal strength training to improve their ceiling for maximal force production [21]. However, the exact benchmarks are highly task dependent; for example, lower DSI values have been reported for unilateral (~0.50–0.60) [3] compared to bilateral (~0.75) assessments [6, 7, 21, 27]. In addition, when using the DSI, it is important to consider the relative effect of each component (force component and ballistic component), as increasing both components simultaneously would result in minimal changes in DSI but would likely have a positive impact on performance. In other words, if both strength and ballistic component increases, athlete has improved his/hers overall physical capacity, while DSI remains unchanged as both components of the equation changed in the same way. Increasing both components of DSI metric would likely have a positive impact on performance given the improvements in an athlete's overall capacity. Additionally, the sporting demands should also be kept at the forefront of a practitioner's mind, when considering which test protocols to utilize. For example, multiple sport-specific movements such as lay-ups, sprints, changing directions, etc., are performed unilaterally in basketball, thus when considering the most appropriate test protocols to administer, it may also make sense to incorporate unilateral test measures [4].

Previous research has shown that the DSI differs between team-sports, with basketball players exhibiting a higher DSI compared to cricket and soccer players [26]. Moreover, female athletes had higher DSI values, mainly due to lower

isometric peak force. Therefore, preliminary evidence suggests that the DSI has the ability to differ between sports and sex. However, to the best of our knowledge, no studies to date have examined the differences between age categories and playing positions within basketball. Moreover, no studies have examined the changes in DSI during the pre-season to in-season in any sport, which would provide meaningful insight about general adaptations regarding the force production at both ends of the strength-power spectrum, during participation in professional sport.

Although the DSI is well documented in the scientific literature, a question about its relationship with athletic performance remains questionable. Most studies have mainly focused on the methodological aspects of the DSI, while its direct relationship with athletic performance has hardly been investigated. Suchomel et al. [24] investigated the relationship between the DSI and other performance characteristics calculated from CMJ and IMTP. The authors reported no association between DSI and CMJ height, a small association with modified reactive strength index ($r=0.24$), and a moderate association ($r=-0.34$) with rate of force development in IMTP. On the other hand, a study on elite surfers reported that the stronger subgroup (based on the IMTP peak force) had lower DSI values and higher CMJ and SJ heights compared to the weaker group [20]. Nevertheless, this result should be interpreted cautiously, while the stronger group tended to have lower DSI values (0.65 vs. 0.76; $P=0.07$), they also had significantly higher CMJ peak force ($P<0.001$). This is consistent with McMahon et al. [13] who reported that the low DSI group had significantly higher IMTP force ($P<0.001$) and concomitant higher CMJ variable scores (including jump height) compared to the high DSI group. While the above studies provide some information on the relationship between DSI and measures of strength and power, the fact that these associations have been established between the ratio (DSI) and the component parts that create it (IMTP and CMJ) must be questioned, given they do not truly represent independent variables. In contrast, assessing the relationship with other independent measures of athletic performance (e.g., linear and CoD speed) would be more informative to practitioners, as it would help determine whether the DSI could serve as an additional proxy measurement in the ongoing monitoring process. With this in mind, and to the best of our knowledge, only one study to date has examined the relationship between DSI and performance on a completely different task [18]. The authors reported that upper body DSI (determined from push-up tasks) had no relationship with sport-specific performance measures in surfers' athletic performance (e.g., time to pop-up). However, both isometric and dynamic strength qualities underlying the DSI were significantly greater in the better performing group

[18]. In summary, the relationships between DSI and independent measures of athletic performance offer an opportunity for further exploration as it can show the direction how to improve sport-specific performance with general physical training (strength or ballistic training), including in basketball.

Consequently, this study had three objectives: (1) to determine differences between DSI scores across age groups (seniors and juniors) and basketball playing positions (guards and forwards), (2) to determine changes in DSI between pre-season and in-season periods of basketball season, and (3) to examine correlations between DSI and sprint and CoD performance. We hypothesized that seniors would have lower DSI values compared to juniors because the former have longer training experience in strength training and therefore should have higher ISQ peak force (ISQ-PF). Moreover, many other factors may support that hypothesis, such as biological maturity differences and weight/muscle mass difference between seniors and juniors. We also assumed that DSI values will be lower in forwards compared to guards as the nature of their game is more contact-based and therefore requires more strength. On the other hand, guards are more explosive and mobile, so we expected them to exhibit a higher peak CMJ force (CMJ-PF).

Methods

Study Design

European basketball season starts with pre-season in October and ends in June and consists of three parts divided by two national team game windows. The study consisted of two separate measurement examinations, the first one during the pre-season in August and the second one during the first national team window (November/December). This was a cross-sectional study conducted in a single visit (total time: ~75 min). Measurements were conducted one day after the off day (i.e., two days after the game). Assessments included bilateral CMJ, unilateral CMJ (SLCMJ), bilateral ISQ, unilateral ISQ, 505 CoD test and 10-m sprint test. First, the participants performed a standardized warm-up, consisting of 10 min of jogging, dynamic stretching, and body-weight strength exercises (squats, all-direction lunges, and planks), followed by 4 familiarization repetitions of CMJs and SLCMJ. For these repetitions, the participants were instructed to gradually increase the effort from ~50% to ~90% of perceived maximal effort. The warm-up was followed by 10 m sprint test, 505 CoD test, jumps and ISQ. For all tests, strong verbal encouragement was performed for each of three repetitions performed, and the average values were taken for

further analyses. There was a 10 min break after the field tests, before jumping and ISQ assessments. The protocol was conducted in accordance with the latest revision of the Declaration of Helsinki. The experimental procedures were reviewed and approved by Slovenian Medical Ethics Committee (approval No. 0120 – 99/2018/5).

Participants

For this study, we recruited a convenience sample of 32 male basketball players (age: 19.6 ± 5.4 years; body height: 195.5 ± 9.6 cm, body mass: 88.3 ± 11.8 kg) from different age categories (juniors: $n=21$; age = 17.6 ± 2.6 years; height = 192.6 ± 7.5 cm; weight = 83.9 ± 8.8 kg; years of experience > 5 years; and seniors: $n=11$; age = 25.7 ± 4.7 years; height: 199.5 ± 9.0 cm; weight = 96.7 ± 12.2 kg; years of experience > 10 years). Participants were part of the youth program, competing in national and international club level. All participants had an average of 10 h of practice (five basketball and two strength sessions) per week, with additional two games per week. None of the participants took part in both age categories. The participants were excluded if they reported any musculoskeletal injuries and pain syndromes within the last year or any other medical conditions that could be exacerbated with the measurement procedure. Participants were informed about the details of protocol and were required to sign an informed consent prior to the beginning of the measurements.

Linear Sprint

The linear sprint was performed over a distance of 10 m using two pairs of timing gates (Brower Timing Systems, Draper, UT, United States). Participants began each sprint 0.3 m behind the starting line to prevent early triggering. The start was from a standing position, and participants were free to choose their front leg, which was kept constant throughout all repetitions. They were instructed to sprint from the start line as fast as possible through both sets of timing gates. Three repetitions were performed with a rest period of 2 min. The time was recorded with an accuracy of 0.001 s.

Change of Direction

CoD was determined with the 505-test using the same timing gates set-up (Brower Timing Systems, Draper, UT, United States). Participants were instructed to sprint to a line 15 m from the start line (the time gates were 10 m from the start line), plant their left or right foot on the line, turn 180°, and sprint 5 m back through the timing gates. Three repetitions were performed for each leg in alternating order, with 2 min

rest between repetitions. To prevent early triggering, participants started 30 cm behind the starting line (as in the sprint test). Additionally, the CoD deficit was calculated as it was previously suggested to provide a more isolated measure of CoD performance [17]. The CoD deficit was calculated by subtracting the time of the 10-m sprint from the time of the 505-test. Therefore, the CoD deficit is the additional time required for an athlete to complete a CoD task compared to a linear acceleration over the same distance [17].

Vertical Jumps

All vertical jumps were performed on a force platform (Type 9229 A, Kistler Instruments, Winterthur, Switzerland). Each jump (bilateral and unilateral) was performed 3 times, with 1 min recovery between trials. The hands were placed on the hips all the times. Participants were instructed to perform explosive countermovement to self-selected depth and to jump as high as possible. For unilateral CMJ, the non-tested leg was slightly flexed at the knee not touching the tested leg. Unilateral jumps were performed in alternating order.

Isometric Squat Testing

The ISQ tests were performed under bilateral and unilateral conditions on the same force platform (Type 9229 A, Kistler Instruments, Winterthur, Switzerland). Position was determined based on the knee angle of 90°, which was checked with a goniometer. Participants had to exert a maximal force against a bar that was so firmly connected to the ground that it could only be lifted to a height corresponding to the respective knee angle (Fig. 1). After two warm-up

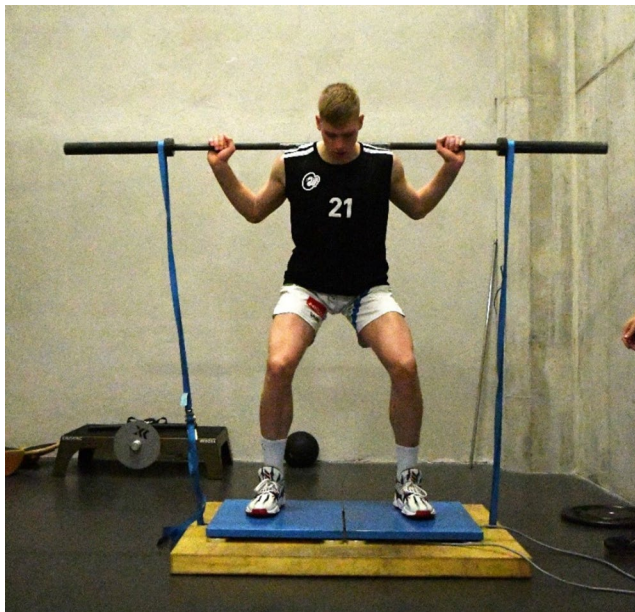


Fig. 1 Set-up for isometric squat testing

repetitions at ~50% and ~75% of maximal effort, three repetitions with maximal exertion were performed with a 2-min rest between repetitions. Before and after each trial, two assistants helped hold and place the bar until the participant was correctly positioned to perform. Unilateral testing was performed in alternating order. The average of three trials for each leg was taken for further analysis.

Data Analysis

Ground reaction force data during jumps and ISQ were sampled with a piezoelectric force platform (Type 9229 A, Kistler Instruments, Winterthur, Switzerland) at 1000 Hz and stored within the MARS Software (Kistler, Winterthur, Switzerland), which enables immediate and reliable calculation of the biomechanical jump variables. Force-time traces were processed with a 5-ms moving average filter. Peak force was taken as the highest force value before the take-off. Jump height was calculated from take-off velocity [14]. For this purpose, the force values were divided by participant's body mass to obtain acceleration values, and then integrated (using trapezoid rule) to obtain velocity. Take-off velocity (TOV) was determined as the velocity reached when the force fell < 10 N. Subsequently, the jump height was calculated as:

$$(\text{Jump height} = \text{TOV}^2 / 2g).$$

In ISQ test, the peak force was taken as the largest mean force in 1-s intervals. Subsequently, DSI variables were calculated from peak force obtained in CMJ and SLCMJ, and peak force obtained during ISQ test as follows:

$$\text{DSI} (\%) = \frac{\text{Peak force in CMJ}}{\text{Peak force in ISQ}}$$

Statistical Analysis

Three general variables in both bilateral and unilateral forms (CMJ peak force, ISQ peak force and DSI) and four performance variables (10 m sprint time, time to complete 505 CoD test and CoD deficit) were taken into statistical analysis. The data are presented as means ± standard deviations. The normality of the data distribution for all variables was verified with Shapiro-Wilk test. Reliability analysis was performed using a two-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals (CI) and coefficient of variation (CV). ICC was interpreted as following: > 0.9 (excellent), 0.9–0.75 (good), 0.75–0.50 (moderate), and < 0.5 (poor) [10]. Absolute reliability was assessed by calculating the CV according to Hopkins (2000) and interpreted as poor (CV > 10%), moderate (CV = 5%–10%), or good (CV < 5%) [2]. We analyzed

the differences according to age group (seniors, juniors), positions (guards, forwards) and time (pre-season, in-season), and explored the relationships among outcome variables. To determine differences between age group (juniors vs. seniors), player positions (big players vs. guards), and interaction between the two factors a 2-way factorial analysis of variance was used. Further post-hoc testing was done independent *t*-tests, and with Mann-Whitney U test for not normally distributed data. A 2-way mixed-model ANOVA was used to determine the influence of time (pre-season vs. in-season), as well as the interaction between time and age, as well as between time and position. Further post-hoc testing was done with paired *t*-tests or Wilcoxon sing-rank test where appropriate. Hedges *g* with 95% confidence intervals was used to determine effect size between groups (age and position) and between pre and in-season results, and was interpreted as following: trivial (<0.2), small ($0.2–0.5$), medium ($0.5–0.8$) and large (>0.8) [12] while the η^2 values were interpreted as: no effect (<0.01), small effect ($0.01–0.039$), a medium effect ($0.06–0.14$) and a large effect (>0.14) [5]. Pearson and Spearman correlation coefficients were used to examine the associations between DSI and performance variables. The associations were interpreted as following: $0.0–0.1$ (no association), $0.1–0.4$ (weak), $0.4–0.6$ (moderate), $0.6–0.8$ (strong) and >0.8 (very strong) [1]. The threshold for statistical significance was set at $\alpha < 0.05$ and all analyses were carried out in SPSS statistical software (version 25.0, CJ278ML, IBM, USA).

Results

The reliability analysis for all outcome variables is shown in Table 1. During pre-season testing, relative reliability was good to excellent for ISQ PF variables ($ICC=0.87–0.91$), moderate to good for CMJ PF variables ($ICC=0.70–0.78$) and good for DSI variables ($ICC=0.84–0.87$). Absolute reliability was either good or moderate for all tests or variables ($CV=3.85\%–5.72\%$). In-season reliability values were similar, with some variables showing slightly better and others slightly worse reliability scores. For sprint and 505-test, absolute reliability was excellent both pre-season ($CV=1.43\%–2.53\%$) and in-season ($CV=1.30\%–2.37\%$), while relative reliability was excellent in-season ($ICC=0.97–0.99$) and good pre-season ($ICC=0.78–0.87$). CoD deficit showed moderate to good relative reliability ($ICC=0.68–0.82$) and poor absolute reliability ($CV=11.63\%–14.34\%$).

Differences Between Age Categories and Player Positions

Data comparing pre-season and in-season results in age categories and player position are presented in Table 2. The 2-way ANOVA indicated a statistically significant effect of age for all ISQ PF variables ($P=0.003–0.019$; $\eta^2=0.180–0.271$), with seniors generally exhibiting larger values (Table 2). There were no statistically significant effects of position ($P=0.099–0.469$), nor age $\times$ position interactions ($P=0.275–0.379$) for ISQ variables. In addition, there were no statistically significant interaction and no statistically significant main effects of age and position for CMJ-PF variables ($P=0.068–0.840$). There was also no age $\times$

Table 1 Reliability measures for pre-season and in-season testing

Outcome	Pre-season				In-season			
	ICC	95% CI	CV	95% CI	ICC	95% CI	CV	95% CI
ISQ PF (N/kg)	0.91	(0.85–0.95)	5.08	(4.34–6.12)	0.92	(0.86–0.95)	4.71	(3.99–5.86)
ISQ-L PF (N/kg)	0.87	(0.79–0.92)	4.02	(3.44–4.84)	0.88	(0.79–0.93)	3.79	(3.20–4.77)
ISQ-R PF (N/kg)	0.90	(0.83–0.94)	3.71	(3.18–4.49)	0.90	(0.83–0.95)	2.81	(2.36–3.51)
CMJ PF (N/kg)	0.78	(0.66–0.87)	3.85	(3.31–4.68)	0.83	(0.71–0.90)	3.52	(3.01–4.34)
CMJ-L PF (N/kg)	0.70	(0.54–0.82)	4.26	(3.64–5.18)	0.78	(0.64–0.87)	4.32	(3.68–5.32)
CMJ-R PF (N/kg)	0.76	(0.63–0.85)	3.60	(3.10–4.37)	0.86	(0.77–0.92)	3.56	(3.03–4.39)
DSI	0.87	(0.79–0.93)	5.72	(4.88–6.94)	0.86	(0.76–0.92)	6.19	(5.25–7.70)
DSI-L	0.84	(0.74–0.90)	5.36	(4.58–6.57)	0.76	(0.61–0.86)	6.13	(5.16–7.73)
DSI-R	0.84	(0.75–0.91)	4.80	(4.12–5.84)	0.83	(0.72–0.91)	4.37	(3.67–5.45)
Sprint (s)	0.87	(0.79–0.92)	1.43	(1.23–1.73)	0.99	(0.98–0.99)	1.30	(1.11–1.60)
505-L (s)	0.78	(0.66–0.87)	2.24	(1.92–2.70)	0.97	(0.94–0.98)	2.37	(2.03–2.91)
505-R (s)	0.81	(0.70–0.88)	2.53	(2.18–3.05)	0.97	(0.95–0.98)	2.22	(1.90–2.72)
CoDD-L	0.77	(0.65–0.86)	12.25	(10.54–14.79)	0.68	(0.51–0.81)	11.81	(9.98–14.5)
CoDD-R	0.82	(0.71–0.89)	14.34	(12.34–17.31)	0.70	(0.53–0.82)	11.63	(9.83–14.28)

CMJ countermovement jump, DSI dynamic strength index, CODD change of direction deficit, SD standard deviation, ISQ isometric squat, L left, R right, PF peak force, ICC intra class correlation coefficient, CV coefficient of variation, CI confidence interval

Table 2 Differences in dynamic strength indexes (and its components) between pre and in season for age and position

Variable	Seniors			Juniors		
	Pre-season	In-season	Hedges g	Pre-season	In-season	Hedges g
ISQ (N/kg)	22.48 ± 2.55	25.04 ± 3.03*#	−0.88 (−1.75, 0.00)	21.34 ± 2.53	21.65 ± 2.65#	−0.12 (−0.72, 0.49)
ISQ-L (N/kg)	16.40 ± 1.47	17.83 ± 1.80*#	−0.84 (−1.71, 0.03)	15.68 ± 1.45	16.49 ± 1.37*#	−0.56 (−1.18, 0.06)
ISQ-R (N/kg)	16.65 ± 1.53	18.09 ± 1.35***	−0.96 (−1.84, −0.07)	16.54 ± 1.48	17.05 ± 1.19#	−0.37 (−0.98, 0.24)
CMJ (N/kg)	23.78 ± 1.64	24.48 ± 1.28	−0.46 (−1.31, 0.39)	24.03 ± 1.94	25.07 ± 2.05*	−0.51 (−1.13, 0.10)
CMJ-L (N/kg)	20.65 ± 1.32	19.85 ± 1.15	−0.15 (−0.99, 0.68)	20.20 ± 1.32	19.99 ± 1.86	−0.05 (−0.66, 0.55)
CMJ-R (N/kg)	19.58 ± 1.64	19.57 ± 1.15	0.01 (−0.83, 0.84)	19.23 ± 1.16	19.96 ± 1.93	−0.45 (−1.06, 0.16)
DSI	1.07 ± 0.12	1.00 ± 0.12#	0.52 (−0.33, 1.37)	1.14 ± 0.13	1.17 ± 0.15#	−0.23 (−0.84, 0.37)
DSI-L	1.21 ± 0.11	1.36 ± 0.32	−0.42 (−1.26, 0.43)	1.28 ± 0.15	1.31 ± 0.33	−0.12 (−0.72, 0.49)
DSI-R	1.20 ± 0.15	1.33 ± 0.32	−0.31 (−1.15, 0.53)	1.22 ± 0.13	1.30 ± 0.32	−0.36 (−0.97, 0.25)
Forwards				Guards		
	Pre-season	In-season	Hedges g	Pre-season	In-season	Hedges g
ISQ (N/kg)	21.19 ± 2.01	22.60 ± 3.32*	−0.51 (−1.24, 0.21)	22.21 ± 2.93	22.96 ± 3.12	−0.24 (−0.92, 0.43)
ISQ-L (N/kg)	15.50 ± 1.24	16.50 ± 1.75*	−0.69 (−1.42, 0.05)	16.30 ± 1.60	17.32 ± 1.56*	−0.62 (−1.31, 0.06)
ISQ-R (N/kg)	16.06 ± 1.14	17.15 ± 1.18*	−0.90 (−1.66, −0.15)	17.03 ± 1.62	17.63 ± 1.43	−0.39 (−1.06, 0.29)
CMJ (N/kg)	23.52 ± 1.76	24.23 ± 1.98	−0.37 (−1.09, 0.35)	24.31 ± 1.85	25.43 ± 1.50**	−0.65 (−1.34, 0.04)
CMJ-L (N/kg)	19.54 ± 1.20	19.30 ± 1.37	0.12 (−0.60, 0.83)	20.17 ± 1.38	20.53 ± 1.70	−0.23 (−0.91, 0.44)
CMJ-R (N/kg)	19.24 ± 1.48	19.05 ± 1.35	−0.04 (−0.76, 0.67)	19.45 ± 1.22	20.33 ± 1.85*	−0.52 (−1.21, 0.16)
DSI	1.12 ± 0.12	1.10 ± 0.19	0.12 (−0.60, 0.83)	1.11 ± 0.14	1.12 ± 0.14	−0.10 (−0.78, 0.57)
DSI-L	1.27 ± 0.12	1.17 ± 0.18*	0.62 (−0.11, 1.35)	1.27 ± 0.17	1.41 ± 0.37	−0.64 (−1.33, 0.05)
DSI-R	1.22 ± 0.11	1.17 ± 0.17	0.37 (−0.35, 1.09)	1.23 ± 0.16	1.40 ± 0.37*	−0.73 (−1.42, −0.03)

CMJ countermovement jump, DSI dynamic strength index, ISQ isometric squat, L left, R right; *significant differences between periods ($P < 0.05$); **significant differences between periods ($P < 0.01$); # significant differences between groups ($P < 0.05$)

position interaction for DSI variables ($P = 0.795\text{--}0.920$). However, juniors generally had statistically significantly larger bilateral DSI ($P = 0.006$; $\eta^2 = 0.24$), but not unilateral DSI ($P = 0.668\text{--}0.696$). In addition, a statistically significant main effect of position was found for both unilateral DSI variants ($P = 0.019$ and 0.023 ; $\eta^2 = 0.18$ and 0.017 for left and right side, respectively), with guards showing higher values. *T*-tests confirmed that during in-season, seniors had statistically significantly higher ISQ-PF ($P < 0.001$; $g = 1.17$), ISQ-L-PF ($P = 0.042$; $g = 0.81$) and ISQ-R-PF ($P = 0.022$; $g = 0.81$), and statistically significantly lower DSI values ($P = 0.004$; $g = 0.70$) compared to juniors. However, these differences were not present during pre-season ($P = 0.131\text{--}0.491$).

Differences in Dynamic Strength Index Between Pre-Season and In-Season

The mixed-model ANOVA showed a statistically significant effect of time (pre-season vs. post-season) for all ISQ peak force variables ($P = 0.001\text{--}0.010$; $\eta^2 = 0.20\text{--}0.48$). While there were no interactions between time and player position ($P = 0.216\text{--}0.952$), ISQ and ISQ-R both showed significant time $\times$ age interactions ($P = 0.005$ and 0.019 , $\eta^2 = 0.23$ and 0.17 , respectively). *T*-test showed that ISQ and ISQ-R improved in seniors ($P < 0.001$; $g = -0.88$

and -0.96 , respectively), but not in juniors ($P = 0.073\text{--}0.492$; $g = -0.12$ and -0.37), while ISQ-L improved both ($P = 0.001\text{--}0.002$; $g = -0.56$ for juniors and $g = -0.84$ for seniors). Regarding the CMJ metrics, the ANOVA indicated that there were no time $\times$ age ($P = 0.113\text{--}0.766$), nor time $\times$ position interactions ($P = 0.079\text{--}0.400$). However, CMJ-PF ($P = 0.001$; $\eta^2 = 0.32$) and CMJ-R peak force ($P = 0.44$; $\eta^2 = 0.13$) improved during in-season. This was also confirmed with *T*-tests for CMJ peak force ($P = 0.010$; $g = -0.5$) and CMJ-R peak force ($P = 0.040$; $g = -0.31$).

There were no main effects of time for any of the DSI variables ($P = 0.121\text{--}0.924$). However, there was a statistically significant age $\times$ time interaction for bilateral DSI ($P = 0.035$; $\eta^2 = 0.14$). This interaction was present because seniors tended to increase their DSI, but not enough to reach statistical significance ($P = 0.051$), while juniors had mostly unchanged DSI ($P = 0.260$). In addition, statistically significant time $\times$ position interactions were observed for both DSI-L and DSI-R ($P = 0.010$ and 0.011 ; $\eta^2 = 0.20$ and 0.19 , respectively). Forwards decreased their DSI-L ($P = 0.023$; $g = 0.62$) and had unchanged DSI-R ($P = 0.211$), albeit the latter also showed an increasing trend (Table 2). On the other hand, guards increased their DSI-R ($P = 0.044$; $g = -0.73$) and tended to increase their DSI-L ($P = 0.050$).

Associations Between Dynamic Strength Index and Performance Metrics

ISQ-PF showed moderate correlations with all CoD variables during in-season ($r = -0.430$ to -0.539), but not during pre-season ($r = -0.09$ to -0.22). Unilateral ISQ-PF on both sides showed negative weak to moderate correlations with all CoD variables except CoD deficit on left side in-season ($r = -0.357$ to -0.481), but not pre-season ($r = -0.05$ to -0.24). CMJ-PF showed significant correlations only with CoD on left side (preseason $r = -0.34$; in-season $r = -0.43$). Regarding DSI, in-season analysis showed weak correlations ($r = 0.36$ to 0.38) with all CoD variables except 505-time on left side, indicating that lower values of DSI corresponds with better CoD ability; however, these relationships were not present in pre-season ($r = 0.01$ to 0.017). Linear sprint time was not associated with ISQ, CMJ or DSI variables (pre-season $r = -0.25$ to 0.15 ; in-season $r = -0.17$ to -0.09). CMJ height variables were moderately associated with some CMJ PF and ISQ PF variables (rightmost 3 columns in Table 3).

Discussion

The aim of the study was to compare DSI values in different age categories and positions among basketball players and to determine their changes during the basketball season, and their associations with CoD and sprint performance. Our results

showed a higher ISQ-PF in seniors and a higher bilateral DSI in juniors. When comparing the data based on player positions, guards exhibited higher values of CMJ and ISQ PF, as well as higher DSI values compared to forwards. Regarding the changes during the basketball season, our results indicate a significant increase in unilateral ISQ and CMJ-PF values and an increase in bilateral DSI values during the basketball season (i.e., from pre-season to in-season testing). In addition, correlation analysis showed moderate associations between ISQ-PF and CoD ability, confirming maximal strength as a likely determinant of CoD. We found only weak associations between DSI and CoD ability.

Previous studies have shown that basketball players have the highest DSI scores among male collegiate team athletes [26], while no study to date has examined the difference in DSI scores between different playing positions in basketball. As hypothesized, juniors had significantly higher DSI scores compared to seniors, but this was mainly due to lower ISQ values. This can almost certainly be explained by the fact that seniors have more experience in strength training, and therefore, they unsurprisingly have significantly higher ISQ-PF. These results show the importance of considering the relative effect of both components (strength and ballistic metric, i.e., CMJ and ISQ PF) when interpreting DSI values, to get better insight about differences between players, training adaptations and inform future training directions.

In line with expected differences between age categories, we also hypothesized the presence of significant differences between playing positions, as the nature of basketball demands

Table 3 Correlation coefficients between dynamic strength indexes (including its components) and sport performance tests pre-season and in-season

	Sprint	505-L	505-R	CoDD-L	CoDD-R	CMJ	CMJ-L	CMJ-R
PRE-SEASON								
ISQ PF	-0.15	-0.22	-0.19	-0.10	-0.09	0.32*	0.25	0.16
ISQ-L PF	-0.13	-0.22	-0.24	-0.11	-0.15	0.24	0.23	0.09
ISQ-R PF	-0.19	-0.10	-0.11	0.04	0.02	0.26	0.24	0.28
CMJ PF	-0.25	-0.42**	-0.26	-0.21	-0.09	0.43**	0.39*	0.37*
CMJ-L PF	-0.02	-0.04	0.073	-0.04	0.097	0.01	0.21	0.27
CMJ-R PF	-0.08	-0.22	-0.18	-0.15	-0.12	0.211	0.37*	0.53**
DSI	0.02	0.02	0.04	0.01	0.02	-0.14	-0.10	-0.02
DSI-L	0.15	0.21	0.29	0.09	0.19	-0.19	-0.18	-0.01
DSI-R	0.07	0.02	0.01	0.17	0.15	-0.18	-0.12	-0.15
IN-SEASON								
ISQ PF	-0.11	-0.54**	-0.48**	-0.43**	-0.45**	0.39*	0.46**	0.32
ISQ-L PF	-0.08	-0.37*	-0.43**	-0.28	-0.48**	0.37*	0.35*	0.19
ISQ-R PF	-0.08	-0.31	-0.33*	-0.24	-0.37*	0.38*	0.47*	0.39*
CMJ PF	-0.17	-0.34*	-0.25	-0.30	-0.16	0.47**	0.48**	0.40*
CMJ-L PF	0.03	-0.04	-0.03	-0.08	-0.09	0.10	0.50**	0.41*
CMJ-R PF	0.09	-0.03	-0.06	-0.12	-0.15	0.19	0.49**	0.51**
DSI	0.01	0.37*	0.36*	0.29	0.39*	-0.16	-0.22	-0.13
DSI-L	-0.17	0.09	0.08	0.15	0.26	-0.15	0.12	0.19
DSI-R	-0.10	0.13	0.08	0.12	0.21	-0.13	-0.15	0.24

PF peak force, CMJ countermovement jump, DSI dynamic strength index, CODD change of direction deficit, ISQ isometric squat, 505 change of direction performance test, PF peak force, L Left, R-right; * $P < 0.05$; ** $P < 0.001$

specific anthropometric characteristics and motor abilities at each position [9]. Although our results were not statistically significant, there were trends indicating higher CMJ-PF in guards, which resulted in higher DSI values, both bilaterally and unilaterally. Interestingly, there were trends showing higher ISQ-PF in guards compared to forwards. Note that our data were normalized to the body mass. When comparing absolute peak force output (data not shown), forwards exhibited higher peak force in all tests. Nevertheless, these results could suggest that forwards could benefit from more intense resistance training to improve their relative strength, as this could lead to better physical performance.

Regarding the changes in DSI and its components between pre-season and in-season periods, significant increases were observed in ISQ-PF in both age categories, whereas CMJ-PF increased only in juniors. Interestingly, when comparing the data between age categories, no significant differences were observed in the pre-season phase, while during the in-season period, ISQ-PF was significantly higher in all variations among seniors. At first glance, this would seem to contradict our hypothesis, as younger athletes with less training experience are traditionally thought to be more sensitive to training adaptations [28]. This observation could be due to several reasons: (a) seniors have more fluctuations in physical condition as they reduce training volume in the off-season, while gradually building the physical condition back up during the pre-season, (b) juniors' preparation period may not be long or intense enough to stimulate training adaptations, (c) differences in training regimes between seniors and juniors lead to different adaptations in each age category, indicating the potential phenomenon of undertraining in younger age categories during the basketball season.

Negative moderate associations between ISQ-PF and CoD ability suggest that higher strength is associated with better CoD ability, which is consistent with previous studies reporting lower limb strength as one of the most important determinants of CoD ability [8]. Furthermore, the positive associations between DSI and CoD ability suggest that lower DSI scores indicate better CoD ability. However, this must be further discussed in terms of DSI components. Since lower DSI values may reflect higher isometric peak force for the same ballistic peak force, the above correlations with DSI are likely due to correlations between CoD and isometric peak force to some degree. On the other hand, a pure relationship between isometric and ballistic peak force may also play a role in influencing CoD capability. Similar results have been reported in the literature in relation to jumping performance [13, 20], indicating that lower DSI values might be better for basketball players' physical performance, especially considering the importance of CoD and jumping power for basketball performance [23, 25]. From a practical perspective, the increase in ISQ-PF during the season, combined with the moderate associations between ISQ-PF

and CoD ability, highlights the importance of strength development for basketball players, especially during the pre-season of the basketball season. However, it has to be noted that if ISQ-PF and CMJ performance both increase, the CoD performance would increase without changes in DSI. Therefore, DSI should not be used in isolation to track training-related progress, but rather to adjust the training content in cases of low or high DSI [21].

Several limitations of the present study should be considered. While knee angle was standardized in the ISQ tests, trunk and ankle position were not. Thus, a more rigorous standardization of the task could have influenced the results. The results might have been different if an isometric mid-thigh pull had been used instead of the ISQ. In addition, experimental design involves only two time points of detection, thus data could vary according to the game results and thus morale of the team. More surveys during the season would be needed for a more reliable assessment. Finally, the sample studied was very homogeneous (i.e., well-trained male basketball players), so the results cannot be generalized to performance metrics (CoD ability) and athletes from other sports.

Practical Application

Our results showed tendencies toward a higher ISQ-PF in seniors and a higher bilateral DSI in juniors, which could be explained by the fact that seniors have more experience in strength training. Compared to the forwards, the guards showed higher DSI values, suggesting that the forwards need more intensive strength training to improve their relative strength. In addition, the increase in peak strength values and the lack of improvement in DSI suggests that due to the ballistic nature of basketball, more maximal strength training is required to optimize the DSI ratio. Our results show correlations between ISQ and DSI with CoD ability, suggesting potential usefulness of these metrics for training-related decisions. Care must be taken when interpreting DSI values, as it is important to consider the relative effect of each component to provide more in-depth information about the individual's physical condition.

Author Contributions JP, FU, CB and NS conceptualized the idea. JP, ZK and FU recruited the subjects and organized the measurement sessions. JP, FU and ZK carried out the measurements and analyzed the data. ZK and NS reviewed the measurement procedures and administration. JP and FU wrote the first draft of the manuscript. ZK, CB and NS worked on finalizing the manuscript.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations and Statements

Competing interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics approval The protocol was conducted in accordance with the latest revision of the Declaration of Helsinki. The experimental procedures were reviewed and approved Slovenian Medical Ethics Committee (approval No. 0120–99/2018/5).

Consent to participate Informed consent was obtained from all individual participants included in the study.

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