

## Neuromuscular control of the knee joint during basketball season in male youth players

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**Background:** Basketball players are among the players with a great risk of anterior cruciate ligament injury due to the high-intensity manoeuvres which have been identified as very common factors preceding this injury. **Objective:** This study aimed to assess differences in leg stiffness and reactive strength throughout a competitive season in youth basketball players and to assess the effect of age and performance level on these variables. **Methods:** The research study involved a total of 48 male basketball players from the age group U14 and U16 played the first and second highest league in Czech Republic. Reactive strength index (RSI) and leg stiffness were measured at the beginning of the season, mid-season, and at the end of the season. Analysis of Variance for repeated measures was used to identify the influence of age, season phases, and levels of performance to monitored variables. **Results:** The results showed significant changes among season phases in RSI ( $F = 4.48, p = .014$ ) and relative leg stiffness ( $F = 7.17, p = .002$ ) in observed players, however significantly higher values at the end of the season than at its beginning were found in RSI only ( $p = .014$ ). Differences between subgroups with different levels of performance were not significant in both categories as well as age differences. **Conclusions:** The current study did not point-out to significant changes among season phases in reactive strength and leg stiffness in adolescent basketball players. The study did not confirm that reactive strength and leg stiffness is gradually improving during adolescence and suggestion that level of performance positively influences reactive strength and leg stiffness was confirmed only in the case of reactive strength.

**Keywords:** overtraining, ACL, leg stiffness, reactive strength index

### Introduction

Anterior cruciate ligament (ACL) injury is considered as the most traumatic and together with ankle injury the most common (3–5% ACL injuries of all the sports-related injuries) injury of lower limb with various of short- and long-term consequences (Gordon, Di Stefano, Denegar, Ragle, & Norman, 2014). Basketball players together with soccer players and handball players are among the players with the great risk of ACL injury (Prodromos, Han, Rogowski, Joyce, & Shi, 2007) due to the high-intensity manoeuvres such as sprinting, rapid changes of direction, landing, jumping, acceleration and deceleration (Abdelkrim, El Fazaa, & El Ati, 2007; Scanlan, Dascombe, & Reaburn, 2011) which has

been identified as a most common situations precluding ACL injury (Boden, Sheehan, Torg, & Hewett, 2010).

Even though basketball is a contact sport, 65–72% of the ACL injuries occurred as a non-contact injury (Krosshaug et al., 2007). Most of the ACL injuries (73%) occur when the player is in possession of the ball while attacking the basket especially during the fastest situation in the game – counterattacks (Krosshaug et al., 2007). The injury incidence is also dependent on the playing position where point guards have been recognized at the highest risk of injury followed by shooting guards (Gordon et al., 2014; Sánchez-Jover & Gómez, 2017).

ACL injury can have serious short- and long-term consequences for patients on their quality of life and activity levels (Dai, Herman, Liu, Garrett, & Yu, 2012). After suffering an ACL injury less than 50% of athletes were able to come back to their sports during the first year. Moreover, almost 25% of athletes suffer ACL injury again in the next two years after the first injury

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(Horsley & Herrington, 2016). ACL injury could also have a negative impact on everyday life such as various problems during walking and issues with everyday activities (Dai et al., 2012). Furthermore, ACL injury has been identified as a significant predictor of early osteoarthritis development (Lohmander, Östenberg, Englund, & Roos, 2004).

According to recent literature, the ACL injury incidence is both chronologically and biologically age-dependent. Shea, Medicine, Pfeiffer, and Apel (2004) identified that the frequency of the ACL injury increases from 13 years of age. This finding corresponds with Rumpf and Cronin (2012) who reported that the group of 13–15 years old athletes are at the highest risk of injury followed by the group of 16–19 years old athletes. Another study (Shea et al., 2004) of youth athletes reported that the highest incidence of ACL injury was in the group of 16–18 years old athletes. Injury incidence was also proven to be related to the level of maturity, especially around the period of peak height velocity (Van Der Sluis, Elferink-Gemser, Brink, & Visscher, 2015).

There has been a significant effort to understand and identify the mechanisms and risk factors of ACL injury over the last two decades, so the prevention programs could be developed (Alentorn-Geli et al., 2009). Current literature proposes several external and internal risk factors including age, muscle strength, muscle stiffness and fatigue (Hughes & Watkins, 2006). Fatigue causes critical changes in neuromuscular control during high-intensity tasks and directly impacts the dynamic stability of the knee (Hughes & Watkins, 2006). In particular, muscle activation, co-activation, kinematics and kinetics, muscle stiffness and reactive strength are inhibited during fatigued conditions (Padua et al., 2006). Therefore, the muscles are able to absorb lower ground reaction forces and the body is forced to use different mechanisms such as tendons and ligaments which are then put under the great load over a brief period of time (Hewett, Ford, & Hoogenboom, 2010). This altered neuromuscular response was also confirmed with basketball players (Fagenbaum & Darling, 2003) when 68–73% of ACL injuries occur in the second half of the game due to the fatigue cumulation (Stergioulas et al., 2007).

Muscle stiffness, leg stiffness in our case, is understood as a stiffening of muscles around a certain joint (torsional joint stiffness) which provides functional stability during ground contact by resisting the movements in tibiofemoral joint (Arampatzis, Bruggemann, Bruggemann, & Klapsing, 2001). Greater stiffness allows players to absorb higher ground forces and thus perform on higher intensity without increasing the risk of passive structures injuries (Hughes & Watkins, 2006).

The level of reactive strength is measured by means of the reactive strength index (RSI). RSI has been developed as a tool to monitor stress on the muscle-tendon complex and is described as the ability to change from an eccentric to concentric muscle contraction (Young, 1995). Low values of RSI are seen to be a reliable measure of poor stretch-shortening cycle (SSC) function for youth athletes (Lloyd, Oliver, Hughes, & Williams, 2009). Furthermore, it is considered as an indicator of potential ACL injury (Flanagan & Harrison, 2006; Raschner et al., 2012).

Basketball season is one of the longest seasons in professional sport (Edwards et al., 2018). Constant physiological stress and high movement demand on the players during the pre-season and competitive season may result in cumulated fatigue which could lead to the presence of higher risk of injury (Taylor, Chapman, Cronin, Newton, & Gill, 2012). Furthermore, accumulated fatigue over a season may also impact player's performance such as technical skills and reaction time (Gabbett, 2008; Royal et al., 2007; Taylor et al., 2012). Thus, the aim of the coaches should be to find the best relationship between training load and recovery to provide players the best conditions for their performance output. This relationship was examined by Caparrós et al. (2016) who concludes that an increased amount of training hours was related to greater team performance, however, it is also associated with a higher risk of injury in basketball players. Therefore, coaches should implement appropriate tools that allow them to monitor training load and fatigue over the season (Manzi et al., 2010). This approach would optimize training adaptations, decrease accumulated fatigue and help athletes to perform at their highest level (Edwards et al., 2018).

There is also currently no youth data exploring the influence of accumulated fatigue throughout a competitive season on injury risk mechanisms in youth basketball players. For these reasons, the aims of this study were to assess differences in leg stiffness and reactive strength throughout a competitive season in youth basketball players and to identify the influence of age, season phases, and level of performance to monitored variables.

## Methods

### Participants

The research study involved a total of 48 male basketball players from the competitive age group U14 ( $n = 24$ , age  $13.6 \pm 0.6$  years, body mass  $59.0 \pm 7.1$  kg, body height  $172.2 \pm 8.1$  cm) and U16 ( $n = 24$ ; age  $15.8 \pm 0.6$  years, body mass  $72.7 \pm 9.5$  kg, body height  $179.3 \pm 6.6$  cm) categories from the Czech Republic.

Twenty-six players (twelve from younger and fourteen from older category) played second highest national league (non-elite players) and took part in four team sessions (six hours per week) and one conditioning session (one hour per week). Twenty-two players (twelve from younger and ten from older category) played the highest national league (elite players) in 2016/2017 took part in four team sessions (six hours per week), one conditioning session (one hour per week), and one individual training session per week (one hour per week).

Table 1 shows the record of the training load of players during both halves of the season. Elite and non-elite U14 team completed three sessions 90 minutes long per week and the same number of matches. Elite U16 team completed four sessions 90 minutes long and two sessions 60 minutes long. Non-elite level U16 team completed three sessions 90 minutes long and two sessions 60 minutes long. Both played the same number of matches (Table 1) during the season. U14 and U16 teams of the elite level spent 18.08% and 23.98% of workload by matches during the whole season, 16.55% and 23.30% by conditioning (strength, speed & agility, repeated sprint ability, game-based conditioning), and 21.47% and 18.37% by recovery and warm-up. U14 and U16 teams of the non-elite level spent 18.19% and 26.47% of workload by matches during the whole season, 14.41% and 22.73% by conditioning (strength, speed & agility, repeated sprint ability, game-based conditioning), and 21.92% and 17.55% by recovery and warm-up.

The study was approved by the local ethics committee. Prior to data collection, the players and their parents were informed about the purpose of the measurements. Written consent in accordance with the Declaration of Helsinki regarding the use of human subjects was then obtained from the participants' parents.

### Measurement procedures

All participants were tested three times throughout the competitive season 2016/2017. The first testing session was two matches into the competitive season (2<sup>nd</sup> week of October), the second was in mid-season (4<sup>th</sup> week of January) and the third at the end of the season (one week after last match, (3<sup>rd</sup> week of May). There are two matches (Saturday and Sunday) every two weeks in basketball competitive season. Thus, all tests were performed on Mondays after a free weekend.

### Reactive strength index

RSI was determined during a 5 maximum hop test which was performed on a mobile contact mat (FITRO Jumper, Fitronic, Bratislava, Slovakia). Participants were instructed to maximize jump height and minimize ground contact time (Dalleau, Belli, Vialoe, Lacour, & Bourdin, 2004). The RSI variable was calculated using the equation of Flanagan and Comyns (2008) as  $RSI = \text{jump height (mm)} / \text{contact time (ms)}$ . The first hop served as counter-movement jump (impetus) and was consequently excluded from analysis with the 4 remaining hops averaged for analysis of RSI. Players performed three trials with a 2-minute rest between

Table 1

*The workload expressed by total time (in minutes) of measured players during the season*

	First half of season (17 weeks)				Second half of season (18 weeks)			
	U14		U16		U14		U16	
	Non-elite	Elite	Non-elite	Elite	Non-elite	Elite	Non-elite	Elite
Matches	1120	1120	2200	2200	1120	1120	2400	2400
Regeneration	0	0	0	510	0	0	0	540
Warm up	1020	1020	1190	1445	1080	1080	1200	1530
Complete conditioning	825	950	1900	2160	950	1100	2050	2310
Strength	325	350	750	800	350	380	830	900
Speed and agility	500	600	300	310	600	680	350	390
RSA	0	0	50	100	0	0	70	100
GBC	0	0	800	950	0	40	800	920
Skills	1500	1450	1350	1550	1800	1650	1530	1630
Game	700	800	1950	1700	850	930	2150	1860
General	550	470	0	0	200	100	0	0
Active recovery	300	250	300	250	300	310	360	300
Total	6015	6060	8890	9815	6300	6290	9690	10570

Note. RSA = repeated sprint ability training; GBC = game-based conditioning; general = non-specific training.

trials. The best value of RSI from the three trials was used in further analysis.

#### *Leg stiffness*

To determine leg stiffness, all players performed three measured sets of 20 sub-maximal bilateral hopping protocol. For each trial, participants were instructed to perform 20 consecutive hops on a mobile 2-axis force platform PS-2142 (Pasco, Roseville, CA, USA) at a frequency of 2.5 Hz to reflect the typical behaviour of a spring model (Lloyd et al., 2009). The frequency of hopping was controlled using a mechanical metronome (Wittner, Isny, Germany). Participants were instructed to: a) keep hands on the hips all the time to avoid upper body interference, b) jump and land on the same spot, c) land with legs fully extended and to look forward at a fixed position to aid balance. Of the three performed sets, the set in which the frequency of jumps best corresponded with the frequency determined by a metronome was selected. For subsequent analysis, the ten consecutive jumps that were closest to the determined frequency of hopping were used (Lloyd et al., 2009). Further, relative leg stiffness (RLS) was calculated by dividing absolute leg stiffness by body mass and limb length (Dalleau et al., 2004) as this method has been shown to be valid and reliable in youth (De Ste Croix, Hughes, Lloyd, Oliver, & Read, 2017; Lloyd et al., 2009).

Twenty minutes of habitual non-specific warm-up was performed by players before the measurement. The warm-up routine was performed under the researcher's supervision.

#### **Statistical analysis**

Statistical analysis was performed using the data analysis software Statistica (Version 13; TIBCO Software, Palo Alto, CA, USA). Data were expressed as mean  $\pm$  SD. The prerequisites of normality and homogeneity of variance were verified using the Shapiro-Wilks and Levene's tests, respectively. Analysis of variance for repeated measures was used to determine changes among season phases of measured variables RSI and leg stiffness. LSD post hoc test was calculated and the effect size was expressed by  $\omega^2$  coefficient according to Tolson (1980), where  $\omega^2 \geq .14$  is large effect,  $.06 \geq \omega^2 > .14$  medium effect, and  $.01 \leq \omega^2 < .06$  is small effect. The statistical significances of all parts of the analysis were determined at an alpha level of .05.

#### **Results**

The measured RSI values at the beginning, mid-season, and at the end of the season in subjects of different

age and performance level are reported in Table 2. The results for leg stiffness are reported in Table 3.

The results of analysis of variance for repeated measures showed significant differences among three (beginning, mid-season, and end of season) measures of average RSI ( $F = 4.48$ ,  $p = .014$ ,  $\omega^2 = .15$ ) and age differences ( $F = 13.36$ ,  $p = .001$ ,  $\omega^2 = .23$ ), but level differences were not significant in both categories ( $F = 0.82$ ,  $p = .360$ ,  $\omega^2 = .04$ ). Post hoc test showed significant differences between the beginning of season and the end of season measurement in category U16 for non-elite ( $p = .040$ ) and elite ( $p = 0.019$ ), age differences in the beginning of season (elite  $p = .040$  and non-elite  $p = .040$ ), mid-season (elite  $p = .037$  and non-elite  $p = .039$ ), and at the end of season (elite  $p = .001$  and non-elite  $p = .020$ ) measurement. We did not find any significant differences among midseason and other season phases.

We found significant differences among the three (beginning, mid-season, and end of the season) measures of average RLS ( $F = 7.17$ ,  $p = .002$ ,  $\omega^2 = .16$ ), but not for the level of performance ( $F = 1.35$ ,  $p = .270$ ,  $\omega^2 = .05$ ) or age differences ( $F = 1.71$ ,  $p = .190$ ,  $\omega^2 = .05$ ). Post hoc test detected significant differences between the beginning of season and end of the season of elite U16 players ( $p = .020$ ) and non-elite U16 players ( $p = .040$ ). We did not find any significant differences among midseason and other season phases.

Table 2

*Mean  $\pm$  SD of reactive strength index (in mm/ms)*

	Beginning of season	Mid-season	End of season
All participants	1.33 $\pm$ 0.27	1.33 $\pm$ 0.26	1.44 $\pm$ 0.33
U14 elite	1.23 $\pm$ 0.22	1.20 $\pm$ 0.19	1.23 $\pm$ 0.17
U14 non-elite	1.26 $\pm$ 0.30	1.23 $\pm$ 0.17	1.34 $\pm$ 0.29
U16 elite	1.47 $\pm$ 0.33	1.48 $\pm$ 0.25	1.61 $\pm$ 0.28
U16 non-elite	1.40 $\pm$ 0.21	1.41 $\pm$ 0.32	1.53 $\pm$ 0.28

Table 3

*Mean  $\pm$  SD of relative leg stiffness*

	Beginning of season	Mid-season	End of season
All participants	38.54 $\pm$ 6.61	34.58 $\pm$ 5.56	35.94 $\pm$ 6.85
U14 elite	37.49 $\pm$ 4.86	33.97 $\pm$ 5.79	35.78 $\pm$ 4.52
U14 non-elite	40.70 $\pm$ 9.85	36.65 $\pm$ 1.03	38.04 $\pm$ 9.19
U16 elite	37.97 $\pm$ 4.99	34.95 $\pm$ 6.48	34.28 $\pm$ 6.20
U16 non-elite	38.16 $\pm$ 6.77	33.87 $\pm$ 1.43	36.52 $\pm$ 7.83



## Discussion

The main finding of the study is that there were significant differences among the three measurements (beginning, mid-season, and end of the season) in the case of RSI and RLS in observed basketball players. However, post hoc analysis revealed significant differences only in the case of RSI between the beginning of season and the end of season measurement. Significantly higher values were found at the end of the season in both players from the competitive category U16 and category U14 and in both subgroups of non-elite performance level and subgroup of elite level. Further, age differences were confirmed only in the case of RSI in all three measurements in both the subgroup of elite performance level and the subgroup of non-elite performance level.

### Reactive strength index

The level of reactive strength is measured by means of the RSI. RSI has been developed as a tool to monitor stress on the muscle-tendon complex and is described as the ability to transition from eccentric to concentric muscle action (Young, 1995). Furthermore, it is considered as an indicator of potential ACL injury (Raschner et al., 2012). Changes in reactive strength are also affected by fatigue (Oliver, Lloyd, & Whitney, 2015). Low values of reactive strength seem to be a reliable measure of poor SSC function for athletes (Lloyd et al., 2009).

In our study, we found a significantly higher RSI at the end of the season than at its beginning. This result does not indicate the accumulation of fatigue during the season and suggests that the ability to change eccentric muscular action to concentric in SSC was not compromised in the players (Lloyd, et al., 2009). Considering that jumping and landing are important aspects of basketball-specific fitness, these findings are also positive from the game performance perspective, specifically in terms of the quality of repeated jumping and landing actions.

Further, our results did not confirm significant interaction between level of performance and influence of fatigue during the season in both U14 and U16 group. These findings are not in continuity with the opinion that the value of RSI grows with the level of performance (Flanagan & Comyns, 2008). On the contrary, our results support findings of some previous studies which point to gradually improving reactive strength during adolescence due to the development of motor control (Lloyd et al., 2012). This opinion was also supported by significantly higher values for the U16 group compared to the U14 group in the current study.

### Leg stiffness

Leg stiffness plays a key role in dynamic knee joint stability, as stiffness represents an ability of the joint's resistance to load through a range of motion (Needle et al., 2014). Reduced RLS values may indicate fatigue-induced changes in muscle-tendon complex activation and consequently, reduced the ability to produce muscle strength and resist against deformities that originated during SSC (Padua et al., 2006). Information about lower limb stiffness is particularly important in terms of risk of injury resulting from a jump or change of direction impact (Oliver & Smith, 2010).

We found significant differences in RLS among three measurements throughout the competitive season in observed youth basketball players. However, post-hoc analysis did not reveal significant differences between measurements in both competitive age groups and performance level subgroups. Our results did not support findings of previous research which indicated that during the season due to the fatigue of the players their muscle stiffness and reactive strength and thus their activation, kinetics and kinematics decrease (Padua et al., 2006). The mean values of RLS tended to decrease during the season and then grow again at the end of the season, however, did not reach values at the beginning of the season. Thus, it can be assumed that the ability of the muscles to resist movement within the tibiofemoral joint (tibiofemoral shear movements), which prevents ACL from being under strain (Hughes & Watkins, 2006) tended to decrease during the season, but not at its end. In this context, we could hypothesise that from the performance perspective, decreased leg stiffness could negatively influence jump and speed performance at the end of the first half of the season (Brughelli & Cronin, 2008). Different results in RLS compared to RSI could be explained by the finding that the RSI demonstrates a limited amount of common variance with leg stiffness (Lloyd, Oliver, Hughes, & Williams, 2012).

As in the case of RSI, our results did not confirm a significant difference between elite and non-elite players in both U14 and U16 group and thus did not support finding that the values of stiffness grow with the level of physical performance (Hobara et al., 2008). As regards age differences, significant differences were not found within the age categories of basketball players, nor in the comparison of elite and non-elite subgroups.

In contrast to RSI, the finding in RLS does not support the suggestion of that leg stiffness is age-specific and is gradually improving during adolescence because athletes rely more on feed-forward mechanisms as they mature (Laffaye, Choukou, Benguigui, & Padulo, 2016; Priestley, 2012). These suggestions are in contrast with the study on female soccer players from competitive

age group U14, U16, and U17 (De Ste Croix et al., 2017), in which fatigue-related changes post simulated soccer in leg stiffness were age and maturational stage-specific.

## Conclusions

The current study demonstrates significant changes in reactive strength of both age categories, and in group U16 changes in leg stiffness during the season in adolescent basketball players. Nevertheless, negative changes due to cumulative fatigue were not confirmed. Our study also did not confirm the suggestion that level of performance positively influences the effect of performance level on reactive strength and leg stiffness and only partly (in the case of reactive strength) confirmed statement that reactive strength and leg stiffness is gradually improving during adolescence.

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## Conflict of interest

There were no conflicts of interest.

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