Journal of Human Kinetics volume 77/2021, 169-179 DOI: 10.2478/hukin-2021-0019
Section III – Sports Training

sciendo

Variation in Lower Limb Power and Three Point Shot Performance Following Repeated Sprints: One vs. Five Changes of Direction in Male Basketball Players

by
Seifeddine Brini[1,2], *Anne Delextrat*[3], *Anissa Bouassida*[1]

Repeated sprint ability (RSA) with five changes of direction was well admitted to replicate real basketball game situations, but the additional changes of direction may affect some fundamental skills and performances in basketball. The aim of this study was to investigate the effects of RSA with one vs. five changes of direction ($IRSA_{5COD}$) on squat jump (SJ), five jump test (FJT) and three point shot (3PS) performances in male basketball players. Sixteen participants (23.4 ± 2.3 years; 1.86 ± 0.10 m; 77.8 ± 7.7 kg) randomly performed eight testing sessions consisting of either RSA (10 repetitions of (15 m + 15 m)) or $IRSA_{5COD}$ (10 repetitions of (5 m + 5 m + 5 m + 5 m + 5 m + 5 m)) performed alone or immediately followed by the SJ, FJT or 3PS. The heart rate (HR) and ratings of perceived exertion (RPE) were continuously recorded, while blood lactate concentration was measured post-tests. Differences between RSA and $IRSA_{5COD}$ were evaluated by a Student t-test for paired samples, while analyses of variance (ANOVAs) with repeated measures assessed differences in SJ, FJT and 3PS performance between baseline, post-RSA and post-$IRSA_{5COD}$. A significantly poorer FJT performance post-RSA was shown compared to baseline (7.47 ± 0.47 vs.7.54 ± 0.47 m, p = 0.01) and post-$IRSA_{5COD}$ (7.47 ± 0.47 vs. 7.56 ± 0.49%, p = 0.048). Significantly lower 3PS accuracy was also observed post-$IRSA_{5COD}$ compared to baseline (41.3 ± 3.1 vs.53.1 ± 2.8%, p = 0.003) and post-RSA (41.3 ± 3.1 vs. 48.1 ± 3.7%, p = 0.033). These results suggest that jump performance required for crucial actions such as lay-ups is negatively affected by longer sprints (15-m) with few changes of direction, while 3PS accuracy is impaired by shorter sprints with many changes of direction. These situations should be replicated when training these particular abilities to optimize training adaptations.

Key words: *fatigue, jumping, coordination, team sport, neuromuscular, performance.*

Introduction

The capacity to repeat sprints (RSA) with limited recovery is undoubtedly a crucial determinant of basketball performance (Caprino et al., 2012; Padulo et al., 2015b; Włodarczyk et al., 2020). To assess this ability, it is important that tests replicate the movement patterns experienced by players on the court. Traditionally, RSA tests were designed as shuttle-run tests, including one (10 x (15 m +15 m); Caprino et al., 2012) or two 180° changes in direction (CODs) (10 x (10 m + 10 m + 10 m); Padulo et al., 2015b).While these tests are relevant to some basketball actions, such as repetitive transitions from offense to defense, shorter sprints are frequently repeated during matches in various directions, for example during set plays. These successions of sprinting actions are better reflected in the newly designed multidirectional RSA tests, consisting of six 5-m sprints with 90º CODs (Padulo et al., 2016; Zagatto et al., 2017).

[1] - *Research Unit, Sportive Performance and Physical Rehabilitation, High Institute of Sports and Physical Education of Kef, University of Jendouba, Kef, Tunisia.*
[2] - *Faculty of Sciences of Bizerte, University of Carthage, 7021 Zarzouna, Bizerte, Tunisia.*
[3] - *Department of Sport and Health Sciences and Social Work, Oxford Brookes University, UK.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 77/2021 in January 2021.

During a basketball match, repeated sprint sequences are frequently followed by other actions such as vertical jumps (jump shots, lay-ups, blocks) that are crucial for its final outcome (Caprino et al., 2012). In view of the limited recovery allowed between actions in basketball (Ben Abdelkrim et al., 2010; Scanlan et al., 2012), several authors have investigated the acute effects of repeated sprints on vertical jump performance. Balsalobre-Fernandez et al. (2014) showed that a repeated sprint sequence (6 x 35 m, separated by 10 s of recovery) induced a 7.7% reduction in countermovement jump (CMJ) performance in male professional players, with a significant correlation between the fatigue index calculated from the RSA test and the decrease in CMJ height. In contrast with these findings, Nikolaidis et al. (2016) found a significant improvement in CMJ performance (+1.8 cm) following ten 15-m sprints performed either in a straight line or in shuttles (15 m + 15 m) in male junior players, with no difference between these two RSA designs. These contrasting findings could be due to the different types of RSA tests used or the populations tested, and highlight the needs to further investigate these aspects with more relevant RSA tests, especially in adult players.

Shooting accuracy is another crucial aspect of basketball performance, with three-point shooting (3PS) efficiency highly associated to its final outcome (Gomez et al., 2016). In particular, it has been shown that compared to losing teams, winning teams are usually characterized by a greater average number of 3PS in the last 5 min of a game (Gomez et al., 2016). Since players are likely to be tired under these conditions, it is essential to investigate the effects of basketball-specific fatigue on 3PS accuracy. A previous study (Ardigo et al., 2018) found that a repeated 15- m shuttle test eliciting 80% of the players' maximal heart rate (HR) induced a significant decrease in 3PS accuracy (-28%) compared to baseline values in male junior players. Similar results were found on 3PS in adult players (Ardigo et al., 2018) and on free-throw shot accuracy (Padulo et al., 2015a). On the other hand, a shorter RSA test performed at a similar intensity did not result in any change in the kinematics of 3PS or ball release variables known to affect accuracy (Slawinski et al., 2018) in junior male players. The main limitation of these studies is that the RSA tests were set to represent the average intensity of a basketball match, while in reality 3PS are often taken after more intense sequences of actions. The mechanisms of fatigue during RSA tests are multifactorial, and include changes in energy supply, metabolic accumulation and neuromuscular factors; for example, many authors observe an increase in blood lactate following RSA (e.g., Caprino et al., 2012).

Within this context, the aim of the present study was to compare the effects of two RSA protocols based on one COD vs. five CODs on lower limb power and 3PS accuracy in male senior basketball players. We hypothesized that the repeated sprint sequence with five CODs would negatively affect lower limb power and shooting accuracy compared to the repeated sprints with one COD only.

Methods

Participants

Sixteen male basketball players (age: 22.6 ± 2.8 years; body height: 1.86 ± 0.10 m; body mass: 77.8 ± 7.7 kg; maximal aerobic power (VO_{2max}) 51.0 ± 2.7 $ml \cdot min^{-1} \cdot kg^{-1}$) from the Tunisian second division (training 4-5 days/week, > 60 min/day, training experience 11.8 ± 3.9 years) volunteered for this study. An *a priori* power calculation showed a required minimal sample size of 12 for a power of 0.80 (G*Power v. 3.0). They were all guards (playing positions 1, 2 and 3), with an equal proportion of the three guard positions. The study was conducted two weeks after the end of the competitive season and was approved by a local research ethics committee in accordance with the Declaration of Helsinki. All participants provided written informed consent to participate in the study.

Design and procedures

Each participant visited the laboratory on ten occasions (Figure 1). The first visit was for anthropometric and baseline measurements, as well as familiarization with the protocol, while the second visit was dedicated to maximal aerobic power assessment (VO_{2max}, 20 m shuttle run test (Leger and Lambert, 1982)). For the 3rd to the 10th visits, participants randomly performed a sequence of tests including either RSA or $IRSA_{5COD}$, performed on their own or immediately followed by either a SJ, a FJT or a 3PS.

The order of these tests was randomized

and visits were separated by at least 48 h of rest. The repeated sprint tests were performed on the basketball court, very close to the three-point line to ensure a limited time between the end of the last sprint and the shots (similarly, the jumps were performed very close to the finish line of the sprints). The heart rate (HR) and ratings of perceived exertion (RPE) (Foster et al., 2001) were recorded throughout the repeated sprint tests, while blood lactate concentration was measured from a finger prick 3 min following these tests performed on their own.

On every testing day, players came to the gymnasium at 8:00 AM and had the same breakfast (coffee with semi-skimmed milk, a healthy snack (Moulin d'Or, 60 g), and a yogurt). After breakfast, no food intake was allowed until after testing.

Measures

Body height and body mass were assessed with a portable stadiometer (Seca, Maresten, UK) and an electronic scale (Pharo 200), respectively. VO_{2max} was estimated after performing a 20-m shuttle running test according to procedures previously described (Leger and Lambert, 1982).

The one COD test (RSA) consisted of ten 30-m shuttle sprints (15 m + 15 m) each with a single COD of 180°, interspersed with 30 s of passive recovery (Caprino et al., 2012). Participants sprinted in a straight line for 15 m, touched a line on the floor with one foot and then following a 180° COD, returned to the start line as fast as possible. The five COD test (intense repeated sprint or $IRSA_{5COD}$) consisted of 10 x 30-m shuttle sprints separated by 30 s of passive recovery, with 3 changes of direction of 180° and 2 changes of direction of 90°, following a "T" letter shaped circuit (Zagatto et al., 2017). From the starting line, participants ran as fast as possible in a straight line for 5 m, touched the second line with one foot, turned back and ran back to the starting line, turned right, ran for 5 m and touched the third line with one foot, turned back and ran back to the starting line, turned right, ran for 5 m and touched the fourth line with one foot and turned back again before running back to the starting/finish line. To balance the physical effort of the legs during the COD for both tests, participants were required to alternate the legs used to change direction. For both tests (RSA and $IRSA_{5COD}$), time was recorded by photocells (Brower timing system, Salt Lake City, UT, USA; accuracy of 0.01 s) and the best time (BT, s) and total time (TT, s) to perform the test were recorded. Subsequently, a fatigue index (FI) was calculated using the Fitzsimons formula ($100 \times (TT/(BT \times 10)) - 100$), (Fitzsimons et al., 1993). Each test was repeated four times (alone, and before a SJ, a FJT and a 3PS), and since no significant difference between repetitions was identified ($p > 0.05$), the average value of BT, TT and FI were then calculated.

The three point shot (3PS) test has been used in a recent study (Ardigo et al., 2018) and consisted of 10 consecutive 3PS (2 consecutive shots from the two corners, the two wings and the point guard positions) with an official basketball (Molten gf7, 600 gr). The percentage of successful shots was calculated: (number scored / 10) x 100 (Ardigo et al., 2018).

Vertical jump performance was assessed using a portable Opto jump mat (Microgate SARL, Italy). Players performed squat jumps (SJ), (Horita et al., 2003), keeping their hands fixed on the hips and were instructed to jump as high as possible. The best of three trials was recorded.

The FJT test is commonly used in basketball to estimate the explosive power of the lower limbs (Hambli et al., 2010). It consisted of a series of 5 jump strides with alternate legs, starting and finishing with both feet together. Three trials were performed, and the best was recorded for further analysis.

During RSA and $IRSA_{5COD}$, the HR was continuously recorded using a heart rate monitor (Polar Electory, Kempte, Finland). At the end of each testing session, each player reported their RPE on the Borg's CR-10 scale (Foster et al., 2001). They were all familiar with this method, which was regularly used during the season. Blood lactate concentration (mmol·L^{-1}) was determined from capillary blood samples obtained from the ear lobe 3 min after the end of the RSA and $IRSA_{5COD}$ tests performed alone, as reported in the literature (Hirvonen et al., 1987). Blood samples were immediately analyzed (Arkray Lactate Pro LT-1710 Kyoto, Japan).

Statistical analyses were performed using SPSS version 24 for Windows (SPSS Inc, Chicago, Il, USA). Values are presented as mean ± SD. The normality of data sets was checked using the

Shapiro-Wilk test. Differences between performance, RPE and blood lactate concentration in RSA and $IRSA_{5COD}$ tests were assessed by paired t-tests. In addition, analyses of variance (ANOVAs) with repeated measures, followed by Bonferroni post-hoc tests were undertaken to assess the differences in physical performance and blood variables between baseline, RSA and $IRSA_{5COD}$. Effect sizes were calculated using Cohen *d* and partial eta squared (ηP^2) and interpreted as small (>0.1), medium (>0.3), and large (>0.5) (Cohen 1977). 95% confidence interval limits for the differences tested (95% CI) were also shown. The reliability of the two repeated sprint tests was assessed by the Intraclass Correlation Coefficient (ICC). Finally the associations between VO_{2max}, blood lactate values, RSA performance and the percentage change in performance in the 3PS, SJ and FJT and blood variables ((post-pre)/pre x100) were checked by a Pearson correlation coefficient. For all these analyses, a *p* value inferior to 0.05 was considered statistically significant.

Results

The reliability analysis indicated ICC values of 0.966 and 0.949, respectively for BT and TT. Significantly faster sprint times were achieved during RSA compared to $IRSA_{5COD}$ (TT: -0.3%, t : 8.716, d = 0.22, p = 0.0001, 95% CI : 0.16-0.26 s ; BT : -0.17%, t : 2.756, d = 0.1, p = 0.015, 95% CI : 0.020-0.005 s, Table 1). However, no significant difference was observed for the FI (p = 0.140) and all mean physiological variables measured during these tests (HR, RPE, blood lactate concentration: p = 0.523, Table 1).

Significant differences were also shown for the FJT (F: 3.660, p = 0.038, ηP^2: 0.196, Figure 2b), with a significantly poorer performance post-RSA compared to baseline (7.47 ± 0.47 *vs.* 7.54 ± 0.47 m, -1.1%, d : 0.15, 95%CI : 0.01-0.14 m, p = 0.01) and compared to post-$IRSA_{5COD}$ (7.47 ± 0.47 *vs.* 7.56 ± 0.49%, -1.2%, d : 0.19, 95%CI : 0.001-0.18 m, p = 0.048).

No significant difference was observed for the SJ between baseline, post-RSA and post-$IRSA_{5COD}$ tests (Figure 2c). Significant differences were also found in 3PS performance (F: 7.541, p = 0.002, ηP^2: 0.335, Figure 2a), with a significantly lower 3PS percentage post-$IRSA_{5COD}$ compared to baseline (41.3 ± 3.1 *vs.* 53.1 ± 2.8%, -22.3%, d : 3.98, 95%CI : 4.0-19.7%, p = 0.003) and post-RSA (41.3 ± 3.1 *vs.* 48.1 ± 3.7%, -9.4%, d : 1.50, 95%CI : 0.5-13.2%, p = 0.033).

Significant correlations were shown between VO_{2max} and TT during RSA (r = -0.637, p = 0.008) and $IRSA_{5COD}$ (r = -0.657, p = 0.006), and BT during RSA (r = -0.614, p = 0.011) and $IRSA_{5COD}$ (r = -0.655, p = 0.003). In addition TT during RSA and $IRSA_{5COD}$ was significantly associated (r = 0.994, p = 0.008). Performance changes following the two repeated sprint tests were significantly correlated for the 3PS (r = 0.775, p = 0.0001) and FJT (r = 0.703, p = 0.002), but not for the SJ.

Discussion

The main findings of the present study showed that sprint times during RSA were significantly faster than $IRSA_{5COD}$, with no significant difference in physiological variables between these tests. In addition, the $IRSA_{5COD}$ test led to a poorer 3PS accuracy compared to baseline and RSA. However, FJT performance was significantly lower following RSA compared to $IRSA_{5COD}$ and baseline. Therefore, our hypothesis was partially accepted.

The $IRSA_{5COD}$ test performed in the present study is a relatively new test characterized by a good test-retest reliability for sprint times in the literature (r ranging from 0.67-0.85 amongst performance variables; Zagatto et al., 2017), and excellent test-retest reliability in the present study. Our results show that sprint times achieved by our players in this test were better than those previously reported (5.90 *vs.* 8.14 and 9.91 s for BT and 59.6 *vs.* 84.0 and 105.1 s in our study and the studies of Zagatto et al. (2017) and Padulo et al. (2016), respectively). These differences could be explained by the fact that our players were male adults, compared to junior players of mixed genders in the two above-mentioned studies. In addition, they were very familiar with the $IRSA_{5COD}$ test and often performed it as part of their training. Our results also showed that sprint times were significantly better in the RSA compared to the $IRSA_{5COD}$ test, which is in accordance with the literature (Padulo et al., 2016).

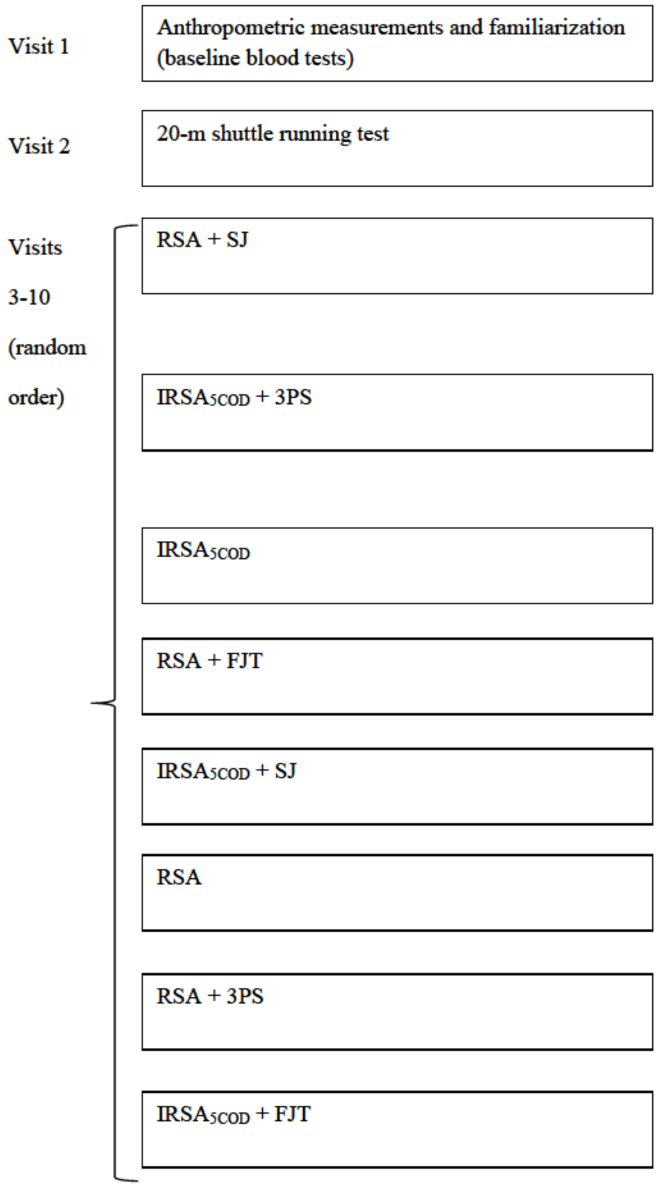

Figure 1

Experimental protocol (example for one participant).

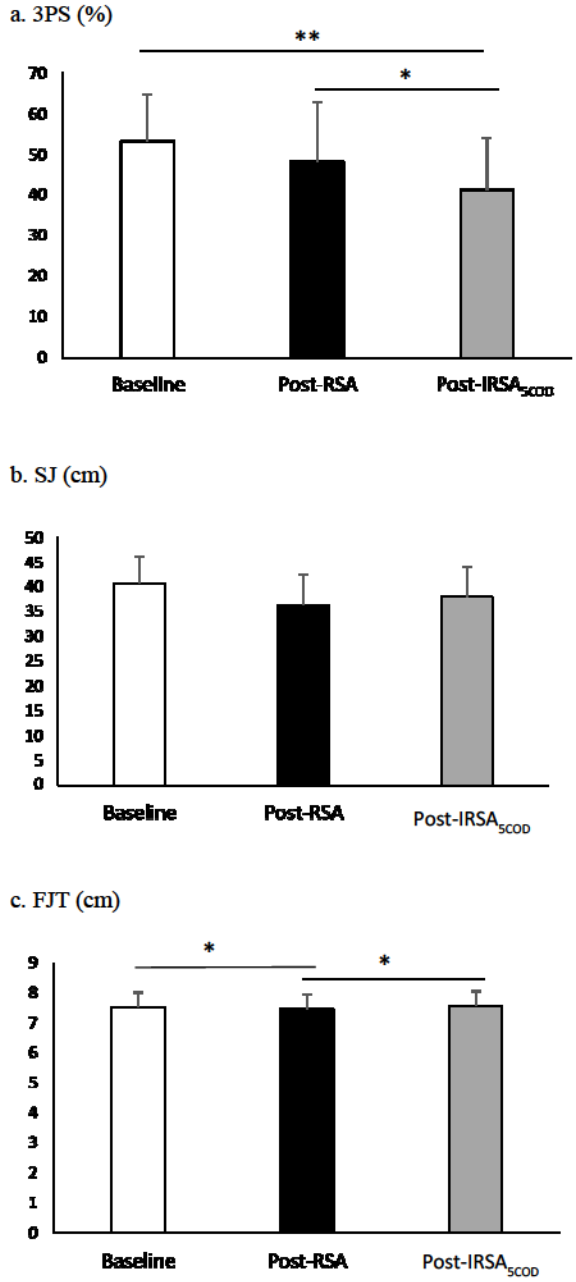

Figure 2

Performance in the three point shot (a-3PS), squat jump (b-SJ), and five jump test (c-FJT) at baseline and immediately following the two repeated sprint test (RSA: one change in direction, IRSA5COD five changes in direction).

Table 1

Mean ± standard deviation values for performance and physiological variables measured during the two repeated sprint protocols.

	IRSA5COD	RSA
Total Time (s)	59.8 ± 0.9	59.6 ± 0.9***
Best Time (s)	5.90 ± 0.10	5.89 ± 0.10*
Fatigue Index%	1.3 ± 0.5	1.2 ± 0.5
HRmean (beat·min-1)	195 ± 1	195 ± 1*
RPE	8 ± 1	7 ±1
[lac] (mmol·L-1)	6.8 ± 2.2	6.6 ± 2.1

***p < 0.01, ***p < 0.001, RSA : repeated sprint test with one change of direction (COD), IRSA5COD : repeated sprint test with five CODs.*

However, other performance indicators, such as the FI as well as the RPE, blood lactate concentration and HR did not differ between repeated sprint tests. These suggest that despite faster sprint times in the RSA compared to the IRSA5COD test, the two tests were performed under similar metabolic conditions. In addition, it is interesting to note that our physiological and RPE values were similar to values reported in the literature for both tests. For example our blood lactate following IRSA5COD values were 6.8 mmol·L-1compared to 7.2 mmol·L-1 in the study of Zagatto et al. (2017), with similar RPE values (ranging from 7-8). Finally, similar correlations were observed between VO_{2max} and sprint performances in both repeated sprint tests in our study and the study of Padulo et al. (2016), (r ranging from -0.61 to -0.66 in our study and from -0.56 to -0.66 in the study of Padulo et al. (2016)).

Furthermore, our results indicate significant impairment in FJT performance following RSA, but not IRSA5COD testing. To our knowledge, our study is the first to examine jump performance following repeated sprints with multiple CODs, which makes the comparison with the literature difficult for this condition.

Our results following RSA are in accordance with previous studies reporting decreases in countermovement jump performance following repeated sprint sequences of 25 to 35 m, performed in a straight line or as a shuttle (Balsalobre-Fernández et al., 2014; Buchheit, 2010) in team sport players. Those authors also reported significant correlations between the decrease in jump performance and the fatigue index during the repeated sprint test (Balsalobre-Fernández et al., 2014; Buchheit 2010). Although no significant association between these variables was shown in the present study, we observed a trend (r = 0.372, p = 0.09). Even if the jump test in the present study involved a series of unilateral horizontal jumps, compared to single bilateral vertical jumps in the above-mentioned studies, both tests assess the explosive power of the lower limbs, and their results are usually significantly correlated (Hambli et al., 2010).

The FJT is a good alternative to vertical jumps when testing team sport players in the field, with no particular equipment required, hence our choice of the test in the present study. Within this context, our results suggest that the explosive power of the lower limbs during unilateral jumps (required for a lay-up for example) is impaired following a repeated sprint sequence with longer sprints, replicating the transition from offense to defense in basketball players. However, the extent of change, while significant, is relatively small and associated to small effect sizes and hence further studies are needed to confirm our findings. In contrast with our results, Nikolaidis et al. (2016) found a significant improvement in CMJ performance (+1.8 cm) following ten 15-m sprints performed either in a straight line or in shuttles (7.5 m + 7.5 m) in male junior basketball players, with no difference between the effects of these two repeated sprint designs. The main difference between this protocol and those of the above mentioned studies consists of the shorter sprints used (15-m straight line or 7.5-m shuttles vs. 25-35 m straight line or 12.5 m shuttles in previous studies; Balsalobre-Fernández et al., 2014; Buchheit 2010), which are closer to the distances used in our IRSA5COD test.

Therefore, it seems that, regardless of the number of CODs, shorter sprint distances during RSA tests are less detrimental to jump performance in basketball players than longer sprint distances. This could be due to the lower speed achieved when sprinting over shorter distances (maximal speed being reached with much greater distances; Morin and Seve, 2011), possibly requiring less effort to decelerate when changing the direction. Within this context, Mackata et al. (2015) analyzed the prerequisite of performance in the initial (10 m) and secondary acceleration (30 m) phases, concluding that the main discriminate factor between the two was stride frequency. While these distances are longer than the ones in our tests, further investigations into sprinting kinematics are needed to understand the determinants of performance in COD tests.

Several other factors could explain these differences, since it was highlighted that performance in straight line sprints (10 m), as well as COD tests performed as a shuttle and COD tests following a « T » shape are influenced by different variables (Chaouachi et al., 2012). While not measured in their study, those authors highlighted the potential role of the lower limb internal/external rotation peak force as well as abductor/adductors power in CODs (Chaouachi et al., 2012). This could potentially explain the lack of impairment in FJT performance following the IRSA5COD test in the present study, since the muscle groups responsible for these movements in the frontal and transverse plane are likely to differ from the main muscle groups (quadriceps, hamstrings, gastrocnemius) involved in the FJT. Regarding movement in the sagittal plane, the non-significant effect of RSA and IRSA5cod on the SJ suggests that the concentric component of the explosive power of the legs is not influenced by previous repeated sprints. Hence it is more likely that the other factors, such as the eccentric component of the stretch shortening cycle or coordination are more susceptible to be impaired following RSA testing.

Our findings showed reduced shooting accuracy (-22.3%) following theIRSA5COD test compared to baseline. To our knowledge, the present study is the first to show a reduction in 3PS accuracy following repeated sprints in multiple directions. Our results are similar to those of a recent study (Ardigo et al., 2018), investigating the effects of a 15-m shuttle exercise at 80% of junior basketball players' maximal HR (HR_{max}), and showing a 28% decrease in the percentage of successful 3PS compared to baseline. Other authors have focused on factors known to affect success in jump shots, such as the kinematics of the body and the ball during the shot (Okazaki et al., 2015), showing contrasting results. Some authors reported no impairment in the kinematic variables known to affect 3PS or free throw shooting accuracy, such as body joint angles and ball release variables (height, speed, angle; Slawinski et al., 2018; Uygur et al., 2010), while one study reported significant impairment in the elbow flexion angle and shoulder and wrist height at ball release when 3PS was preceded by an exhaustive intermittent exercise (Erculj and Supej, 2009).

The discrepancies between the results of these studies on shooting accuracy and shooting kinematics could be explained by the characteristics of the intermittent exercise preceding the shot. Indeed, it seems that studies that found significant impairment in shooting technique or accuracy used shorter sprints (between 9 and 15-m shuttle distances), and a longer total exercise time (about 6 min in the study of Erculj and Supej (2009) and the present study, and longer in the study of Ardigo et al. (2018) with a total distance covered of 1600 m).

In contrast, studies using longer shuttle sprints (20-30 min) and shorter total exercise time (99-137 s) did not show any impairment in 3PS accuracy (Slawinski et al., 2018; Uygur et al., 2010). These times/distances are not very representative of the movements performed during a basketball game, suggesting that the former studies are more ecologically valid. Practically, these results altogether suggest that 3PS accuracy seems more affected by the cumulated fatigue associated to a longer repeated sequence than the transient fatigue linked to a shorter succession of movements. This is particularly important because 3PSs are likely to be taken at the end of quarters or of the match and are crucial for its outcome (Gomez et al., 2016).

A surprising result of the present study is the lack of impairment in 3PS efficiency following RSA testing, compared to baseline, and significantly lower 3PS efficiency after IRSA5COD compared to RSA testing. These results cannot be explained by metabolic factors, as similar HR and blood lactate values were reported following both repeated sprint tests. A more likely explanation of the differences between these conditions includes the mechanical constraints and specific structure of these tests, since it has been shown that the mechanical properties and determinants of performance were different in various tests involving CODs (Chaouachi et al., 2012). Some authors suggested that shooting accuracy could be decreased by greater levels of fatigue due to previous exercise (Okazaki et al., 2015; Rodacki et al., 2002). Indeed, if fatigue takes place in specific muscles required for a task, other synergistic muscle groups not normally involved in the task will be recruited (Rodacki et al., 2002), which is likely to affect shooting kinematics, coordination and postural control (Slawinski et al., 2018), coordination and postural control during the shot, and may explain the impairment in 3PS accuracy in our study. It is difficult to assess if greater levels of fatigue, defined as the incapacity to maintain the same level of performance, were achieved following IRSA5COD compared to RSA testing in the present study, because the FI during the repeated sprint tests was similar in both tests and FJT performance was only impaired after RSA testing, suggesting limited fatigue effects.

However, fatigue relies on complex mechanisms, and it is possible that other aspects of fatigue, such as central fatigue took place in our study, despite the lack of impairment in sprint and jump performance. The 3PS also relies to a great extent on whole body coordination (Okazaki et al., 2015; Rodacki et al., 2002). In this context, one reason why accuracy was reduced after IRSA5COD, but not RSA testing in the present study might be the more frequent trunk movements during the former. Indeed, change of direction performance has been linked to lateral and rotational movements of the trunk (Marshall et al., 2014), and the repetition of these movements could hinder the trunk capacity to transfer the force produced by the lower limb onto the upper limb during 3PS (Miller and Bartlett, 1996). It is also possible that a decreased capacity to maintain balance after the IRSA5COD test is responsible for the decrease in 3PS performance. In favor of this hypothesis, Okazaki et al. (2015) reported that shooting accuracy was impaired if the shot was taken after a movement involving the upper limb or trunk, such as catching a pass, making a cut or an offensive rebound.

The main limitation of the present study is the relative lack of ecological validity of the repeated sprint sequences. Indeed, during a basketball match, sprints are performed in many different directions, using various movement patterns (forward and backward running, lateral shuffles, etc…), with or without the ball. Therefore, further studies should include repeated sprints or shuffling sequences using these movement patterns and fundamentals skills, with or without the ball and in more directions to better replicate the reality of a basketball game.

In conclusion, the findings of this study show that the explosive power of the lower limbs and shooting accuracy are affected to different extents following repeated sprint sequences. The explosive power of the lower limbs, required for jumping (lay-up, block), but also high-intensity explosive movements, such as shuffling and changes in direction, seems more affected by longer (15 m) sprints and few CODs, experienced for example after a fast break and transition from offense to defense, or steal. In contrast, 3PS accuracy is impaired following shorter (5 m) sprints and many CODs, such as movements performed in offense or defense during set plays. These particular situations should be considered by basketball coaches and implemented before practicing these skills to optimize their performance in competition.

Acknowledgements

We would like to thank all the players who took part in this study.

References

Ardigò LP, Kuvacic G, Iacono AD, Dascanio G, Padulo J. Effect of Heart rate on Basketball Three-Point Shot Accuracy. Front Physiol, 2018; 9: 75

Ben Abdelkrim N, Castagna C, Jabri I, Battikh T, El Fazaa S, El Ati J. Activity Profile and Physiological Requirements of Junior Elite Basketball Players in Relation to Aerobic-Anaerobic Fitness. *J Strength Cond Res,* 2010; 24(9): 2330–2342

Balsalobre-Fernández C, Tejero-González C, Del Campo-Vecino J, Bachero-Mena B, Sánchez-Martínez J. Relationships among Repeated Sprint Ability, Vertical Jump Performance and Upper-Body Strength in Professional Basketball Players. *Arch Med Deporte,* 2014; 31(3): 148–153

Bishop DC, Wright C. A Time-Motion Analysis of Professional Basketball to Determine the Relationship between Three Activity Profiles: High, Medium and Low Intensity and the Length of the Time Spent on Court. *Int J Perf Anal Sport,* 2006; 6(1): 130–139

Buchheit M. Performance and Physiological Responses to Repeated-Sprint and Jump Sequences. *Eur J Appl Physiol,* 2010; 110(5): 1007–1018

Caprino D, Clarke ND, Delextrat A. The Effect of an Official Match on Repeated Sprint Ability in Junior Basketball Players. *J Sports Sci,* 2012; 30(11): 1165–1173

Chaouachi A, Manzi V, Chaalali A, Wong DP, Chamari K, Castagna C. Determinants Analysis of Change-of-Direction Ability in Elite Soccer Players. *J Strength Cond Res,* 2012; 26(10): 2667–2676

Cohen J. *Statistical Power Analysis for the Behavioral Sciences (2nd Edition).*Hillsdale, NJ: Lawrence Earlbaum; 1977

Erculj F, Supej M. Impact of Fatigue on the Position of the Release Arm and Shoulder Girdle Over a longer shooting distance for an elite basketball player. *J Strength Cond Res,* 2009; 23(3): 1029-1036

Fitzsimons MB, Ward DD, Wilkinson A. Cycling and Running Tests of Repeated Sprint Ability. *Aus J Sci Med Sport*, 1993; 25(4): 82-87

Foster CJ, Florhaug A, Franklin J,Gottschall L, Hrovatin LA, Parker S, Doleshal P, Dodge C. A New Approach to Monitoring Exercise Training. *J Strength Cond Res,* 2001; 15(1): 109–115

Mackala K, Fostiak M, Kowalski K. Selected Determinants of Acceleration in the 100m Sprint. *J Hum Kinet,* 2015; 45: 135–148

Gomez MA, Gasperi L, Lupo C. Performance Analysis of Game Dynamics during the 4th Game Quarter of NBA Close Games. *Int J Perf Anal Sport*, 2016; 16(1): 249–263

Hambli M, Chaouachi A, Kaouech F, Castagna C, Wisløff U, Chamari K. The Five-Jump Test for Distance as a Field Test to Assess Lower Limb Explosive Power in Soccer Players. *J Strength Cond Res,* 2010; 22(3): 944–950

Hirvonen JS, Rusko RH, Harkonen M. Breakdown of High-Energy Phosphate Compounds and Lactate Accumulation during Short Supramaximal Exercise. *Eur J Appl Physiol Occup Physiol,* 1987; 56(3): 253–259

Horita TP, Komi V, Hamalainen I, Avela J. Exhausting Stretch-Shortening Cycle (SSC) Exercise Causes Greater Impairment in SSC Performance than in Pure Concentric Performance. *Eur J Appl Physiol Occup Physiol,* 2003; 88(6): 527–534

Leger LA, Lambert J. A Maximal Multistage 20-m Shuttle Run Test to Predict VO_{2max}. *Eur J Appl Physiol OccupPhysiol,*1982; 49(1): 1–12

Marshall BM, Franklyn-Miller AD, King EA, Moran KA, Strike SC, Falvey EC. Biomechanical Factors Associated with Time to Complete a Change of Direction Cutting Maneuver. *J Strength Cond Res,* 2014; 28(10): 2845–2851

Miller S, Bartlett R. The Relationship between Basketball Shooting Kinematics, Distance and Playing Position. *J Sports Sci,* 1996; 14(3):243–253

Morin JB, Seve P. Sprint Running Performance: Comparison between Treadmill and Field Conditions. *Eur J Appl Physiol,* 2011; 111(8): 1695–1703

Nikolaidis PT, Meletakos P, Tasiopoulos I, Kostoulas I, Ganavias P. Acute Responses to 10x15 m Repeated Sprint Ability Exercise in Adolescent Athletes: The Role of Change of Direction and Sport Specialization. *Asian J Sports Med*, 2016; 7(2): e30255

Okazaki VHA, Rodacki ALF, Satern MN. A Review on the Basketball Jump Shot. *Sports Biomech,* 2015; 14(2): 190–205

Padulo J, Attene G, Migliaccio GM, Cuzzolin F, Vando S, Ardigò LP. Metabolic optimisation of the basketball free throw. J Sports Sci, 2015a; 33(14): 1454-1458

Padulo J, Bragazzi NL, Nikolaidis PT, DelloIacono A, Attene G, Pizzolato F, Dal Pupo J, Zagatto AM, Oggianu M, Migliaccio GM. Repeated Sprint Ability in Young Basketball Players: Multi-Direction vs. One-Change of Direction (Part 1). *Front Physiol,* 2016; 7: 133

Padulo J, Laffaye G, Haddad M, Chaouachi A, Attene G, Migliaccio GM, Chamari K, Pizzolato F. Repeated Sprint Ability in Young Basketball Players: One vs. Two Changes of Direction (Part 1). *J Sports Sci,* 2015b; 33(14): 1480–1492

Padulo J, Nikolaidis PT, Cular D, DelloIacono A, Vando S, Galasso M, Lo Storto D, Ardigò LP. The Effect of Heart Rate on Jump-Shot Accuracy of Adolescent Basketball Players. *Front Physiol,* 2018; 9: 1–7

Rodacki ALF, Fowler NE, Bennett SJ. Vertical Jump Coordination: Fatigue Effects. *Med Sci Sports Exerc,* 2002; 34(1): 105–116

Scanlan AT, Dascombe BJ, Reaburn P, Dalbo VJ. The Physiological and Activity Demands Experienced by Australian Female Basketball Players during Competition. *J Sci Med Sport,* 2012; 15(4): 341–347

Slawinski J, Louis J, Poli J, Tiollier E, Khazoom C, Dinu D. The Effects of Repeated Sprints on the Kinematics of 3-Point Shooting in Basketball. *J Hum Kinet,* 2018; 62(1): 5–14

Uygur M, Goktepe A, Ak E, Karabörk H, Korkusuz F. The Effect of Fatigue on the Kinematics of Free Throw Shooting in Basketball. *J Hum Kinet,* 2010; 24(1): 51–56

Włodarczyk M, Kantanista A, Kusy K, Zieliński J, Pospieszna B. Practical analysis of the metabolic response to a resistance training session in male and female sprinters. *TRENDS in Sport Sciences* 2020; 27(1): 35-39

Zagatto AM, Ardigo LP, Barbieri FA, Milioni F, DelloIacono A, Camargo BHF, Padulo J. Performance and Metabolic Demand of a New Repeated-Sprint Ability Test in Basketball Players: Does the Number of Changes of Direction Matter? *J Strength Cond Res,* 2017; 31(9): 2438–2446

Corresponding author:

Dr Anne Delextrat,
Department of Sport and Health Sciences and Social Work,
Oxford Brookes University, Gipsy lane, OX3 0BP, Oxford, UK.
E-mail: adelextrat@brookes.ac.uk