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ABSTRACT

Purpose: To examine differences between adult male basketball players of different competitive levels (study 1) and changes over a basketball season (study 2) of knee extensor peripheral muscle function during a multi-stage changes of direction exercise (MCODE). **Methods:** In study 1, 111 players from 4 different divisions completed the MCODE during the regular season. In study 2, the MCODE was performed before (T1) and after (T2) the preparation period and during the competitive season (T3) by 32 players from division I, II and III. The MCODE comprised 4 levels of increasing intensity for each player. The peak twitch torque (PT) of knee extensors was measured after each level. PT_{max} (the highest value of PT) and fatigue were calculated. **Results:** In study 1, we found possibly small differences (ES±90%CI: -0.24±0.39) in fatigue between division I and II. Division I was characterized by likely (ES: 0.30 to 0.65) and very likely-to-almost certain (ES: 0.74 to 1.41) better PT_{max} and fatigue levels compared to division III and VI, respectively. In study 2, fatigue was very likely reduced (ES: -0.91 to -0.51) among all divisions from T1 to T2, while PT_{max} was likely-to-very likely reduced (ES: -0.51 to -0.39) in division II and III. **Conclusions:** Professional basketball players are characterized by a better peripheral muscle function during a MCODE. Most of the seasonal changes in peripheral muscle function occurred after the preparation period. These findings inform practitioners on the development of training programs to enhance the ability to sustain repeated changes of direction efforts.

Key Words: Competitive level; Metabolic power; Neuromuscular fatigue; Peak torque; Seasonal variation.

INTRODUCTION

Basketball is a physically demanding team sport characterized by frequent high-intensity phases,[1] during which neuromuscular factors are heavily taxed.[2] Players are frequently asked to quickly accelerate, decelerate and change direction during basketball games.[1] Specifically, time-motion analysis of matches revealed that male players change activity on average every 1-3 s performing more than 1000 movements per game.[1]

As several studies reported the change of direction (COD) ability to be a main determinant for successful participation in basketball, numerous tests have been developed to assess COD performance.[3] Despite these tests are usually characterized by multiple variables (e.g. number of COD, total distance covered, type of force application), total running time is often used as the main outcome.[4] However, some authors have recently proposed the use of the COD deficit (i.e. the additional time that one directional change requires when compared to a pure linear sprint over an equivalent distance) to better assess the COD ability.[5] While the physiological characteristics of basketball players have received considerable attention over the past years,[2] only few studies have compared the COD ability and the ability to sustain repeated COD efforts of adult players competing at different levels.[6-11] COD exercises were found to discriminate professional and semi-professional adult male basketball players from their lower level counterparts,[7,10,11] while professional players (division I vs division II) appeared to be characterized by a similar COD ability.[8,9] However, some limitations of these previous studies should be acknowledged, such as the limited number of players involved and only two competitive level groups compared in each study. For these reasons, a further solid comparison of the ability to sustain COD efforts among adult players of different competitive levels is required.

Besides competitive level, there is limited information regarding the possible changes in COD ability or in the ability to sustain repeated COD efforts across an entire basketball season. Hoffman et al.[12,13] observed no variations in T-test performance during preparation and competitive periods in collegiate and young basketball players. On the contrary, when assessed with the line drill test or V-cut test, the performance of junior players resulted substantially affected by the period of the season.[13-15] Thus, monitoring the ability to sustain repeated COD efforts across an entire basketball season might be helpful for periodization purposes.

The COD ability has been reported to be affected by lower body strength and power.[3,4] Indeed, high levels of strength were reported to permit athletes to carry out the COD movements in lower body positions, enhancing the ability to produce greater force during the deceleration and reacceleration phases of the COD movement.[16] In addition, lower body strength characteristics have been shown to be reduced after COD runs.[17,18] However, the aetiology of neuromuscular fatigue during repeated COD efforts has yet to be investigated. This information might be useful for practitioners considering the detrimental effects of neuromuscular fatigue on the ability to sustain repeated COD efforts and, thus, on basketball performance. Despite fatigue induced by COD may be caused by a combination of central and peripheral factors, peripheral mechanisms appear to be more involved during such high-intensity short-duration exercises, while central mechanisms have been reported to develop especially following submaximal prolonged exercises.[19] Accordingly, Ferioli et al.[11] have recently provided novel insights into peripheral muscular function during a repeated COD exercise in basketball, observing better peripheral contractile properties of the knee extensor muscles for players of higher competition level. However, further research is required to provide a thorough knowledge on peripheral muscular function during repeated COD efforts, which might help to develop more appropriate training programs. Additionally, monitoring the neuromuscular function during repeated COD efforts across the different phases of the competitive season might be useful to plan and adjust training strategies accordingly.

Therefore, in the present study we evaluated peripheral fatigue and contractility of the knee extensor muscles during repeated COD efforts in a large cohort of adult basketball players with the aims to examine 1) differences between players of different competitive levels (from elite to amateur levels) and 2) changes over an entire basketball season. The secondary objective of this study was to further verify the construct validity of the measurement of peripheral muscular function during a standardized multi-stage COD exercise (MCODE).

METHODS

Subjects and Design

The present investigation consisted of two separate observational studies involving a total of 111 male basketball players from 4 different divisions (I, II, III and VI), who participated in one or both studies during a single competitive season. Data collection started in 2014 and finished in 2017. After verbal and written explanation of the experimental design and potential risks and benefits of the study, written informed consent was signed by all players or their respective parents/guardians if underage. The study was approved by the Independent Institutional Review Board of MAPEI Sport Research Centre in accordance with the Helsinki Declaration. To avoid potential confounding effects on the outcome variables, no heavy training sessions were performed the day preceding the assessments and no stretching exercises were allowed prior to the evaluations. Before the commencement of each MCODE, the athletes carried out a standardized warm-up consisting of a continuous run at a constant speed, followed by countermovement jumps and high-intensities intermittent runs. All the basketball players included in this study completed the standard training program of their respective team and were free of injury in the 6 months preceding the tests. On average, division I and II athletes trained 6-10 times a week, while division III and VI players performed 4-7 and 2-3 training sessions a week, respectively. Training sessions lasted 60-120 min, excluding cool down and/or stretching exercises and including warm-up. Division I, II and III performed two strength training sessions per week in addition to a conditioning session on the court (e.g. speed and agility). Division VI performed only technical-tactical training sessions. Division II, III and VI teams completed one game per week, while division I teams played one or two games per week.

Study 1

Differences between competitive levels. 111 male basketball players competing in the Italian Serie A (division I, n=27, age: 25.3 ± 5.2 years, stature: 198.4 ± 9.5 cm, body mass: 95.9 ± 12.2 kg), Serie A2 (division II, n=25, age: 24.5 ± 3.9 years, stature: 197.4 ± 7.4 cm, body mass: 93.3 ± 11.4 kg), Serie B (division III, n=32, age: 24.1 ± 5.7 years, stature: 192.8 ± 7.9 cm, body mass: 89.0 ± 11.6 kg) and Serie D (division VI, n=27, age: 21.6 ± 5.3 years, stature: 187.1 ± 8.3 cm, body mass: 78.8 ± 9.8 kg) took part in the present study. Players were selected from a total of 14 basketball teams (i.e. 3 or 4 teams per division) and performed the MCODE during the competitive phase of the seasons 2014-15, 2015-16 or 2016-17. Knee extensors peripheral muscular function was measured during the MCODE. Playing roles were equally represented in all division groups to avoid potential bias effects of playing position on the outcome variables.

Study 2

Seasonal changes. In the second study, data were collected from 32 adult male basketball players competing in the Italian Serie A (division I, n=11, age: 27.0 ± 6.1 years, stature: 200.5 ± 9.9 cm, body mass: 100.0 ± 11.0 kg), Serie A2 (division II, n=10, age: 23.8 ± 4.7 years, stature: 195.6 ± 7.3 cm, body mass: 89.9 ± 11.9 kg) and Serie B (division III, n=11, age: 24.2 ± 5.2 years, stature: 190.3 ± 7.1 cm, body mass: 84.5 ± 10.7 kg). Players were selected from a total of 6 basketball teams (i.e. 2 teams per division) during the competitive seasons 2015-16 or 2016-17. Athletes completed the MCODE 3 times during the basketball season: the first week of the preparation period (T1), within the first 2 weeks after the start of the competitive season (T2), and during the competitive phase of the season (T3), at least 9 weeks after T2. Knee extensors peripheral muscular function was measured at all time points during the MCODE. All the testing sessions were performed in the same conditions (i.e. testing venue, time of the day and test procedures). All the basketball players included in this study performed more than 80% of the team training sessions.[11,20]

Methodology

The MCODE[11] comprised 4 levels of increasing standardized intensity. The players, paced by an audio signal, ran back and forth repeatedly with 180° CODs over an 8-m course. During the first and second levels, athletes carried out 11 CODs in 31.5 s and 28.5 s respectively, while the third and the fourth levels were composed by 13 CODs performed in 30 s and 26 s respectively. The instantaneous running speed sustained by each player during the different COD levels was recorded using a radar device (Stalker ATS, Radar Sales, Minneapolis, MN). Furthermore, actual instantaneous metabolic power was estimated for each COD level using the equation proposed by Di Prampero et al.[21] and subsequently modified by Osgnach et al.[22] The peripheral muscular function of the knee extensor muscles was assessed with a series of electrically-evoked isometric contractions (see below) at baseline (prior to the standardized running warm-up) and 30 s after the completion of each COD level. Athletes were comfortably seated in a purpose-built leg extension machine with the knee joint flexed at 90° and were secured to the leg extension machine via multiple Velcro® straps. Knee extension torque was recorded (sampling rate: 250 Hz) using a load cell (AIP, Varese, Italy) mounted on the leg extension machine and connected to a data acquisition system (BIOPAC MP100; BIOPAC Systems, Inc., Santa Barbara, CA). Electrically-evoked contractions were obtained by stimulating the femoral nerve with a constant-current high-voltage stimulator (Digitimer DS7AH, Hertfordshire, United Kingdom) and surface electrodes (Compex, Ecublens, Switzerland) placed in the femoral triangle (cathode, 5 × 5 cm) and in the gluteal fold (anode, 10 × 5 cm). Electrodes were positioned by the same examiner and their location was marked on the skin for repeated assessments. The intensity of a single rectangular pulse (duration: 200 μs) was first progressively increased by 10-mA increments until the electrically-evoked twitch peak torque of the knee extensors showed a plateau. This intensity was increased by a further 20% and maintained for the ensemble of the tests.[23] Both at baseline and after each COD level, three single stimuli were delivered (one every 3 s) and the mean twitch peak torque (PT) was calculated (Figure 1). The four PT values obtained at the end of each COD level were plotted against the actual corresponding metabolic power (measured by the radar system). A regression line was then calculated by interpolating the four measured PT using a polynomial equation of second order (Figure 2). The following parameters were calculated from the individual PT-metabolic power curves: 1) PT_{max}, as the highest value of PT retrieved from the regression equation; 2) fatigue, as the percent decline from the PT_{max} to the PT corresponding to a metabolic power of 31 $W \cdot kg^{-1}$;[11] 3) MP_{max}, the metabolic power corresponding to the PT_{max} (Figure 2).[11] This procedure was carried out separately for the right and left knee extensor muscles and the mean value of the two sides was used for the statistical analysis.

Statistical analysis

The participants' descriptive results are reported as means ± standard deviations (SD). The magnitude-based inference approach was used to analyse the data according to Hopkins et al.[24] All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors.[24] Standardized differences were calculated and interpreted as follows: ≤0.2, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1.2-2.0, large; >2.0-4.0, very large.[24] Probability was also calculated (mechanistic approach) to compare the true (unknown) differences and the smallest worthwhile change, which was obtained multiplying the between-subject SD by 0.2. Quantitative chances of harmful, trivial or beneficial effects were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. When the probability of having higher or lower values than the smallest worthwhile change was less than 5%, the true difference was assessed as unclear. Test-retest reliability of all the variables was determined using the typical error of measurement expressed as coefficient of variation. Eleven division VI basketball players were tested on two occasions and coefficients of variation of 5.3%, 5.3% and 4.6% were respectively obtained for PT_{max}, fatigue and MP_{max}. Customized spreadsheets and SPSS statistical software (version 24.0, IBM SPSS Statistics, Chicago, IL, USA) were used for the analyses.

RESULTS

Study 1

Peripheral muscular function of knee extensors and MP_{max} measured during the MCODE according to competitive level are presented in Table 1, while standardized differences between groups are reported in Figure 3. We found unclear differences in MP_{max} and PT_{max} between division I and II athletes, while differences in fatigue were possibly small. Division III was characterized by likely lower PT_{max} and fatigue compared to division I, while possibly small differences were found in MP_{max} between these two groups. We found very likely-to-almost certain differences in PT_{max}, fatigue and MP_{max} between division I and VI.

Study 2

Seasonal changes in peripheral muscular function of knee extensors and MP_{max} measured during the MCODE are presented in Table 2, while standardized differences between time points are reported in Figure 4. Very likely reductions in fatigue were found between T1 and T2 in all divisions, but unclear variations were found between T2 and T3. MP_{max} was very likely greater after the preparation period in division I players and likely increased from T2 to T3 in division III athletes. From T1 to T2, PT_{max} was likely-to-very likely reduced in division II and III athletes, but unclear differences were observed among division I players.

DISCUSSION

The present study provides novel insights into the differences among a large cohort of basketball players of different competitive level and the changes over an entire basketball season of knee extensor peripheral muscular function during repeated CODs. The main findings of this study were that athletes of higher competitive level (division I and II) demonstrated better muscle PT_{max}, while lower-level players (division VI) showed greatest amounts of muscle fatigue during repeated COD runs. Fatigue was reduced after the preparation period among all divisions, but unclear changes were observed during the competitive phase of the season. Changes in PT_{max} during the different phases of the season appeared to be influenced by the competitive level of the players, with division II and III (not division I) players showing a slight decline during the season.

Previous studies comparing the ability to perform COD exercise in basketball players of different competitive levels reported conflicting results.[6-11] In the present study, we proposed a novel application for the objective quantification of peripheral fatigue induced by repeated CODs. The peripheral fatigue and PT_{max} of the knee extensor muscles measured during the MCODE were partially affected by the competitive level of play. Unclear and possibly small differences were observed respectively for PT_{max} and fatigue among professional players (i.e. division I and II), which might suggest a comparable ability to sustain repeated COD efforts. However, when comparing elite professional players (i.e. division I) with semi-professional and amateur ones (i.e. division III and VI, respectively), the former where characterized by a likely-to-very likely greater PT_{max}. This might be due to the greater mass of lower body muscles of division I players,[25] which might have a beneficial effect on force and power production. Similarly, we found likely-to-almost certain greater fatigue levels among division III and VI compared with division I players. However, when comparing division II to division III players, unclear and likely small differences were respectively observed for fatigue and PT_{max}

(comparison not presented in the results section). These results might reflect the chronic physical adaptations occurred among higher-level players as a consequence of the different training and game loads that they are usually required to sustain.[20,26] Accordingly, division I athletes exert greater external workloads than lower-level counterparts during basketball games, while the activity demands of division II and III competitions are similar.[27] Furthermore, the better qualities observed among professional players might be a consequence of the long-life selection process imposed on the athletes.[28] In addition, the MP_{max} recorded during the MCODE was almost certain higher among division I players compared to division VI individuals. These results confirm previous findings reporting professional players to be characterized by better peripheral contractile properties and unclear differences in fatigue levels of knee extensors during repeated COD efforts than semi-professional athletes.[11] All together, these results suggest that knee extensor peripheral muscular function might discriminate professional athletes from their lower level counterparts in terms of intrinsic muscle contractile properties. In addition, the ability to sustain repeated high-intensity COD exercise without the occurrence of severe peripheral fatigue might be considered as an important characteristic for successful participation in basketball.

The majority of changes in knee extensor peripheral muscular function during the MCODE occurred during the preparation period and were affected by the competitive level of play. Unclear changes were observed in PT_{max} during the preparation period among division I players, but a likely reduction was found from T2 to T3. On the contrary, after the preparation period, the ability to intrinsically produce force was impaired among division II and III players. However, this quality was restored during the competitive season, when division II and division III athletes were characterized by a similar PT_{max} compared to T1 (i.e. T1 vs T3: division II, ES= -0.08±0.19; division III, ES= -0.14±0.30). These contrasting results between elite professional and subelite professional/semi-professional players might be explained by a better ability of higher-level players to tolerate greater training loads compared to lower-level athletes. Furthermore, the higher physiological load at which division I athletes are subjected during both training and competition during the regular season might have led to a sort of contractile overreaching.[11,26] The fatigue measured during the MCODE was very likely reduced after the preparation period in all divisions. These findings suggest that after the preparation period, the knee extensor muscles of professional and semi-professional basketball players are less fatigable during repeated COD runs, despite a preserved ability to sustain repeated COD efforts during the regular season. Similar results have been previously reported during the preparation period among a small cohort of professional and semi-professional basketball players.[11] After the preparation period, the MP_{max} of division I players was very likely greater compared to T1. Indeed, after the preparation period the PT_{max} was present at higher absolute exercise intensity and the occurrence of fatigue was postponed. Thus, it might be speculated that the ability to produce maximal power during repeated CODs was increased during the preparation period and preserved during the competitive phase of the season among elite professional players. On the contrary, unclear differences were found in MP_{max} during the different phases of the season among division II players, while likely greater values of MP_{max} were observed from T2 to T3 among division III athletes.

The limited data available in literature on seasonal variations in the ability to sustain CODs efforts among adult male basketball players do not allow for a through comparison with previous studies. The main limitation of this study is that basketball players were selected from just one national tournament, thus the present data might not be necessarily considered representative of high-level basketball players. Furthermore, it is difficult to explain the observed level differences and seasonal changes with full confidence as training/game loads, which might have affected the outcomes of this study, were not monitored.

PRACTICAL APPLICATIONS

The ability to sustain repeated CODs efforts at high intensities without the occurrence of severe peripheral fatigue should be considered as an important determinant of basketball physical performance. Therefore, it should be incorporated into modern conditioning programs. The results of the present study might be used to identify the weaknesses of the athletes according to their competitive level and phase of the season. Thus, strength and conditioning coaches should develop specific and individualized training programs to enhance the identified limiting factors. For example, emphasis should be placed on strength training with accentuated eccentric muscle actions or specific running exercises including repeated sprints with CODs as suggested by the current research on this topic.[4,29] Furthermore, monitoring knee extensor peripheral muscular function changes during the different phases of the competitive season might be useful to optimize training loads and prevent overreaching. From a practical point of view, an impairment of peripheral muscle function during the regular season should alert practitioners on the dosage and effectiveness of the training and recovery strategies. The results of this study also confirm the construct validity of the measurement of knee extensor peripheral muscular function during the MCODE in basketball players.

CONCLUSIONS

The present study demonstrated that professional basketball players (i.e. division I and II) are characterized by a better knee extensor peripheral muscular function (i.e. PT_{max} and fatigue) during repeated COD runs compared to their lower level counterparts. Also, the majority of the seasonal changes in peripheral muscular function during repeated COD exercises occurred after the preparation period, when the knee extensor muscles showed lower levels of fatigue.

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REFERENCES

1. Stojanovic E, Stojiljkovic N, Scanlan AT, Dalbo VJ, Berkelmans DM, Milanovic Z. The activity demands and physiological responses encountered during basketball match-play: a systematic review. *Sports Med.* 2018;48(1):111-135.
2. Ziv G, Lidor R. Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. *Sports Med.* 2009;39(7):547-568.
3. Wen N, Dalbo VJ, Burgos B, Pyne DB, Scanlan AT. Power testing in basketball: current practice and future recommendations. *J Strength Cond Res.* 2018;32(9):2677-2691.
4. Brughelli M, Cronin J, Levin G, Chaouachi A. Understanding change of direction ability in sport: a review of resistance training studies. *Sports Med.* 2008;38(12):1045-1063.
5. Nimphius S, Callaghan SJ, Spiteri T, Lockie RG. Change of direction deficit: a more isolated measure of change of direction performance than total 505 time. *J Strength Cond Res.* 2016;30(11):3024-3032.
6. Spiteri T, Binetti M, Scanlan AT, Dalbo VJ, Dolci F, Specos C. Physical determinants of Division 1 Collegiate basketball, Women's National Basketball League and Women's National Basketball Association athletes: with reference to lower body sidedness. *J Strength Cond Res.* 2017:*In press*.
7. Delextrat A, Cohen D. Physiological testing of basketball players: toward a standard evaluation of anaerobic fitness. *J Strength Cond Res.* 2008;22(4):1066-1072.
8. Sekulic D, Pehar M, Krolo A, et al. Evaluation of basketball-specific agility: applicability of pre-planned and non-planned agility performances for differentiating playing positions and playing levels. *J Strength Cond Res.* 2017;31(8):2278-2288.
9. Koklu Y, Alemdaroglu U, Kocak FU, Erol AE, Findikoglu G. Comparison of chosen physical fitness characteristics of Turkish professional basketball players by division and playing position. *J Hum Kinet.* 2011;30:99-106.
10. Lockie RG, Jeffriess MD, McGann TS, Callaghan SJ, Schultz AB. Planned and reactive agility performance in semiprofessional and amateur basketball players. *Int J Sports Physiol Perform.* 2014;9(5):766-771.
11. Ferioli D, Bosio A, Bilsborough JC, La Torre A, Tornaghi M, Rampinini E. The preparation period in basketball: training load and neuromuscular adaptations. *Int J Sports Physiol Perform.* 2018;13(8):991-999.
12. Hoffman JR, Fry AC, Howard R, Maresh CM, Kraemer WJ. Strength, speed and endurance changes during the course of a division I basketball season. *J Strength Cond Res.* 1991;5(3):144.
13. Hoffman JR, Kaminsky M. Use of performance testing for monitoring overtraining in elite youth basketball players. *Strength Cond J.* 2000;22(6):54-62.

14. Montgomery PG, Pyne DB, Hopkins WG, Minahan CL. Seasonal progression and variability of repeat-effort line-drill performance in elite junior basketball players. *J Sports Sci.* 2008;26(5):543-550.

15. Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, Arjol-Serrano JL, Casajus JA, Mendez-Villanueva A. Validity of the V-cut test for young basketball players. *Int J Sports Med.* 2015;36(11):893-899.

16. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci.* 2013;13(6):646-652.

17. Hader K, Mendez-Villanueva A, Ahmaidi S, Williams BK, Buchheit M. Changes of direction during high-intensity intermittent runs: neuromuscular and metabolic responses. *BMC Sports Sci Med Rehabil.* 2014;6(1):2.

18. Buchheit M, Spencer M, Ahmaidi S. Reliability, usefulness, and validity of a repeated sprint and jump ability test. *Int J Sports Physiol Perform.* 2010;5(1):3-17.

19. Taylor JL, Gandevia SC. A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. *J Appl Physiol (1985).* 2008;104(2):542-550.

20. Ferioli D, Bosio A, La Torre A, Carlomagno D, Connolly DR, Rampinini E. Different training loads partially influence physiological responses to preparation period in basketball. *J Strength Cond Res.* 2018;32(3):790-797.

21. di Prampero PE, Fusi S, Sepulcri L, Morin JB, Belli A, Antonutto G. Sprint running: a new energetic approach. *J Exp Biol.* 2005;208(Pt 14):2809-2816.

22. Osgnach C, Poser S, Bernardini R, Rinaldo R, di Prampero PE. Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med Sci Sports Exerc.* 2010;42(1):170-178.

23. Neyroud D, Vallotton A, Millet GY, Kayser B, Place N. The effect of muscle fatigue on stimulus intensity requirements for central and peripheral fatigue quantification. *Eur J Appl Physiol.* 2014;114(1):205-215.

24. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-13.

25. Ferioli D, Rampinini E, Bosio A, La Torre A, Azzolini M, Coutts AJ. The physical profile of adult male basketball players: Differences between competitive levels and playing positions. *J Sports Sci.* 2018;36(22):2567-2574.

26. Scanlan A, Dascombe B, Reaburn P. A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. *J Sports Sci.* 2011;29(11):1153-1160.

27. Ferioli D, Schelling X, Bosio A, La Torre A, Rucco D, Rampinini E. Match activities in basketball games: comparison between different competitive levels. *J Strength Cond Res.* 2018:Submitted.

28. Drinkwater EJ, Pyne DB, McKenna MJ. Design and interpretation of anthropometric and fitness testing of basketball players. *Sports Med.* 2008;38(7):565-578.

29. Chaabene H, Prieske O, Negra Y, Granacher U. Change of direction speed: toward a strength training approach with accentuated eccentric muscle actions. *Sports Med.* 2018;48(8):1773-1779.

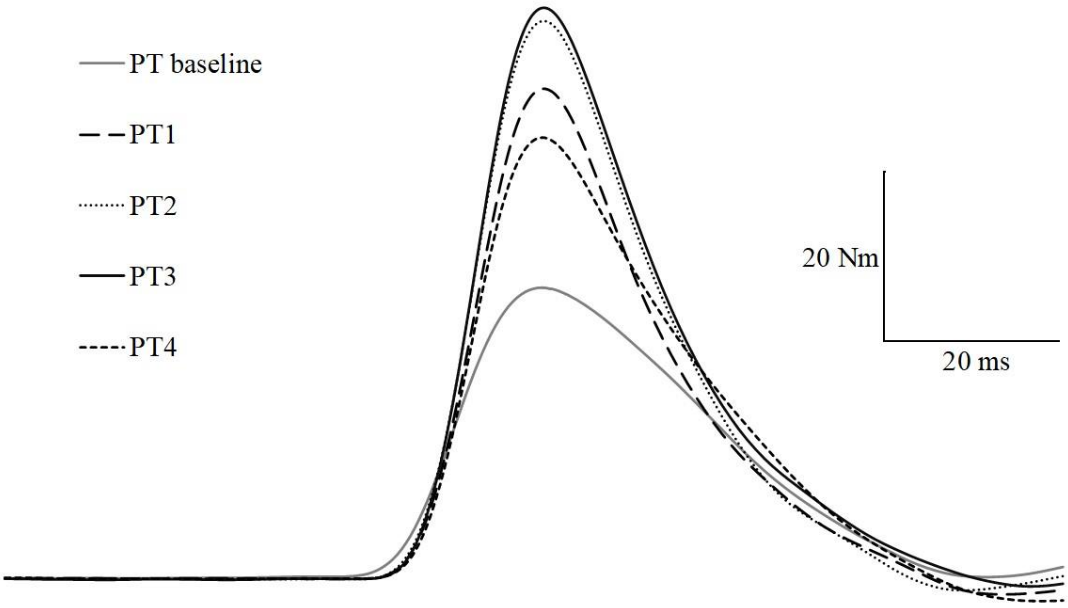

Figure 1. Example of the evoked twitch contractions recorded at baseline and 30 s after each level of the multi-stage change of direction exercise.

Twitch torque response recorded after the first (PT1), second (PT2), third (PT3) and fourth (PT4) level of the multi-stage change of direction exercise.

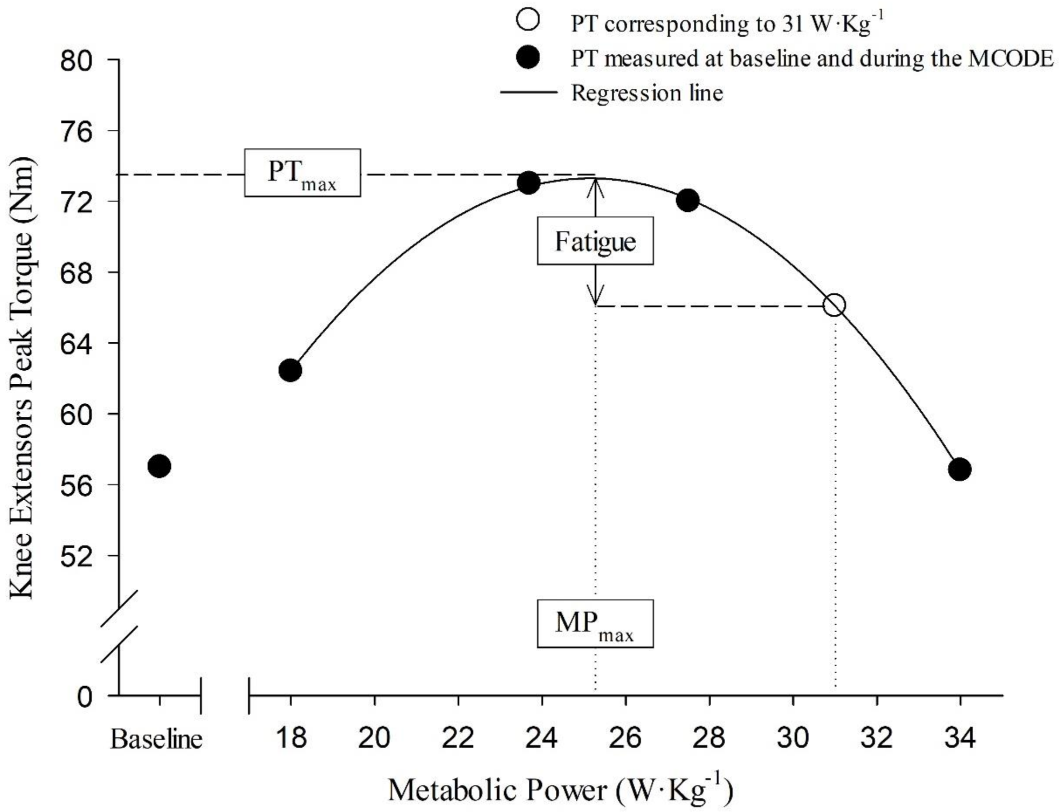

Figure 2. Example of the regression line calculated by interpolating the twitch peak torque measured after each level of the multi-stage change of direction exercise (MCODE).

PT_{max}, highest value of peak torque calculated from the peak torque-metabolic power relationship; fatigue, percent decline from the PT_{max} to the peak torque corresponding to a metabolic power of 31 $W \cdot kg^{-1}$; MP_{max}, metabolic power corresponding to the PT_{max}.

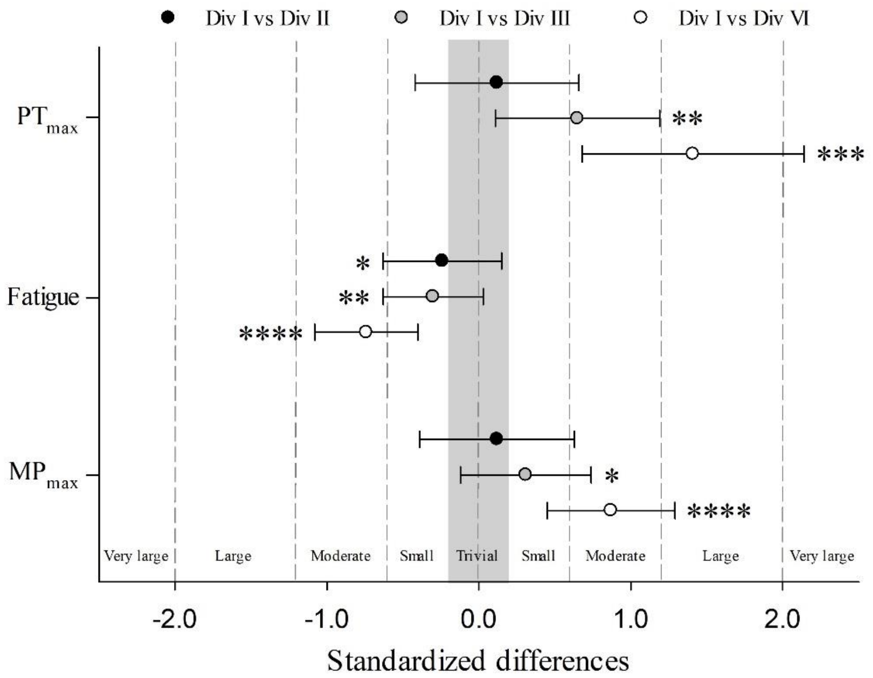

Figure 3. Between-groups standardized differences (90% confidence intervals) for knee extensor peripheral muscle function variables and MP_{max} measured during the multi-stage change of direction exercise. * possible, ** likely *** very likely, **** almost certain difference between division I and other divisions.

PT_{max}, highest value of peak torque calculated from the peak torque-metabolic power relationship; Div, division; fatigue, percent decline from the PT_{max} to the peak torque corresponding to a metabolic power of 31 $W \cdot kg^{-1}$; MP_{max}, metabolic power corresponding to the PT_{max}.

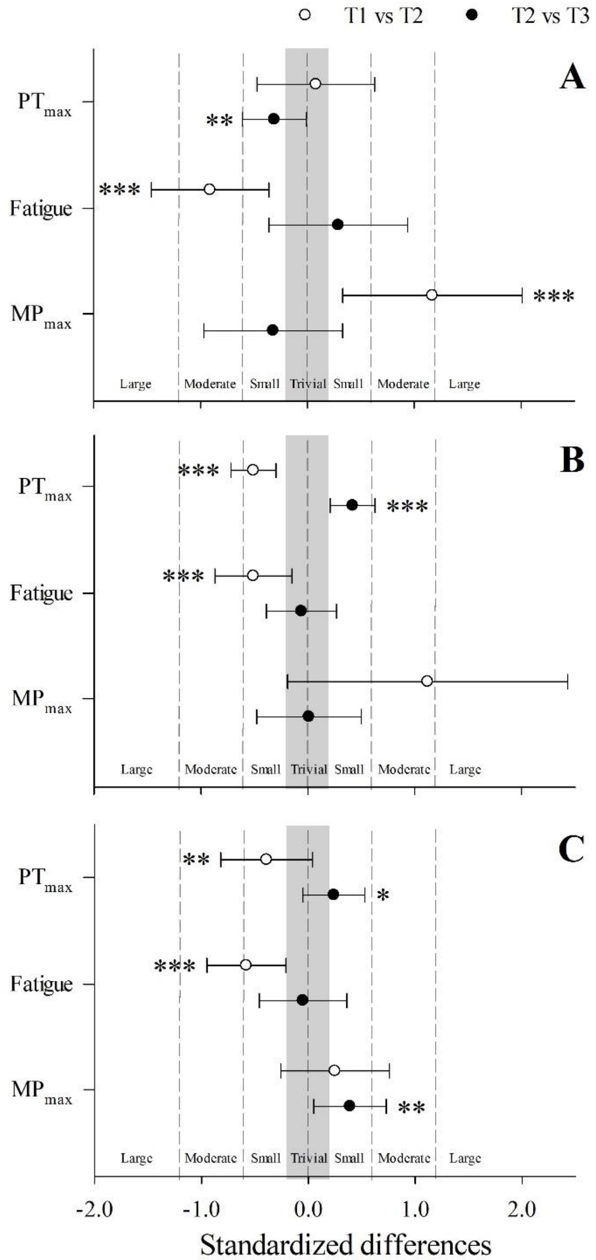

Figure 4. Between-time points standardized differences (90% confidence intervals) for knee extensor peripheral muscle function variables and MP_{max} measured during the multi-stage change of direction exercise in division I (A), division II (B) and division III (C) players. * possible, ** likely *** very likely change.

PT_{max}, highest value of peak torque calculated from the peak torque-metabolic power relationship; fatigue, percent decline from the PT_{max} to the peak torque corresponding to a metabolic power of 31 $W \cdot kg^{-1}$; MP_{max}, metabolic power corresponding to the PT_{max}.

Table 1. Metabolic power and peripheral muscle function of knee extensors measured during the multi-stage changes of direction exercise.

	DIVISION I ***n=27***	**DIVISION II** ***n=25***	**DIVISION III** ***n=32***	**DIVISION VI** ***n=27***
PT_{max} (N·m)	73.1 ± 17.4	71.5 ± 12.7	65.0 ± 12.2	61.1 ± 8.3
Fatigue (%)	10.5 ± 8.3	13.5 ± 12.2	15.7 ± 16.8	28.7 ± 23.9
MP_{max} (W·kg^{-1})	25.4 ± 2.1	25.2 ± 1.7	24.7 ± 2.1	23.3 ± 2.4

Abbreviations: PT_{max}, highest value of peak torque calculated from the peak torque-metabolic power relationship; fatigue, percent decline from the PT_{max} to the peak torque corresponding to a metabolic power of 31 W·kg^{-1}; MP_{max}, metabolic power corresponding to the PT_{max}.

Table 2. Metabolic power and peripheral muscle function of knee extensors measured during the multi-stage changes of direction exercise at different time points.

	Team	T1	T2	T3
PT_{max} (N·m)	Division I	79.9 ± 11.3	80.8 ± 13.0	76.4 ± 12.6
	Division II	77.1 ± 11.4	70.8 ± 11.7	76.1 ± 12.2
	Division III	72.9 ± 12.8	67.5 ± 13.6	71.0 ± 11.3
Fatigue (%)	Division I	25.6 ± 13.3	12.5 ± 9.2	15.4 ± 11.3
	Division II	24.9 ± 26.2	10.2 ± 14.9	9.3 ± 9.0
	Division III	24.3 ± 22.9	9.9 ± 9.4	9.4 ± 9.9
MP_{max} (W·kg^{-1})	Division I	23.0 ± 1.6	25.0 ± 1.8	24.4 ± 2.0
	Division II	24.3 ± 1.3	25.9 ± 3.6	25.9 ± 1.8
	Division III	24.6 ± 1.7	25.1 ± 1.9	25.9 ± 2.1

Abbreviations: PT_{max}, highest value of peak torque calculated from the peak torque-metabolic power relationship; fatigue, percent decline from the PT_{max} to the peak torque corresponding to a metabolic power of 31 W·kg^{-1}; MP_{max}, metabolic power corresponding to the PT_{max}; T1, before the preparation period; T2, after the preparation period; T3, during the competitive phase of the season.