

THE EFFECT OF FATIGUE ON KINEMATICS AND KINETICS OF BASKETBALL DRIBBLING WITH CHANGES OF DIRECTION

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Abstract:

Basketball dribbling is one of the key elements in basketball game. There is a lack of studies investigating the effect of fatigue on kinematics and kinetics in basketball dribbling. There are two primary aims of this study: (1) to explore the effect of fatigue on kinematics and kinetics in dribbling with the change of directions; (2) to determine the effect of fatigue on dribbling speed. Fourteen Croatian senior male basketball players (age: 21.16 ± 3.43 years; body height: 188.81 ± 6.88 cm; body mass: 87.81 ± 6.06 kg; body fat: $13.34 \pm 3.52\%$), not power forwards or centers, participated in the study. Each player performed two types of change of direction (COD) while dribbling: front COD and spin move in the non-fatigued and then in the fatigued state. Xsens suit and Novel insoles were used to measure the kinematic and kinetic parameters. In terms of the front COD, the results of this study demonstrated that the maximum angular velocity in the knee ($p=.028$) and wrist joint ($p=.007$) as well as maximum force ($p=.004$) significantly decreased in the fatigued state. In terms of the spin move, the results showed that there were significant differences in pelvis velocity ($p=.000$), the maximum angular velocity in the knee joint ($p=.020$), and the first step velocity ($p=.010$) between the fatigued and non-fatigued states. No significant difference was found in the pelvis position, minimum angle in the knee joint and maximum force. Importantly, dribbling speed significantly decreased in the fatigued state ($p=.002$). The findings of this study suggest that coaching staff should design appropriate training programs to optimize players' ability to resist fatigue when dribbling under real game speed conditions.

Key words: *dribble, change of direction, spin move, velocity, angular velocity, joint angle*

Introduction

During the competition, there are three essential action options for the next movement when a player holds the ball—he/she may dribble, pass, or take a shot (Arias-Estero, 2013). In a set offense, a player with a proficient dribbling technique is able to break the opponent's intensive defense (e.g., using a crossover, penetration, and spin move), which creates free space to pass the ball to his/her teammates thus creating an open shot opportunity for them (Arias, Argudo, & Alonso, 2012; Arias-Estero, 2013), or to penetrate to the restricted area (paint). Additionally, it has been previously observed that fast break (Christmann, Akamphuber, Müllenbach, & Güllich, 2018; Conte, Favero, Niederhausen, Capranica, & Tessitore, 2017; Evangelos, Alexandros, & Nikolaos, 2005; Matulaitis & Bietkis, 2021) and transition to offense (Matulaitis & Bietkis, 2021; Milanović, Selmanović, & Škegro, 2014) are the most scoring efficient modes of attacking, both of which require high-speed dribbling to provide a temporal-spatial advantage over the defender while driving to the basket (Conte, et al.,

2017). Moreover, Conte, Favero, Niederhausen, Capranica, and Tessitore (2016) have pointed out that the proper technique of passing and dribbling reduces the number of turnovers and induces more assists (Arias, et al., 2012). Therefore, it can be said that the effective dribbling technique plays an important role in determining the outcome of a match. When it comes to dribbling in basketball, one can recognize dribbling in place, dribbling in a straight line, dribbling with a change-of-pace, and dribbling with a change of direction (COD) (Krause & Nelson, 2018). Furthermore, it has been stated that dribbling with COD is the most frequently used way of dribbling during the competition (Cortis, et al., 2011; Fujii, Yamada, & Oda, 2010).

Given the importance of dribbling technique, various aspects have been investigated so far (Dos Santos, Pacheco, Basso, Bastos, & Tani, 2020; Guimarães, et al., 2019; Robalo, Diniz, Fernandes, & Passos, 2021). A number of studies have investigated the frequency and efficiency of dribbling in basketball games and have reported that dribbling skills are constantly used during basketball games

with elite players dribbling during ~10% of the live time (Andrić, 2011; Scanlan, Dascombe, & Reaburn, 2011; Scanlan, Dascombe, Kidcaff, Peucker, & Dalbo, 2015). In addition, some other aspects of dribbling skills have been investigated such as skill improvement (Dos Santos, et al., 2020; Fujii, et al., 2010), technique evaluation (Conte, et al., 2020; Jakovljević, Karalejić, Ivanović, Štrumbelj, & Erčulj, 2017; Robalo, et al., 2021), and the effect of supplementation on dribbling performance (Scanlan, et al., 2019). Surprisingly, literature revealed few studies detecting the influence of fatigue on basketball dribbling performance.

Basketball is an intermittent high-intensity team sport characterized by short sprints, abrupt jumps, shufflings, and CODs, which can lead to acute and accumulated chronic fatigue (Erčulj, Blas, & Bračić, 2010; Mancha-Triguero, García-Rubio, Calleja-González, & Ibáñez, 2019; Li, Knjaz, & Rupčić, 2021; Mancha-Triguero, García-Rubio, Gamonales, & Ibáñez, 2021). It is well understood that fatigue has a negative influence on players' performance (Calleja-González, et al., 2016; Erčulj & Supej, 2009; Mulazimoglu, Yanar, Tunca Evcil, & Duvan, 2017; Thorpe, Atkinson, Drust, & Gregson, 2017). Several studies observed the effect of different physiological loads on shooting performance, reporting that shooting accuracy significantly decreased (Erčulj & Supej, 2009; Rupčić, et al., 2020). Similarly, the passing performance has been investigated by several studies, showing that passing accuracy decreased when players were in the fatigued state (Li, et al., 2021; Lyons, Al-Nakeeb, & Nevill, 2006). Consequently, it is specifically important that players maintain a high level of skill performance under the influence of fatigue in order to win a game (Conte, et al., 2017).

With the development of technology, many researchers have used motion capture systems to objectively analyze basketball players' skill execution (Erčulj & Supej, 2009; Nakano, Fukashiro, & Yoshioka, 2020; Okazaki & Rodacki, 2012; Okubo & Hubbard, 2015; Uygur, Goktepe, Ak, Karabörk, & Korkusuz, 2010). In the past, researchers have shown an increased interest in the influence of fatigue on kinematics of basketball skills (Erčulj & Supej, 2009; Uygur, et al., 2010). Erčulj and Supej (2009) observed the influence of fatigue on kinematics of shooting. Their findings revealed that the position of the release arm and shoulder significantly changed when players were shooting under the moderate- and high-intensity fatigue conditions (Erčulj & Supej, 2009). Uygur et al. (2010) found that fatigue did not affect selected kinematic variables of the free throw. To the best of the author's knowledge, however, no previous study has investigated the influence of fatigue on kinematics of basketball dribbling.

Therefore, there were two primary aims of this study: (1) to determine the effect of fatigue on kinematics and kinetics of dribbling with COD and (2) to observe the effect of fatigue on speed of dribbling with COD. It was hypothesized that differences in kinematic and kinetic parameters as well as in dribbling speed would be observed between dribblings of both types performed in the non-fatigued and fatigued state.

Methods

Participants

Fourteen Croatian senior male basketball players (age: 21.16 ± 3.43 years; body height: 188.81 ± 6.88 cm; body mass: 87.81 ± 6.06 kg; body fat percentage: $13.34 \pm 3.52\%$; basketball experience: 9.42 ± 4.14 years) from three professional basketball clubs volunteered to participate in this study. Inclusion criteria were a regular participation in practice sessions and competitions, and the absence of any injury in the past six months. The additional inclusion criterion was playing in the positions of either point guards ($n=5$), shooting guards ($n=4$), or small forwards ($n=5$) since basketball is a game in which players have position-specific roles according to which outside players should have a high level of fitness related to dribbling (Sekulic, et al., 2017). The exclusion criterion was playing in the positions of power forwards and centers. Players refrained from heavy training for at least one day preceding testing sessions. Prior to the testing, participants were fully informed of the study protocol and provided a written informed consent. The obtained data were treated with the greatest confidentiality and scientific rigor as their use was being restricted by the guidelines for research projects following the scientific method required in each case, complying with the Organic Law 15/1999 of the 13th of December on the Protection of Personal Data (OLPPD); the proceedings used respected the ethic criteria of the Responsible Committee of Human Experimentation and the Helsinki Statement of 2008, updated in Fortaleza, October 2013 (2013 version). All testing procedures were approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (ethical approval number: 108/2020), according to the ethical standards of the Declaration of Helsinki.

Experimental procedures

Instruments

In order to monitor players' fatigue levels, blood lactate (BL) concentration measurements were conducted using a portable lactate analyzer (Lactate Scout 3, manufacturer: SensLab GmbH, Leipzig, Germany) at four time points: before warm-up, after warm-up, after the first testing, and after the fatigue protocol. Additionally, heart rate (HR) was

monitored throughout the testing by a heart rate monitor (Polar H10, manufacturer: Polar, Kempele, Finland). The reliability and validity of Lactate Scout 3 and Polar H10 were previously confirmed (Belić, et al., 2016; Hinde, White, & Armstrong, 2021; Speer, Semple, Naumovski, & Mckune, 2020; Tanner, Fuller, & Ross, 2010).

Kinematic parameters were measured using the Xsens MVN inertial system (Xsens Technologies B.V., Enschede, The Netherlands). The players wore a full-body suit equipped with 17 wireless motion trackers (sampling frequency of 60 Hz) to ensure a full 3D motion analysis. The kinematic parameters were derived from the corresponding MVN Studio BIOMECH software (Xsens Technologies B.V., Enschede, The Netherlands). A previous study has verified the reliability and validity of the Xsens kinematic suit for the kinematic analysis of basketball skills (Robert-Lachaine, Mecheri, Larue, & Plamondon, 2017). In addition, it was used in previous studies for measuring similar data on the basketball court (Li, et al., 2021; Slawinski, et al., 2018).

For kinetic analysis pressure insoles were inserted in the participants' shoes for pressure detection with the sampling rate of 100Hz (Novel Pedar model W, Germany). Insoles are thin and light (2mm), having minimal influence on players' performance during testing, which is particularly important during a very dynamic COD in dribbling. Data were derived from the corresponding Novel software (Loadsol analysis 25.3.6). Previous studies have confirmed the reliability and validity of the Novel pressure insoles for analyzing foot pressure in sports (Sorrentino, et al., 2020; Stricker, Scheiber, Lindenhofer, & Müller, 2010). The standard calibration of pressure insoles was performed according

to the manufacturers' instructions (Novel GmbH, Munich).

Players were asked to dribble and change direction as fast as possible. Their time was recorded by photocells (WittyGate, Microgate, Bolzano, Italy). The reliability and validity of photocells were proved and used by previous studies (Balsalobre-Fernández, et al., 2019; Doyle, Browne, & Horan, 2020).

Protocol

This study used a repeated measurements study design—measurements of the kinetic and kinematic parameters of CODs in dribbling were conducted first in the non-fatigued and then in the fatigued state. All the fourteen players underwent the same protocol: they had one day of rest before the testing that consisted of the following: warm-up, a non-fatigued dribbling test, a fatigue protocol, and a fatigued dribbling test.

Prior to the testing procedure, basic anthropometric measurement was executed and data were used for the systems calibration, performed according to the instruction of the manufacturer (Xsens Technologies B.V., Netherlands). In order to ensure that all the participants were familiarized with the testing protocol, the warm-up consisted of five minutes of jogging, five minutes of dynamic stretching, and five minutes of low intensity dribbling consistent with the testing protocol. Afterwards, the calibration was conducted according to the manufacturers' instructions and the players were asked to stand in N-pose. After the calibration and synchronization, the players were asked to abduct their arms (up to first approx. 90° and then 180°) to ensure that the system was correctly calibrated, after which the dribbling testing commenced. In order to synchro-

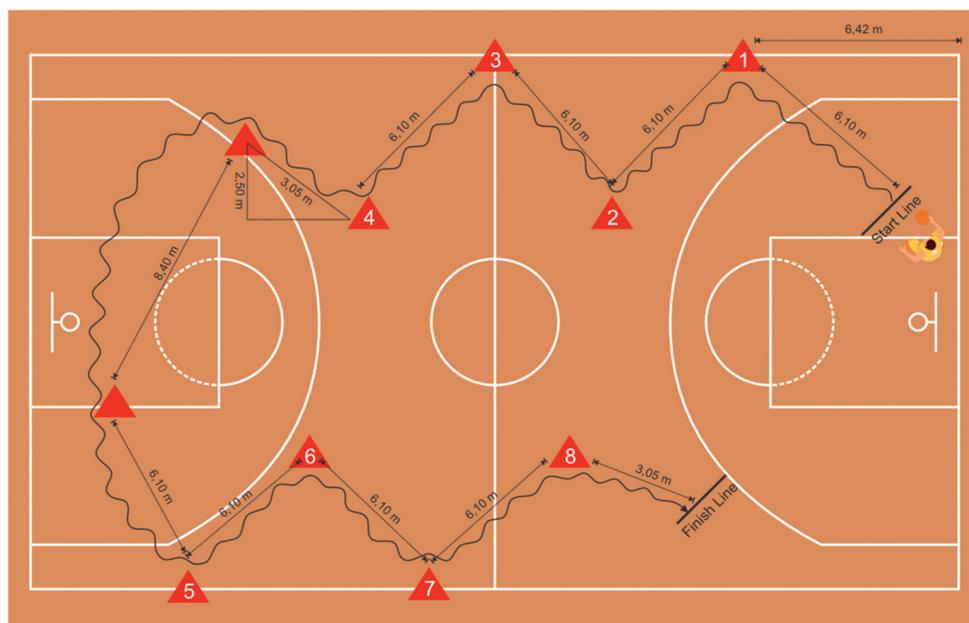


Figure 1. The illustration of the dribbling protocol.

nize both the kinetic and kinematic systems, the players were asked to lift their either left or right leg three times off the ground just before starting dribbling. That was the signal for the alignment of time-lapse of both systems.

The dribbling testing protocol is presented in Figure 1. The players dribbled the ball in full speed down the dribbling route (from the start line until the finish line) twice: first in the non-fatigued and then in the fatigued state. Every participant started his task execution with his right hand and changed movement directions when they approached the cones (from cone 1 to cone 8). The skill of the front COD in dribbling was performed at cones 1, 2, 5, and 6, and the spin move was performed at cones 3, 4, 7, and 8. Distance between the middle of the start line and the court baseline was 2.10 meters and distance between each two cones, where the players changed direction, was 6.10 meters. The photocells were placed at the start and finish line for measuring dribbling speed.

After the first dribbling test (non-fatigued state), the players were asked to perform the fatigue protocol: a 300-meter shuttle run (15×20 m with COD of 180°). This fatigue protocol was employed due to having similarities with actual game situations in which a player runs forward and backward consecutively and its reliability was previously verified (Callister, et al., 2010; Sporiš, et al., 2014). During the 300-meter shuttle run, the players were instructed to sprint as fast as possible and the sprint time was recorded by photocells (WittyGate, Microgate, Bolzano, Italy). Afterwards, the players performed the dribbling task once again so that we can observe the difference in dribbling kinematic

and kinetic COD performance between the non-fatigued and fatigued states.

Variables

Analysis of kinematic and kinetic variables was conducted on two types of dribbling: front COD and spin move. These two types of COD have been previously identified as the basic dribbling skills (Krause & Nelson, 2018). The following variables were measured:

The dribbling time the players needed to complete the testing protocol (in seconds).

For the front COD: the lowest pelvis position (PP_{\min}) (cm), the highest pelvis position (PP_{\max}) (cm), and the average pelvis position (PP_{aver}) (cm) at the moment when the players performed the front COD; the minimum angle in the knee joint of the outside leg (KA_{\min}) ($^\circ$); the maximum angular velocity in the knee joint of the outside leg during the concentric phase ($Knee_AV_{\max}$) ($^\circ/s$); the maximum angular velocity in the wrist joint ($Wrist_AV_{\max}$) ($^\circ/s$) from the point at which the player flexed his outside hand to switch the ball to his inside hand; the first step velocity (FSV) (cm) at the moment the player started to move to the reverse direction (COD has been performed); the maximum force of the outside foot during the concentric phase ($Force_{\max}$) (N).

In Figure 2 the movement pattern of the front COD in dribbling is presented.

For the spin move: the lowest pelvis position (PP_{\min}) (cm), the highest pelvis position (PP_{\max}) (cm), and the average pelvis position (PP_{aver}) (cm) during the spin move performance; the pelvis maximum velocity during the spin move executed by the rota-

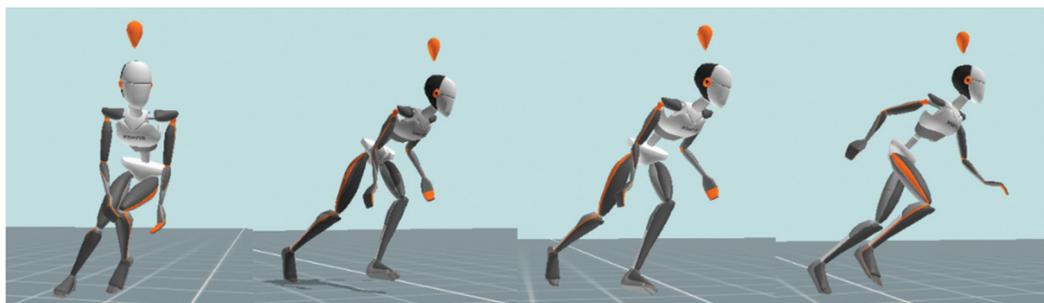


Figure 2. The movement pattern of the front change of direction.

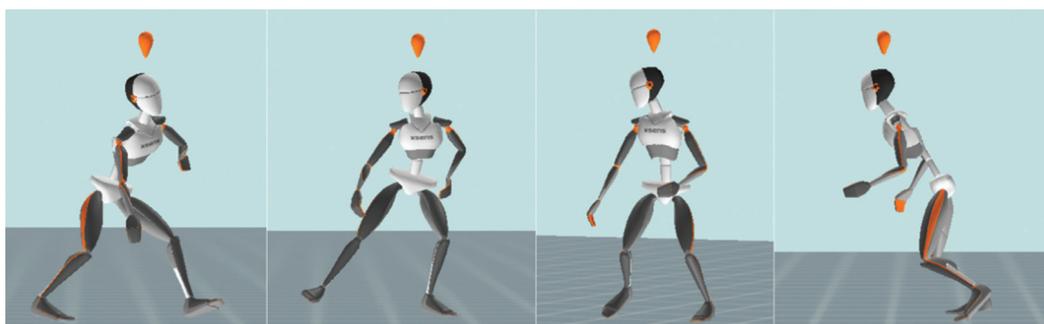


Figure 3. The movement pattern of the spin move.

tion of the pelvis (PV_{max}) (m/s); the minimum angle in the knee joint of the inside leg (KA_{min}) ($^{\circ}$); the maximum angular velocity in the knee joint of the inside leg during the concentric phase ($Knee_AV_{max}$) ($^{\circ}/s$); velocity of the first step (FSV) (m/s); the maximum force of the inside foot during the concentric phase ($Force_{max}$) (N).

Figure 3 demonstrate the movement pattern of the spin move.

Statistical analysis

With the use of the G*power program, the sample size (the number) of dribbles with COD needed for inferential statistical analysis was calculated ($n = 98$) at statistical significance of $p < .05$; statistical power 0.8; effect size 0.3, and two groups. Kinematic and kinetic parameters of dribbling were measured in every COD performance during a dribbling execution (giving a total of 224 CODs performed, 56 of each type in each state of fatigue). Unfortunately, 24 CODs were excluded from the final analysis due to some technical issues with the equipment or movement pattern execution. Overall, a total of 200 properly executed and measured CODs (50 of each type in each state of fatigue) was analyzed in this study.

All analyses were executed in the statistical package Statistica, version 13.5.0.17 (TIBCO Software Inc, Palo Alto, CA, USA; release date: November 2018). Values were expressed as mean \pm standard deviation. Basic descriptive parameters

were calculated for all the measured variables. The normality of the data distribution was confirmed by a Shapiro-Wilk test. To verify the differences in the kinematic variables between the fatigued and non-fatigued states, an analysis of variance (ANOVA) for repeated measurements was applied. To determine the difference in dribbling speed between the non-fatigued and fatigued states, a t -test for dependent samples was conducted and the effect size was determined using the Cohen's d . The level of statistical significance was set at $\alpha = .05$.

Results

Front COD

Table 1 shows that there was a significant difference between the fatigued and non-fatigued state ($p = 0.000$).

Table 1. The results of ANOVA for repeated measurements (for groups)

Test	Value	F	p
Wilks	0.75	3.87	0.000*

Note. * Marked values were significant when $p < .05$.

Table 2 and Figure 4 provide the descriptive parameters and results of ANOVA for repeated kinematic and kinetic measurements executed in the fatigued and non-fatigued states. First, the mean value of $KNEE_AV_{max}$ significantly decreased in the

Table 2. Descriptive parameters and results of ANOVA for repeated measurements of the fatigued and non-fatigued states

Variable	Group	N	Mean	Min	Max	SD	F	p
PP_{min} (cm)	Non-fatigued	50	76.79	64.93	91.30	6.47	0.15	0.700
	Fatigued	50	77.31	65.56	93.80	6.92		
PP_{max} (cm)	Non-fatigued	50	90.51	76.12	107.05	6.53	0.06	0.804
	Fatigued	50	90.85	75.03	108.93	6.96		
PP_{aver} (cm)	Non-fatigued	50	82.72	71.21	98.16	6.08	0.29	0.589
	Fatigued	50	83.42	72.25	99.98	6.86		
KA_{min} ($^{\circ}$)	Non-fatigued	50	118.70	103.52	132.56	7.16	0.14	0.707
	Fatigued	50	119.23	102.58	132.88	6.93		
$KNEE_AV_{max}$ ($^{\circ}/s$)	Non-fatigued	50	429.72	222.59	664.81	109.01	4.97	0.028*
	Fatigued	50	378.63	180.72	661.01	119.79		
$WRIST_AV_{max}$ ($^{\circ}/s$)	Non-fatigued	50	387.56	115.26	709.03	164.31	7.62	0.007*
	Fatigued	50	300.85	96.52	771.62	149.34		
FSV (m/s)	Non-fatigued	50	4.78	2.58	7.32	1.06	1.09	0.299
	Fatigued	50	4.55	1.26	6.21	1.14		
$Force_{max}$ (N)	Non-fatigued	50	1782.26	1109.16	2747.52	347.06	8.89	0.004*
	Fatigued	50	1608.42	1132.95	2043.40	222.52		

Note. * $p < .05$; PP_{min} – the lowest pelvis position at the moment when the players performed the front change; PP_{max} – the highest pelvis position at the moment when the players performed the front change; PP_{aver} – the average pelvis position at the moment when the players performed the front change; KA_{min} – the minimum angle in the knee joint of the outside leg; $Knee_AV_{max}$ – the maximum angular velocity in the knee joint of the outside leg during the concentric phase; $Wrist_AV_{max}$ – the maximum angular velocity in the wrist joint from the point that the players flexed their outside hand to switch the ball to the inside hand; FSV – the first step velocity at the moment when the players performed the front change; $Force_{max}$ – the maximum force of the outside foot during the concentric phase.

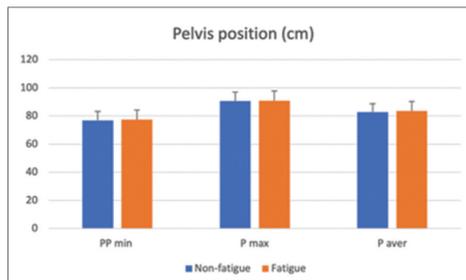


Figure 4 (a) comparison of the pelvis position

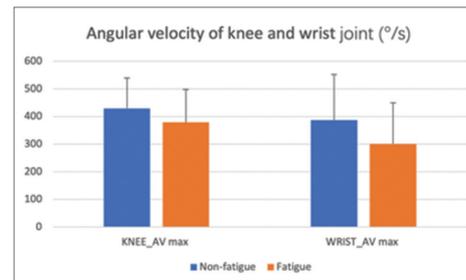


Figure 4 (b) comparison of the angular velocity

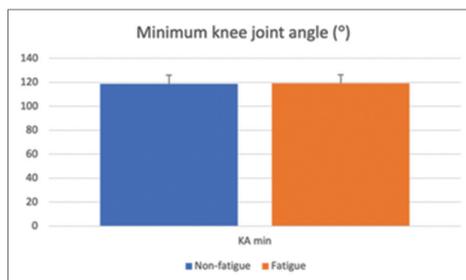


Figure 4 (c) comparison of the minimum knee angle

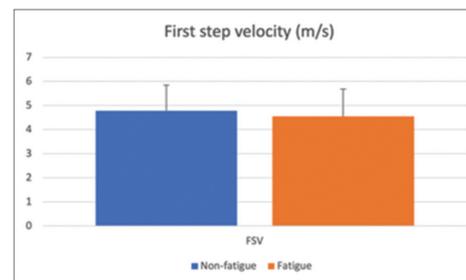


Figure 4 (d) comparison of the first step velocity

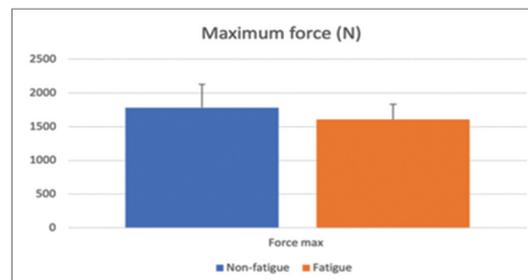


Figure 4 (e) comparison of the maximum force

Figure 4. The comparison of the variables for the front COD.

fatigued compared to the non-fatigued state (fatigued=378.63 °/s; non-fatigued=429.72 °/s; $p=.028$). Additionally, the mean value of $WRIST_AV_{max}$ considerably decreased in the fatigued compared to the non-fatigued state (fatigued=300.85 °/s; non-fatigued=387.56 °/s; $p=.007$). Furthermore, the mean value of $Force_{max}$ dramatically decreased in the fatigued compared to the non-fatigued state (fatigued=1608.42 N; non-fatigued=1782.26 N; $p=.004$). Second, the mean value of FSV was lower in the fatigued than in the non-fatigued state (fatigued=4.55 m/s; non-fatigued=4.78 m/s) but there was no significant difference between the two variables ($p=.229$). Last, the PP_{min} , PP_{max} , and PP_{aver} all slightly increased in the fatigued state compared to the non-fatigued state. Likewise, the KA_{min} was higher in the fatigued state than in the non-fatigued state (fatigued=119.23 °; non-fatigued=118.70 °). However, there was no significant difference in terms of PP_{min} ($p=.700$), PP_{max} ($p=.804$), PP_{aver} ($p=.589$) and KA_{min} ($p=.707$).

Spin move

The analysis of variance (ANOVA) for repeated measurements was used to observe the biomecha-

nical difference in dribbling performance between the non-fatigued and fatigued states. As Table 3 shows, there was a significant difference between the two groups of variables ($p=.003$).

Table 3. The results of ANOVA for repeated measurements (for groups)

Test	Value	F	p
Wilks	0.78	3.20	0.003*

Note. * Marked values were significant when $p<.05$.

Table 4 and Figure 5 present the descriptive parameters and results of ANOVA for repeated kinematic and kinetic measurements executed in the fatigued and non-fatigued states. First, the mean value of PV_{max} significantly decreased in the fatigued state compared to the non-fatigued state (fatigued=2.79 m/s; non-fatigued=3.15 m/s; $p=.000$). Likewise, the mean value of $KNEE_AV_{max}$ was dramatically decreased in the fatigued state (fatigued=286.90 °/s; non-fatigued=328.63 °/s; $p=.020$). Moreover, FSV was considerably lower in the fatigued than in the non-fatigued state (fatigued=7.41 m/s; non-fatigued=7.76 m/s; $p=.010$). Second, the

Table 4. Descriptive parameters and results of ANOVA for repeated measurements of the fatigued and non-fatigued states

Variable	Group	N	Mean	Min	Max	SD	F	p
PP _{min} (cm)	Non-fatigued	50	78.82	70.16	98.25	6.59	0.76	0.386
	Fatigued	50	80.02	69.23	96.670	7.25		
PP _{max} (cm)	Non-fatigued	50	92.08	78.57	109.95	7.39	0.46	0.498
	Fatigued	50	93.07	80.75	106.43	7.20		
PP _{aver} (cm)	Non-fatigued	50	86.71	76.35	104.56	7.19	0.20	0.656
	Fatigued	50	87.36	74.93	102.00	7.42		
PV _{max} (m/s)	Non-fatigued	50	3.15	2.42	4.09	0.37	16.88	0.000*
	Fatigued	50	2.79	1.12	3.69	0.49		
KA _{min} (°)	Non-fatigued	50	111.98	92.85	135.21	9.61	1.14	0.288
	Fatigued	50	114.21	91.92	141.67	11.28		
KNEE_AV _{max} (°/s)	Non-fatigued	50	328.63	202.29	563.13	90.92	5.60	0.020*
	Fatigued	50	286.90	49.10	559.78	85.33		
FSV (m/s)	Non-fatigued	50	7.76	6.43	9.07	0.62	6.83	0.010*
	Fatigued	50	7.41	4.87	8.84	0.71		
Force _{max} (N)	Non-fatigued	50	1736.77	963.54	2786.40	415.88	3.64	0.059
	Fatigued	50	1583.00	982.80	2838.60	389.24		

Note. * p<.05; PP_{min} – the lowest pelvis position at the moment when the players performed the spin move; PP_{max} – the highest pelvis position at the moment when the players performed the spin move; PP_{aver} – the average pelvis position at the moment when the players performed the spin move; PV_{max} – the maximum velocity of the pelvis at the moment when the players performed the spin move by rotating their pelvis; KA_{min} – the minimum angle in the knee joint of the inside leg; Knee_AV_{max} – the maximum angular velocity in the knee joint of the inside leg during the concentric phase; FSV – the first step velocity at the moment when the players performed the spin move; Force_{max} – the maximum force of the inside foot during the concentric phase.

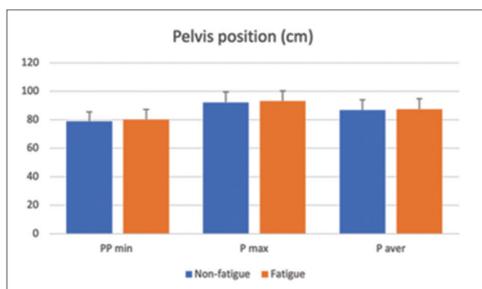


Figure 5 (a) comparison of the pelvis position

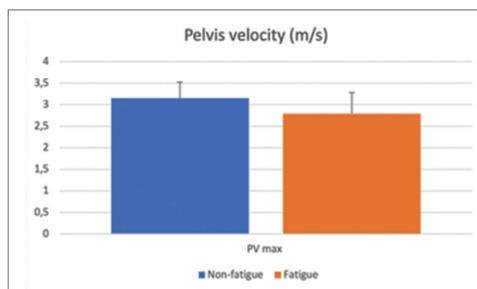


Figure 5 (b) comparison of the pelvis velocity

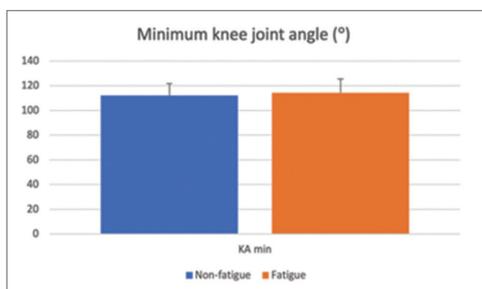


Figure 5 (c) comparison of the knee angle

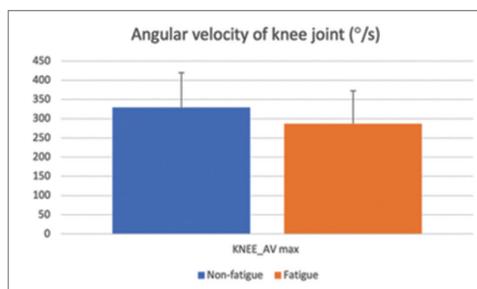


Figure 5 (d) comparison of the angular velocity

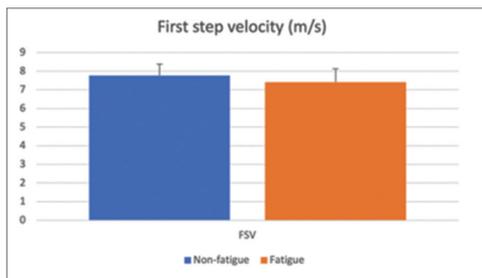


Figure 5 (e) comparison of the first step velocity

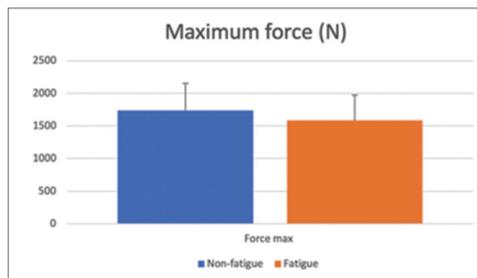


Figure 5 (f) comparison of the maximum force

Figure 5. The comparison of the variables for the spin move.

Table 5. The results in dribbling speed of the *t*-test for dependent samples

Group	N	Mean (s)	SD	p	Cohen's (d)
Non-fatigued	14	17.50	0.87	0.002*	1.001
Fatigued	14	18.53	1.52		

Note. * Marked values were significant when $p < .05$.

Table 6. Descriptive statistics of heart rate (HR) and blood lactate (BL) variables between the non-fatigued and fatigued states

Variable	N	Mean	Minimum	Maximum	SD
HR_B_WU (beats/min)	14	79.07	58.00	102.00	11.47
HR_A_FT (beats/min)	14	173.36	156.00	194.00	11.84
HR_A_FP (beats/min)	14	188.57	173.00	203.00	9.39
HR_D_ST _{max} (beats/min)	14	178.86	164.00	197.00	10.28
BL_B_WU (mmol/l)	14	1.26	0.60	1.70	0.35
BL_A_WU (mmol/l)	14	2.74	0.70	5.80	1.55
BL_A_FT (mmol/l)	14	5.55	2.60	10.00	2.52
BL_A_FP (mmol/l)	14	11.06	6.70	15.70	3.19

Note. BL_B_WU – the players' heart rate before warm-up; HR_A_F – the players' heart rate after the first testing (non-fatigued state); HR_A_FP – the players' heart rate after the fatigue protocol; HR_D_ST_{max} – the players' heart rate during second testing (fatigued state); BL_B_WU – the players' blood lactate before warm-up; BL_A_WU – the players' blood lactate after warm-up; BL_A_FT – the players' blood lactate after the first testing (non-fatigued state); BL_A_FP – the players' blood lactate after the fatigue protocol (fatigued state).

Force_{max} in the fatigued state decreased compared to the non-fatigued state but no statistical significance was reached (fatigued=1583 N; non-fatigued=1736.77 N; $p=.059$). Last, similar to the results for the front COD dribbling, the mean values of PP_{min}, PP_{max}, PP_{aver} and KA_{min} were slightly higher in the fatigued state than in the non-fatigued state but no significant differences were obtained—PP_{min} ($p=.386$), PP_{max} ($p=.498$), PP_{aver} ($p=.656$), and KA_{min} ($p=.288$).

To determine the difference in dribbling speed between the non-fatigued and fatigued states, a *t*-test for dependent samples was applied. As can be seen from Table 5, the players needed significantly ($p=.002$) more time in the fatigued state compared to the non-fatigued state (fatigued=18.53 s; non-fatigued=17.50 s).

The physiological response during testing

Table 6 shows an overview of the participants' heart rate and blood lactate values in the non-fatigued and fatigued states. The mean HR value was 79.07 beats/min and 188.57 beats/min before warm-up (non-fatigued state) and after the fatigue protocol (fatigued state), respectively. Additionally, the mean BL value was 1.26 mmol/L and 11.06 mmol/L before warm-up (non-fatigued state) and after the fatigue protocol (fatigued state), respectively. The aforementioned results revealed that there was a significant difference between the non-fatigued and fatigued states in fatigue levels.

Discussion and conclusions

Dribbling with COD is motorically the most complex type of dribbling and players perform it frequently during competition due to a high level of pressure from defenders (Krause & Nelson, 2018). Previous studies have reported that fatigue has a negative influence on basketball players' performance (Erculj & Supej, 2009; Mulazimoglu, et al., 2017). Surprisingly, little is known about the effect of fatigue on kinematics and kinetics of basketball dribbling. The aim of this study was to determine the effect of fatigue on kinematics and kinetics of dribbling with COD as well as the effect of fatigue on dribbling speed. The results of the present study showed that there was a significant difference in dribbling kinematics and kinetics between the fatigued and non-fatigued states. Additionally, dribbling speed significantly decreased in the fatigued state compared to the non-fatigued state. The findings are in line with our previously formulated hypotheses.

In this study, the mean value of the players' HR was 79.07 ± 11.47 beats/min in the state before warm-up (non-fatigued state) and 188.57 ± 9.39 beats/min in the state after the fatigue protocol (fatigued state). Additionally, the mean value of the players' BL concentration was 1.26 ± 0.35 mmol/L in the state before warm-up (non-fatigued state) and 11.06 ± 3.19 mmol/L in the state after the fatigue protocol (fatigued state). There were some studies investigating the response of HR and BL to the real game situation (McInnes, Carlson, Jones, & McKenna, 1995;

Torres-Ronda, Ric, Llabres-Torres, de Las Heras, & Schelling, 2016). Torres-Ronda et al. (2016) assessed players' HR during a friendly basketball game, reporting that the peak HR was 198 beats/min. Another study by McInnes et al. (1995) observed the physiological response to basketball competition, stating that the mean maximum BL concentration for all subjects was 8.5 ± 3.1 mmol/L, with the highest individual having 13.2 mmol/L. Given the aforementioned results, it can be concluded in this study that the conditions during testing in the fatigued state were similar to real basketball competition (game speed).

For the front change (FCOD) and spin move (SM), the selected variables of this study were pelvis position, KA_{\min} , $KNEE_AV_{\max}$, $WRIST_AV_{\max}$, FSV, and $Force_{\max}$. The pelvis position was used to observe the difference of the center of mass between the non-fatigued and fatigued states. Similarly, the KA_{\min} was used to observe the lowest position of the knee so to identify if the players lowered their body when the defenders (cones) were close to the ball handler. The assumption was that, if the aforementioned variables in the fatigued state had higher values, it would mean that the player, his center of mass, was in a higher position, which might consequently induce the possibility of losing ball possession and affect the realization of spatial and temporal advantage over the defender. Additionally, $Force_{\max}$ was selected because it plays an important role in the players' FSV. Namely, FSV determines if a player can pass by the defender successfully. Furthermore, the $KNEE_AV_{\max}$ was selected because the players with a higher $KNEE_AV_{\max}$ could generally perform a quick first step. Moreover, the players with higher $WRIST_AV_{\max}$ are able to switch the ball from the outside to the inside hand quickly so that they cannot only protect the ball well but also make a quick COD to pass by the defenders. Last, the PV_{\max} in SM was selected because a higher velocity of pelvis rotation was not only critical for ball possession keeping but it also facilitated achieving a spatial and temporal advantage over the defender.

Consistent with literature, this study found that there were significant differences between the non-fatigued and fatigued states in the kinematics of FCOD and SM, which was in agreement with previous studies showing that the kinematic parameters of basketball skills changed when the players were under the influence of fatigue (Erculj & Supej, 2006, 2009; Rupčić, et al., 2020). Additionally, the current study found that there was a statistically significant difference in $Force_{\max}$ (kinetic) with respect to FCOD between the fatigued and non-fatigued states (fatigued=1608.42 N; non-fatigued=1782.26 N; $p=.004$). This finding is in line with previous studies confirming that fatigue can cause the reduction in the capacity of muscles to

generate force (Arora, Budden, Byrne, & Behm, 2015; Morin, Samozino, Edouard, & Tomazin, 2011; Wan, Qin, Wang, Sun, & Liu, 2017), which results in a player who is unable to continue moving at the same level of performance (Cortes, Onate, & Morrison, 2014; Morin, et al., 2011). However, the $Force_{\max}$ did not significantly decrease in the fatigued state in terms of SM (fatigued=1583 N; non-fatigued=1736.77 N; $p=.059$). A possible explanation for this result may be the technical difference between the FCOD and SM execution. When players perform SM, they first make a forceful step with the inside foot, then the pressure on the inside foot is shifted onto the outside foot with the rotation of the pelvis following the first step (Krause & Nelson, 2018). In terms of FCOD, however, the player conducts the first step by fully pressing the ground with the same foot. Therefore, the foot pressure of the support leg during the concentric phase is supposed to be lower in SM compared to FCOD. As a result, the $Force_{\max}$ did not significantly decrease in the fatigued state.

The results of this study revealed that dribbling speed significantly decreased in the fatigued state ($p=.002$), corresponding to previous studies which concluded that fatigue had a negative influence on basketball players' performance (Erculj & Supej, 2009; Mulazimoglu, et al., 2017; Thorpe, et al., 2017). These results may be explained by the fact that the reduction of force production leads to the decrease of dribbling speed as it has been proved that there is a strong correlation between velocity and force (Janicijevic, et al., 2020; Zivkovic, Djuric, Cuk, Suzovic, & Jaric, 2017). Furthermore, previous studies have pointed out that a greater lower body strength (Spiteri, Cochrane, Hart, Haff, & Nimphius, 2013) and the subsequent application of a greater force and impulse (Spiteri, et al., 2014) enable athletes to perform a more effective and rapid motor response. In accordance with the present results, numerous studies have found the same result that sprint speed decreases when the subjects are in the fatigued state (Dal Pupo, Detanico, Achedias, & Santos, 2017; Morin, et al., 2011). Morin et al. (2011) investigated the effect of fatigue on force production and force application technique during repeated sprints. Sprint speed and force production dramatically decreased. Furthermore, Dal Pupo et al. (2017) studied the fatigue effect of a simulated futsal match protocol on sprint performance and the kinematics of the lower limbs, demonstrating a significant decrement in sprint speed.

In our study, the $KNEE_AV_{\max}$ ($p=.028$) and $WRIST_AV_{\max}$ ($p=.007$) in the fatigued state significantly decreased compared to the non-fatigued state with respect to FCOD. Additionally, the mean value of $KNEE_AV_{\max}$ dramatically decreased in the fatigued state ($p=.020$) regarding SM. These results may be explained by the fact that fatigue

caused the reduction in muscle strength, velocity, and coordination (Janicijevic, et al., 2020; Morin, et al., 2011; Zivkovic, et al., 2017), which ultimately reduced angular velocities in individual joint systems. Our study can explain the decrease of the FSV in both FCOD and SM by the fact that fatigue caused the decrease in force production and then further led to the deterioration of FSV. Similarly, the mean value of PV_{max} in SM significantly decreased in the fatigued state ($p=.000$), which was likely to be associated with this factor.

In this study, the pelvis position (PP_{min} , PP_{max} , PP_{aver}) was higher and KA_{min} was larger in the fatigued state than in the non-fatigued state regardless of whether in FCOD or SM. Previous studies have stated that decreases in the lower limb muscle activation due to fatigue could result in changes in pelvis position, and the reduction in strength tended to increase the players' center of mass (Lessi, dos Santos, Batista, de Oliveira, & Serrão, 2017; Lessi & Serrão, 2017). As a result, theoretically, the KA_{min} is supposed to also be increased when the players' pelvis position increases.

In summary, the major conclusion drawn from this study according to the results was that fatigue significantly affected the kinematics and kinetics of basketball dribbling. Additionally, dribbling speed significantly decreased when the players were under the fatigued state. The higher pelvis position, the lower angular velocity in the knee and wrist joint, and the lower force production when the players are under the fatigued state may induce their inability

to take advantage over the defender successfully. Additionally, the decrease in dribbling speed under the fatigued state will make players less able to pass quickly by the defender during the fast break and transition to offense, which consequently makes them lose the opportunity of scoring.

Practical application

The findings of this study have provided evidence for the coaching staff why they are required to design appropriate training programs to optimize the players' fatigue resistance needed in dribbling. There is an exceptional need, after the skill has been adopted, to practice it under the conditions of high load and game speed in order to decrease the expected reduction in execution efficiency. Segments that have shown statistical significance should be in the focus of expert coaches being able to evaluate skill performance and constantly improve it using a large number of training operators under high load. It is important to ultimately achieve skill performance automatism in players whose skill execution will remain close to perfect even under the conditions of extreme load in order to be able to respond to the challenges of modern basketball in which defensive pressure on the player with the ball is extremely high. Only players who can demonstrate a high level of skill performance under high loads (both cognitive and physical) can find the best solution in spatial and temporal on-court alignment and ultimately achieve exceptional situation-related efficiency.

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Ethical Approval Information

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (ethical code 108/2020, November 27, 2020).

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