

Igor Štirn^{1,*}
Tjaša Brišnik¹
Frane Erčulj¹

VERTICAL LOAD ASSESSMENT IN MEN AND WOMEN 3X3 BASKETBALL

UGOTAVLJANJE OBREMENITEV V NAVPIČNI SMERI PRI KOŠARKI 3X3

ABSTRACT

The purpose of the study was to evaluate the frequency and intensity of players' actions associated with jumping in the 3x3 basketball game, to compare these data between men's and women's teams, and to compare the data obtained with existing data from 5-on-5 basketball. Jumps during the five final games of the men's and women's national championship were recorded using the inertial measurement device VERT which was previously calibrated using force platform. The significance level set for the study was $p \leq 0.05$. The number and height of jumps during the execution of jump shots from outside and inside the paint, lay-up shots, rebounds, and blocks were monitored. Female and male players performed 1.05 and 1.63 jumps per minute, respectively, in the 3x3 basketball game. For all jumps observed, the number of jumps was higher in males than in females, and the largest differences were found in jump shots inside the paint and jump when blocking ($p < 0.05$). The relative intensity of the jumps, expressed as a percentage of the maximum countermovement jump obtained before the play, showed that heights of just over 50% of the maximum were most common, except for the male players executing layup shots where the heights reached over 70% of the maximum. Comparing the results with previous studies, we summarize that the performance level of the athletes influences the frequency of actions. Low level teams executed fewer actions than high level teams, in parallel to their physical fitness.

Keywords: jump, shot, throw, external load

¹*Faculty of sport, University of Ljubljana, Ljubljana, Slovenia*

IZVLEČEK

Namen študije je bil izmeriti pogostost in intenzivnost akcij igralcev povezanih s skoki v košarkarski igri 3x3 tako pri ženskah kot pri moških ter rezultate primerjati z obstoječimi podatki iz košarke 5x5. Z uporabo inercialnih merilnih naprav VERT, ki so bile predhodno kalibrirane s pomočjo pritiskovne plošče smo zaznali in izmerili vse skoke igralcev med zaključnimi petimi tekmami državnega prvenstva v košarki 3x3. Spremljali smo število in višino skokov izvedenih znotraj in zunaj rakete, med polaganjem, pri obrambnih in napadalnih skokih za žogo in pri blokiranju nasprotnih igralcev. Ugotovili smo, da do igralci v košarkarski igri 3x3 opravili 1,05 in 1,63 skoka na minuto. Pri vseh opazovanih skokih je bilo število skokov večje pri moških kot pri ženskah, največje razlike so bile ugotovljene pri skokih znotraj rakete in pri skokih pri blokiranju ($p < 0,05$). Relativna intenzivnost skokov, izražena kot odstotek od največjega skoka z nasprotnim gibanjem, izmerjenega pred tekmo, je pokazala, da so bile najpogostejše višine nekaj višje kot 50 % od najvišjih. To ne velja za skoke med polaganjem pri moških, katerih višine so dosegale tudi več kot 70 % največje višine. Če primerjamo rezultate s prejšnjimi študijami, vidimo, da na pogostost posameznih akcij vpliva tudi stopnja zmogljivosti oziroma treniranosti športnikov; ekipe nižje ravni so, v skladu s svojo slabšo fizično pripravljenostjo, izvedle manj akcij (skokov) kot ekipe na višji ravni.

Gljučne besede: skok, strel, met, zunanja obremenitev

Corresponding author:* Igor Štirn,
Faculty of sport, University of Ljubljana, Gortanova
ulica 22, 1000 Ljubljana, Slovenia
E-mail: igor.stirn@fsp.uni-lj.si

INTRODUCTION

Basketball is one of the most popular team sports in the world. In its original form, which originated in the United States in the late 19th century, and according to FIBA (Fédération Internationale de Basketball) rules, two teams of five players each play against each other, trying to score more points than the opposing team. Since then, basketball has been played outdoors one on one, two on two and three on three, but in the last decade, the three against three form advanced to competitive sport and was labeled 3x3 (www.fiba3x3.com). In 2010, it was included in the Youth Olympic Games for the first time, and 10 years later, it was played at the 2020 Tokyo Olympics OG. Besides the advancement to competitive level, 3x3 basketball is the most famous and widely played urban team sport.

It is the nature of the sport of basketball that much of the motion is directed to the rim, which is 3.05 m above the floor. In other words, the vertical component of movement, and thus the different variations of jumping, are prevalent in basketball and of paramount importance to success (Russell et al., 2021). Approximately 50% or more of throws are made by jumping with both legs (i.e., jump shots) (Erčulj & Štrumbelj, 2015; Tang & Shung, 2005) and another 15 to 20% of all throws are made after a single-leg takeoff, i.e., lay-ups (Erčulj & Štrumbelj, 2015). Jumping exerts large forces on the body (Linthorne, 2001; Ortega, et al., 2010). During concentric push-off (i.e., squat jump), which rarely occurs in the game, the applied forces average 250% of body weight (BW). In the eccentric part of the countermovement jump, they can reach 300% of the body weight, mainly due to the active braking phase. However, the highest forces to which the body is subjected occur during landing. Impact forces during landing can reach up to 600% of BW for females and 750% of BW for males (Abián et al., 2008), some peaks can even reach 900% of BW (McNitt-Gray, 1991; Ortega et al., 2010). Such forces are also generated during drop jumps, especially when the fast SSC muscle action is performed with a short contact time (< 200 ms). Frequent impacts with large forces represent an overload on the human musculoskeletal system, and injuries are likely developed. The entire lower limb kinetic chain is under stress - ankles, knees, hips and finally spine can be affected (Nigg, 1985).

For the above reasons, it is imperative to consider the external load to which athletes are exposed (Fox, Scanlan, & Stanton, 2017). External load has been assessed by monitoring velocities, accelerations, jumps, forces, etc. Inertial measurement units (IMU) with built-in accelerometers, gyroscopes, and magnetometers have recently been used for this data acquisition. IMU such as the one used in our study (VERT) records the number of jumps as

well as their height. The accuracy of these devices has been studied and found to be acceptable (Brooks et al., 2018; Charlton et al., 2017; MacDonald et al., 2017). Some newer models also records landing and kinetic energy, however, this data has not yet been shown to be reliable as a large amount of variability has been found (Damji, et al., 2021).

Being a popular sport a number of studies have been conducted on the physical demands of basketball (Feroli et al., 2020; Pernigoni et al., 2021; Piedra & Caparros, 2021). Loads in horizontal plane, i.e. running in different directions and changing direction, the different modes of running (forward, backward, lateral, with/without the ball, etc.), and the movement velocities have been monitored most frequently, mostly using motion tracking systems and inertial measurement devices (Abdelkrim, et al., 2007; Puente et al., 2017; Stojanović et al., 2018; Svilar et al., 2019). However, one of the most recent systematic reviews on this topic still bring to an end that it is not possible to draw definitive conclusions about the actual physical demands of basketball based on the current literature (Russell et al., 2021), therefore more studies are required. Some of the studies analyzed in the above-mentioned review monitored the jumps performed during the play. Svilar et al. (Svilar et al., 2019; Svilar, Castellano, & Jukic, 2018; Svilar, Castellano, Jukic, & Casamichana, 2018) recorded and analyzed some training sessions, training games with non-stopping and regular stopping time and training matches and concluded that the loads in vertical plane (mainly evaluated by the number and heights of the jumps) were greater than in other two planes. Young players were investigated (Abdelkrim et al., 2007), as well as semiprofessional and professional players (Puente et al., 2017; Scanlan et al., 2011). Research in female basketball does not lag behind, also monitoring young, elite and professional players (Matthew & Delestrat, 2009; Roell et al., 2020; Scanlan et al., 2012; Taylor et al., 2015b). Finally, loads in all planes of movement were the object of interest of the research regarding the activity demands and injuries (Ghali et al., 2020; Taylor et al., 2015a).

When it comes to an in-depth analysis of external loading from high impact forces during jumping (and landing) in 3x3 basketball, the literature is more modest. We found only three studies observing jumps in 3x3 basketball (Conte et al., 2019; Montgomery & Maloney, 2018b, 2018a). Regarding jumps, last two studies deal with the same data showing that the average number of jumps per game in elite 3x3 competitions were 5.24 ± 3.66 (jump heights below 0.2m), 11.89 ± 5.41 (between 0.2-0.4m), 2.40 ± 1.81 (above 0.4m) for men and 7.27 ± 5.45 (jump heights below 0.2m), 10.01 ± 4.99 (between 0.2-0.4m) and 6.19 ± 4.29 (above 0.4m) for women. Analyzing performance profile in 3x3 Conte et al. (2019) monitored shots and

rebounds, however they were focused more on statistic values and did not take into consideration whether these actions were performed with or without jumping.

Obviously, there is a gap in the literature regarding the distribution of jumps (offensive, defensive, shots, rebounds) as well as their relative intensity, i.e. height in relation to the individual maximum jump height. Since 3x3 basketball is played on half a basketball court, using one backboard and rim more action such as starting, breaking and especially jumping can be expected. In other words, the vertical component is likely to be even more important compared to basketball 5x5. Therefore, the aim of our study was to evaluate the frequency and intensity of players' actions associated with jumping, to compare these data between men and women teams, and to compare the obtained data with the existing data from basketball 5 on 5.

METHODS

Participants

Members of a male team (20.6 ± 0.3 years old, height = 1.97 ± 0.07 m , weight = 100.1 ± 13.2 kg) and a female team (22.2 ± 3.2 years old, height = 1.78 ± 0.05 m , weight = 75.5 ± 8.3 kg) were observed during the final five games of the national 3x3 basketball championship. According to the rules, each team consisted of four players (three on the court + one substitute). All players were informed about the purpose and procedure of the study; they participated voluntarily, were healthy and uninjured, and signed a written informed consent. The study was conducted in accordance with the Declaration of Helsinki and with the approval of the University Ethics Committee.

Measures

The inertial measurement device VERT (Mayfonk Athletic, Florida, USA) was used to record jumping activity during the games. VERT contains a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer. The device measures $6 \times 3 \times 0.5$ cm and was worn on an elastic belt at the level of the L3 or L4 vertebrae to be close to the body's center of mass as suggested by the developers. The VERT recorded the number of jumps and jump height. All four players of each team were monitored simultaneously, however only three were on the court at the same time and one on the bench. The playing time of an individual player was monitored but not considered; only team statistics was analyzed. VERT devices were first calibrated, as the absolute values obtained were not accurate. A force plate with corresponding software, which

is the gold standard for jump measurements, was used to calibrate the VERT. A volunteer was equipped with the unit as described and performed seven jumps, starting with small jump heights and increasing steadily to the maximum height. The heights measured simultaneously with the force platform and VERT were plotted on a graph and a linear curve was fitted to the data. A linear equation was created for each sensor and used to calculate the "true" height. The R-squares of all fitted linear curves were also obtained and showed good linearity ($R^2 = 0.951 \pm 0.026$).

Before the first game and after regular warm up for the match, each player performed three maximum countermovement jumps without arm swing. Subject stood in an upright position with arms placed on the hips. From this position, he squatted to 90° knee flexion position, then extended the legs, and performed the take-off to jump as high as possible. The highest jump was used to normalize jumps performed during the game so that relative heights could be calculated. We measured all jumps executed during the game. We defined three types of jump shots and two jumps without the ball: jump shot inside the paint (PS), jump shot outside the paint, i.e., distance shot (DS), the lay-up shot (LUS), rebound jump (REB), and jump while blocking the opponent's shot (BLO). Note that the LUS was the only one-legged jump, while all other jumps were performed with both legs. We measured the frequency of all jumps as well as their height. To observe the type of jump, all games were recorded with a video camera. Three consecutive jumps were performed at the beginning of the game to synchronize the video and jump recordings. All Vert jump data files were exported to a Microsoft Excel (2016) spreadsheet (The Microsoft Corporation, Redmond, Washington) for subsequent matching with the jumps derived from the video. Data from both sources were synchronized based on the time of the initial jumps. In this way, the jumps recorded by the Vert device and those from the video recording could be accurately matched based on the time of their occurrence and labeled according to the above definitions. Games were played according to the official rules, i.e. each game lasted 10 minutes or until one of the two teams scored 21 points. Attack was limited to 12 seconds.

Design and Procedures

The players of one female and one male team were equipped with an inertial measurement device VERT and all jumps performed during the final five games of the national championships were recorded and analyzed. At the same time, the games were video recorded to distinguish between different game actions such as jump shots, rebounds and blocks. The

frequency distribution as well as the intensity of jump actions, expressed as jump height in relation to maximum jump height, were determined. Differences between the female and male games were observed, as well as a comparison with 5x5 basketball from the literature. The frequency and intensity of jumps performed during the game are of paramount importance in planning physical preparation.

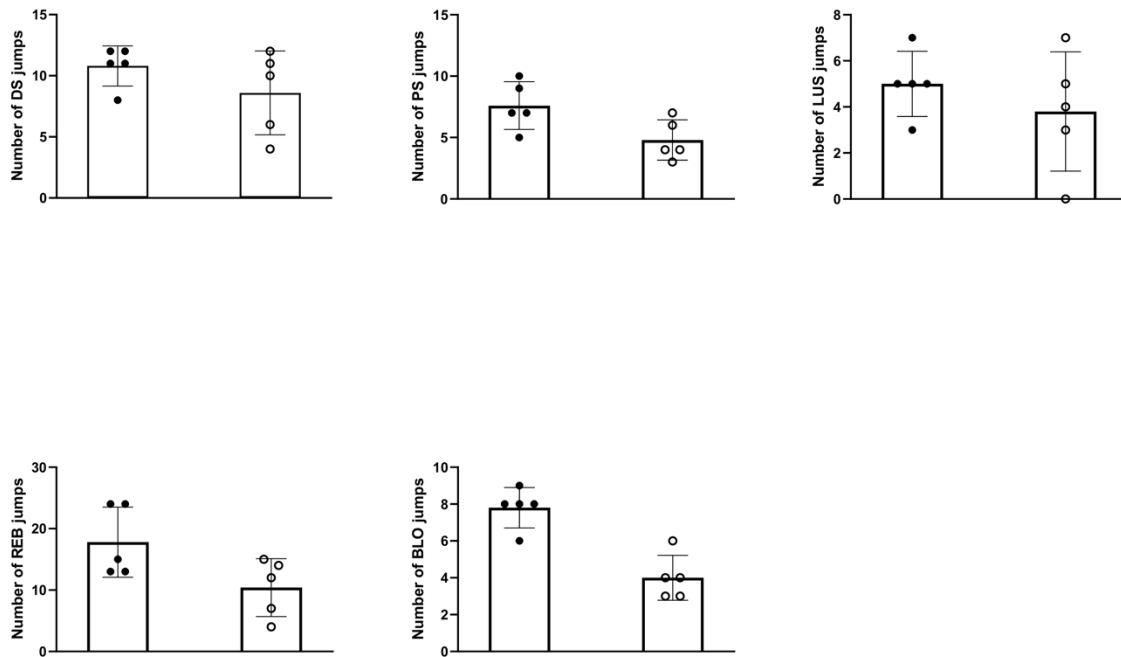
Statistical analyses

Descriptive data are presented as means and standard deviations and frequency plots. Normal distribution of the dependent variable was tested using the Shapiro-Wilk test ($p > 0.05$). To test for differences between males and females, we used the independent t-test and Mann-Whitney U-test for normally and non-normally distributed data, respectively. The alpha level for significance was set to < 0.05 . The magnitude of the effect was determined by calculating the Cohen's d effect size (ES). ES for the Mann-Whitney U test was calculated by dividing the absolute (positive) standardized test statistic Z by the square root of the number of pairs.

RESULTS

In five games, 245 and 158 jumps (1.63 and 1.05 per minute) were recorded in men and women, respectively. Points scored per game were 16 ± 4.2 and 12 ± 2.8 for men and women, respectively. A significant difference between men and women in the number of jumps performed per game was found for PS (7.60 ± 1.95 vs. 4.80 ± 1.64 ; $t = 2.46$, $p = 0.040$; $d = 1.5$ (95% CI: 0.10-3.01) and BLO (17.80 ± 5.72 vs. 10.40 ± 4.7 ; $t(8) = 5.17$, $p < 0.001$; $d = 3.27$, 95% CI: 1.81-4.73). Frequency distribution, mean and standard deviation of jumps of three different shots (DS, PS, LUS) per game are shown in Figure 1 top row and the corresponding data for jumps while rebounding (REB) and while blocking (BLO) are shown in the bottom row.

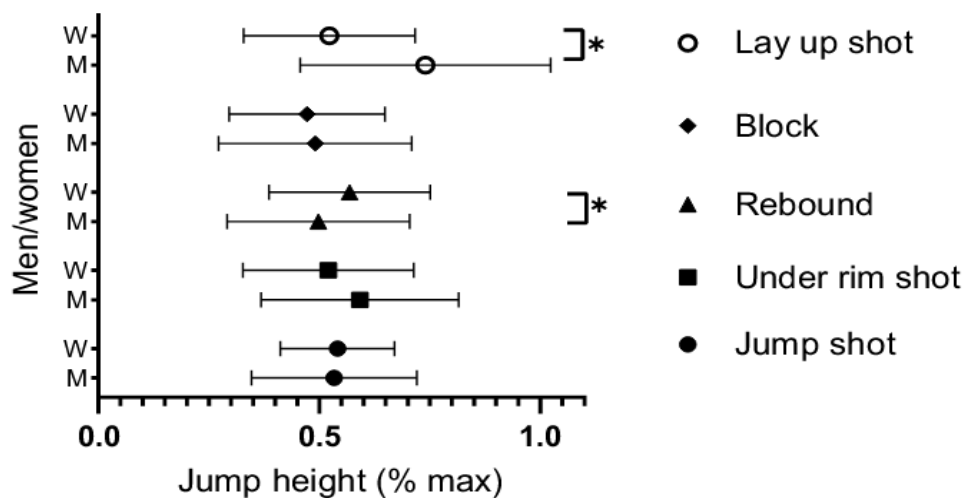
Figure 1. Frequency distribution, mean and standard deviation of jumps.



*Distance shots (DS), paint shots (PS), lay-up shots (LUS), rebounding (REB) and blocking (BLO) for male (black circles) and female (open circles).

When analyzing the relative jump heights, the test for normality of the data showed significance for DS, REB, BLO, and LUS, which means that a nonparametric test was used to evaluate the differences in the relative jump heights between the groups, while the t-test was used for normally distributed PS. The mean jump heights of the countermovement jump test performed before the first match were 0.481 ± 0.069 m for males and 0.314 ± 0.046 m for females. The tests of the differences between males and females in relative jump heights are shown in Table 1. The comparison of relative jump heights between males and females for different jumps is shown in Figure 2. The results of the t-test and Mann-Whitney U-test and the effect sizes are shown in Table 1. Note the significant differences for LUS and REB.

Figure 2. Comparison of relative heights of different jumps for male (M) and female (W).



*Note significant differences for lay-up shot and rebounds. * $p < 0.05$.

Table 1. Differences between man and women in relative heights of the jumps.

Jump	t-test/MWU	Cohen`s D/ES	Effect size
PS	0,201 ^a	0,337 ^c	moderate
DS	0,876 ^b	0,016 ^d	none
REB	0,012 ^{b*}	0,211 ^d	small
BLO	0,761 ^b	0,040 ^d	none
LUS	0,008 ^{b*}	0,398 ^d	moderate

*Note that except for the PS Mann-Whitney U test was used. * $p < 0.05$. a independent t-test; b Mann-Whitney U test; c Cohen`s D; d effect size.

DISCUSSION AND CONCLUSIONS

The aim of this study was to evaluate the loads in the vertical plane during the men's and women's 3x3 basketball game. In this regard, all jumps during the games were recorded and their frequency was presented in relation to the type of jump (i.e. distance shot, rebound, etc.) and intensity in relative heights calculated in relation to the maximum countermovement jump measured in testing conditions. For all jumps observed, the number of jumps was higher in

males than in females, and the largest differences were found at PS and BLO. In terms of the relative intensity of the jumps, heights just above 50% of the maximum height were the most common, except for the male players executing layup shots where the heights reached above 70% of the maximum.

The greater number of jumps in male players compared to female players is consistent with research conducted in basketball, with males averaging 41-56 jumps per game (Abdelkrim et al., 2007; McInnes et al., 1995; Scanlan et al., 2011; Scanlan et al., 2015)) and females averaging 19-43 jumps per game (Conte et al., 2015; Matthew & Delextrat, 2009; Scanlan et al., 2015). It is likely that these data show that the men's matches are played at a faster rate. In our study, the male team scored on average one-third more points (16 ± 4.2 vs 12 ± 2.8), in ten minutes of play as defined by the rules, resulting in more action on offense and defense. It was shown previously that the score has a direct influence in the external load during official matches (Carmona & Carlos, 2019). We observed male players performed more shots inside the paint and jumped more frequently to block opponents. These results are related, as more shots provide more opportunity and need to block. Perhaps we can conclude that the men's game was played closer to the rim and with more action below the rim compared to the women's game. However, future research using methods of tracking the players' movements will test this hypothesis.

It is interesting to note, however, that the relative intensity of jumps, represented as a percentage of the maximum CMJ obtained in the test condition, was similar in males and females for most jump actions, with the exception of rebounds and lay up shots (see Figure 2). Note that female players jumped relatively higher than males in rebounding and not vice versa; the possible reasons for this are not clear. The differences were even more pronounced in the jumps during the execution of the lay-up shots where male players executed relatively higher jumps. It is worth noting that lay up shot jumps were the only jumps performed with one leg. Vertical jumps with one leg, where three steps are taken, can regularly be higher than jumps with two legs, which are performed from a standing position or one to three steps before the jump. This is in contrast to Tai et al. (2018) who found greater GRF production in single-leg jumps compared to double-leg jumps, but jump height was higher in double-leg jumps. On the other hand, in the study comparing a three stride run-up followed by a single-leg or double-leg takeoff, higher jump heights were regularly obtained (before and after the intervention, for the experimental and control groups) for single-leg jumps ((Young et al., 2001). This increase was attributed to the simultaneous swing of the arms and one leg during the take off as it has been shown that

the combination of arms and free leg swing can contribute approximately 15-30% to the vertical momentum of the body during the jump (Ae et al., 1983). Thus, this was most likely the reason why the relative heights of the lay-up shots measured in our study reached 74% of the maximum CMJ, while the majority of other jumps recorded were just above 50 % CMJ (see Figure 2).

Regarding the relative intensity of the jumps performed, our results are consistent with the reports of Montgomery and Malone (2018a). They did not divide jumps by play action, but instead divided them into a lower, middle, and higher band in terms of jump height. Similar to our data, where most jumps were about 50% of the maximum, most jumps they recorded were in the middle band between 20 and 40 cm height (11.9 ± 5.4 for females and 10.0 ± 5.0 for males). In the lower band, the frequency was slightly lower for females and males (5.2 ± 3.7 and 7.3 ± 5.5 , respectively), while the number of jumps above 40 cm was significantly higher for males (6.2 ± 4.3) than for females (2.4 ± 1.8). The latter was to be expected since the jump height bands were defined based on absolute values and not many female basketball players can jump higher than 40 cm. Adding together the low, mid, and high band jumps reported by Montgomery and Malone, we find that a female player completed approximately 20 jumps and a male player 23 jumps per game. This is clearly more than in our study, where only 10.5 ± 0.9 and 16.3 ± 0.8 jumps per player per game were recorded. It is likely that this is due to the level of the athletes. While our data were collected during the national championship, Montgomery and Malone (2018a) conducted their study on top athletes participating in European and World Championships as well as in professional 3x3 events.

It is known from 5x5 basketball that players' load accumulates more units in the vertical plane than in the other two planes (Svilar et al., 2018). During training sessions, elite players performed an average of 50 jumps and 13 more defined as high height jumps (higher than 40 cm), with no significant differences between guards, forwards, and centers. During a practice game with regular time interruptions, the total number of jumps was 1.76 ± 0.76 per minute and slightly less during an official game (1.11 ± 0.53 jumps per minute) (Svilar et al., 2019). In the Euroleague, a player playing 20 minutes jumps an average of 45 times, or 2.25 times per minute (www.elstrengthcoach.com). Some other studies report 1.24 jumps per minute (Abdelkrim et al., 2007), 1.28 (McInnes et al., 1995) for males and 1.0 per minute for females (Conte et al., 2015; Matthew & Delextrat, 2009). In our study, we found 1.63 jumps per minute for males and 1.05 for females, which is slightly more. However, it would be inappropriate to draw any conclusions from the comparison between elite and national players and between basketball and 3x3 basketball, except perhaps to suggest that the level of players and competition may

influence the data in question. Then again, Scanlan et al. (2015) reported no significant differences between semi-professional and professional players.

There are some limitations in our study. One is the small sample size and the other is the lack of monitoring some other data that would help us get a complete picture. Nonetheless, 3x3 basketball is one of the fastest growing sports and the problems associated with it are significant, especially because it is an urban sport, which means that a number of ordinary people play every day. By "ordinary" we mean the lack of physical fitness required to play the game. In this context, any information that could help to understand the stresses to which the musculoskeletal system is exposed to during the game is of great importance. We hypothesized that there would be more vertical jumps compared to basketball due to the smaller court, fewer players, and shorter possession time (key features of 3x3 basketball rules). This was not the case, although some serious comparisons cannot be made due to the lack of literature and the ability to compare only the different levels of players participating in the studies. Still, the women averaged 10 jumps per 3x3 basketball game and the men averaged 16. This is not a major threat with respect to a player's total load. It is true that jumping accounts only for 0.6–2.0%, of real time (Abdelkrim et al., 2007; Conte et al., 2015), but on the other hand it was clearly declared as an inherently vertical sport, requiring jumping and landing activities 2 to 4 times greater than soccer and volleyball (Taylor et al., 2015a). Therefore, jumps should not be neglected among other actions that were not examined in this study but play a role in basketball (e.g. sprinting, breaking, cutting, accelerating). Even though the jumps were mainly performed at half-maximal CMJ height, 3-5 forces of the body weight still act at impact and represent a large stress on the players' musculoskeletal system.

In basketball, many actions are performed in the vertical plane, which forces players to make many jumps. The players' musculoskeletal system is subjected to great forces when they push-off and especially when they land. Coaches should be aware of these facts and consider them when designing strength and conditioning programs to improve performance and prevent injuries. When executing jump shots inside and outside the paint, lay-up shots, rebounds, and block actions, national level female and male players executed 1.05 and 1.63 jumps per minute, respectively, in the 3x3 basketball game. This is slightly more jumps compared to studies conducted in 5x5 basketball. However, a reliable comparison is not possible due to the different quality level of the players. The men's game was faster compared to the women's, resulting in more offensive and defensive actions in the same amount of playing time as well as more points. There were also more jumps in the paint in men, indicating more contact plays, while the

differences in perimeter area were smaller. However, the relative jump heights were similar for males and females, averaging just over 50% of the maximum height, with some individual jumps approaching the maximum height. Comparing our results to previous reports, we conclude that athlete level affects the number of actions; lower level players performed fewer actions than high-level players, which is likely the reflection of their physical fitness. While active players could be satisfactorily prepared by their coaches for the demands of a 3x3 game, there are some concerns in this context regarding urban recreational players.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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