The Relationship Between External and Internal Load Parameters in 3x3 Basketball Tournaments

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Abstract

Background: 3x3 basketball games are characterized by high-intensity accelerations and decelerations, and a high number of changes of direction and jumps. It is played in tournament form with multiple games per day. Therefore, optimal regeneration is crucial for maintaining a high performance level over the course of the tournament. To elucidate how load of a match affects the athletes' bodies (i.e., internal load), muscular responses to the load of 3x3 games were analyzed. We aimed to investigate changes in contractility of the m. rectus femoris (RF) and m. gastrocnemius medialis (GC) in response to the load of single 3x3 games and a 3x3 tournament.

Methods: Inertial movement analysis was conducted to capture game load in 3x3. Changes in contractility were measured using tensiomyography (TMG). During a two-day tournament, TMG measurements were conducted in the morning and after each game. Additionally, off-game performance analysis consisting of jump and change-of-direction (COD) tests was conducted the day before the tournament.

Results: External load correlated significantly to changes in contraction velocity in GC, but not in RF. There was no significant correlation between maximum radial displacement of the muscle and external load variables in GC and RF. Athletes of the RF group responded with either decreased or increased muscle contractility after a single 3x3 game. Concerning off-game performance, small to no correlations can be reported when analyzing TMG parameters, COD time, and jump height. No systematic changes in muscle contractility were found over the course of the tournament in RF and GC.

Conclusion: The athletes' external 3x3 game load and their performance level did not affect muscular contractility after a single 3x3 game or a complete 3x3 tournament, indicating that elite athletes can resist external load without relevant local muscular fatigue. With respect to the course of the tournament, it can therefore be concluded that the breaks between games are sufficient to return to the initial level of muscle contractility.

1 Background

3x3 basketball is a sport consisting of numerous accelerations, decelerations, jumps, and changes of direction which occur in about 10 min of game duration¹. Compared to 5-on-5 basketball, games are organized as tournaments, which results in teams playing several matches per day, usually on two or more consecutive days². Knowing the workload of the games is important to understand sport-specific demands to plan training sessions accordingly and to establish optimal regeneration or preparation routines during tournaments^{3,4}. The main goal is to improve the athletes' performance while reducing the risk of overtraining and injuries^{5,6,7}. During a tournament, a decline in performance should also be prevented since this, along with the athletes' tactical behavior, can be considered a key parameter for winning competitions. In terms of load monitoring, a distinction is usually made between internal and external load parameters. External load is the physical work performed during training or competition, whereas internal load represents the individual response to those impacts⁸. With the development of microsensor technology in sport, quantifying load has become more applicable, e.g., daily monitoring of training sessions is feasible. However, there is a wide variety of parameters from which to choose carefully, depending on the particular issue.

Most commonly, peak heart rate (HR), time spent in so-called “work zones” (e.g., defined by the percentage of the individual maximum HR), or HR averages are used to measure the athletes' internal load^{9,10,11}. In 3x3, an average HR of about 164 beats per minute is reported for males and females¹. During a tournament, most of the time is spent in the range of 90–100% of the athletes' peak HR².

Since, in addition to the cardiovascular stress, various tissues that comprise the musculoskeletal system are also mechanically stressed by load occurring during the activity, it is important to have a closer look at external load parameters. Commonly used parameters are the so-called player load (PL, a parameter that summarizes changes of acceleration in x-, y-, and z-direction), acceleration (ACC), deceleration (DEC), and jump count. In 3x3, Montgomery and Maloney (2018) reported that 17% of males' and 13% of females' total accelerations are high-speed movements, defined as accelerations with more than $3.5 \text{ m}\cdot\text{s}^{-1}$. The number of decelerations exceeds the number of accelerations in moderate ($> 2.5 \text{ m}\cdot\text{s}^{-1}$) and high-speed movements in males and females^{1,12}. Within a single 3x3 game, female athletes perform $33.53 (\pm 13.76)$ DEC and $32.75 (\pm 13.85)$, male athletes perform $44.16 (\pm 18)$ DEC and $33.92 (\pm 14.59)$ ACC. Another parameter that might affect the musculoskeletal system is the jump count since the athletes need to generate concentric force to lift off the ground and they need to resist eccentric forces during landing. Willberg et al. (2022) reported 3x3 male athletes to perform $21.8 (\pm 8.5)$ jumps per game (1.7 per minute) and females to perform $16.6 (\pm 7.5)$ jumps per game (1.4 per minute)¹².

These numerous mechanical loads are expected to affect the muscular and tendon structures of the athletes since, according to Wang et al. (2013), mechanical stressors directly lead to tissue damage and repair¹³. A method to capture the internal load caused by biomechanical stress by measuring muscle contractility is tensiomyography (TMG). TMG is a non-invasive method using a single electrical stimulus to assess maximal radial displacement of the muscle belly (Dm) and contraction velocity (Vc). The mechanical reaction of the muscle is a sensitive method to find changes in muscle contractility before changes in muscle architecture¹⁴. Increasing radial displacement/contraction velocity following intense voluntary muscle contraction can be interpreted as post-activation potentiation (PAP)^{15,16}. The underpinning effect is caused by an increase in calcium sensitivity of the actin-myosin complex due to phosphorylation of the myosin regulatory light chain¹⁵. Decreasing contractility of a muscle, which is accompanied by loss of performance^{17,18,19}, can be explained by intracellular accumulation of inorganic phosphate¹⁹.

Accordingly, TMG data can be used as an indicator of current contractility of the muscle. Increased TMG levels can be caused either by changes of muscle activation or of muscular mechanics. TMG has previously been used to measure muscular reactions on mechanical load. Both, a decrease of contractility due to high loads^{20,21} and potentiation of contractility have been reported.

However, there are some difficulties when conducting TMG measurements. First, the result of a TMG measurement depends not only on the load but also on athletes' state²² since highly trained athletes are supposed to respond differently to external load than untrained subjects. Therefore, explosive-body-performance tests are recommended to get more information on the subjects' athletic state²³. Second, especially when there is a limited amount of time for the measurements, there is a need to define the most relevant muscle. Hamner, Seth, and Delp (2010) reported the quadriceps muscle group to be the largest contributor to braking during the early part of the stance phase and the m. gastrocnemius medialis (GC) to predominantly contribute during the second phase of braking²⁴. Since DEC count is high in 3x3, it is to be assumed that changes in contractility can

be analyzed within m. rectus femoris (RF) and GC. Also, change-of-direction (COD) movements are assumed to have an impact on muscle contractility (especially of RF) since they result in decelerations and consequently eccentric contractions when braking the center of mass to initiate a directional change²⁵.

Since, especially in 3x3, athletes need to resist a high amount of eccentric load and CODs during a game, we hypothesized that changes in TMG parameters can be seen in GC and RF when comparing muscle contractility before and after a game. As described above, 3x3 is played as a tournament. Therefore, we aimed to report on external load and TMG parameters during a two-day international tournament. We assumed that with increased game load, certain TMG parameter values (Dm and Vc) would decrease.

2 Methods

2.1 Anthropometrics

28 elite 3x3 athletes (age: 27 ± 4.4 years; size: 194.1 ± 5.7 cm; weight: 98.1 ± 9.8 kg), all competing on an international level, participated in the study. Each participant provided written consent for participation in the study, which was approved by the local ethics committee (Grant Number: 2021-30). TMG measurement was conducted on GC in one group and RF in the other group. Athletes were randomly assigned to the groups. TMG data were visually inspected for each athlete to increase reliability. For this purpose, the individual TMG curves of the athletes were compared for each measurement. In case of atypical curves, e.g., by co-contractions of the deep musculature, the data of the athletes were excluded from analysis. For this reason, 23 athletes were included in the final analysis. Anthropometric data are shown in Table 1.

Table 1
Descriptive statistics of the group. *SD* = standard deviation, GC = M. Gastrocnemius medialis, RF = M. Rectus femoris.

		<i>N</i>	Minimum	Maximum	Mean	<i>SD</i>
GC	Age	14	23	34	27.7	4.1
	Size	14	184.5	199.3	191.6	5.1
	Weight	14	83.5	109	95.5	8.2
	Arm span	14	192	213.6	199.5	6.2
RF	Age	9	22	34	26.6	4.6
	Size	9	187	205	195.8	5.6
	Weight	9	82.1	118.2	99.8	10.7
	Arm span	9	195	213	203.9	6.3

2.2 Measurement Setup

Data were acquired at a two-day international tournament (Heidelberg, Feb. 2021). To measure the subjects' athletic state, a COD test (HAST²⁶), drop jumps (DJ), and countermovement jumps (CMJ) were conducted. Athletes performed three trials for each test. The value of the best trial (shortest COD test duration/best DJ Index/highest jump height) was included in the analysis. DJ Index was calculated by dividing jumping height (cm) by ground contact time (ms).

External load parameters were measured using a local positioning system (Catapult Clearsky, Catapult Sports, Melbourne, Australia). 20 anchor nodes were installed at the venues according to the manufacturer's recommendations. Spatial calibration was conducted using a tachymeter (Leica TS06 Total Station, Leica Geosystems AG, Switzerland). Utilizing a narrow UWB frequency (3.1 to 10.6 Hz), the system can locate receiver tags (Vector 7, Catapult Sports, Melbourne, Australia) in the surveyed area. Full-court coverage was tested before each measurement. Via Ethernet cabling, the master anchor was connected with the data processing laptop, allowing life tracking and tagging with a 10 Hz frequency. Data were processed using the manufacturer's software (Openfield™ version 3.3.0, Catapult Sports, Melbourne, Australia). Vector 7 receiver tags (81 mm length, 43.5 mm width, 15.9 mm thickness) were attached at the upper back, between the athletes' shoulders using Vector Elite Vest (Catapult Sports, Melbourne, Australia) which allows ECG heart rate analysis due to embedded HR sensors. A 3D-accelerometer (± 16 G, 100 Hz), a magnetometer ($-D \pm 4900$ μ T, 100 Hz), and a gyroscope (-2000 degrees per sec, 100 Hz) are built into the receiver, allowing inertial movement analysis. To gain more information about internal load, athletes were asked to rate their perceived exhaustion per session (session RPE) using a Borg-scale²⁷ 15–30 min after the end of the game.

For the TMG measurement (TMG; TMG-BMC Ltd., Ljubljana, Slovenia), a high-precision (4 μ m) displacement sensor with a spring constant of 0.17 N*mm⁻¹²⁸ was placed perpendicularly on the muscle belly. The sensor measures the radial displacement over time of a muscle and transfers these data into a digital signal²⁹. The locations of the sensor and electrodes were based on the suggestion by Perotto and Delagi (2011)³⁰. Briefly, for the position of the sensor on the RF, the Spina iliaca anterior superior, as well as the middle of the upper edge of the patella was palpated. A tape measure was then used to determine the midpoint between these two points. The location was marked with a waterproof pen to always measure the same location throughout the tournament³¹. When necessary, the sensor position was slightly adjusted to measure the largest possible point of the muscle belly³². An inter-electrode distance of 5 cm was used for the position of the electrodes (self-adhesive; axion, 4x4 cm)³³. Subjects lay in a supine position on an examination couch with the TMG cushion for thigh measurements placed under the right leg to ensure a knee angle of 120°³⁴. Similarly, the position of the sensor of the GC measurement was determined according to Perotto and Delagi (2011)³⁰. The medial femoral condyle was palpated, followed by asking the subject to plantarflex the foot with the knee extended to determine the lower beginning of the muscle belly. The center of these two points defined the position of the sensor. Again, an inter-electrode distance of 5 cm was used. For the measurement of the GC, the subjects lay in a prone position on the examination couch, with the TMG cushion for the measurements of the lower leg placed below the ankle joint in such a way that a pretension of the muscle was given. To trigger the mechanical response of the respective muscle, a single monophasic square wave with a 1 ms pulse was delivered from the TMG stimulator. Since the measurements were taken during basketball competitions, the measurement protocol had to be adjusted due to time constraints. Therefore, only one of the two muscles of the right half of the body was measured from each player. In addition, comparatively large jumps in pulse amplitude were chosen (60 mA, 80

mA, and 100 mA) and measured at 30 s intervals to save time. Randomly, the athletes were allocated to the groups of GC or RF.

On each day, a baseline measurement was conducted in the morning before any training activity occurred. During the tournament, TMG was set up in a separate space near the court site. After each match, the athletes were asked to get there as quickly as possible, with the athletes of a team always being tested in the same order to maintain approximately the same time between the end of the match and the TMG measurement throughout the tournament. Therefore, each athlete was measured up to seven times within two days (see Fig. 1).

2.3 Data processing

Openfield™ was used to process positional and inertial movement data, which were included in the analysis as external load parameters. Player Load © was calculated using the manufacturer's algorithm (t = time, fwd = forward acceleration, side = sideways acceleration, vert = vertical acceleration).

$$PL = \sqrt{(fwd_{t=i+1} - fwd_{t=i})^2 + (side_{t=i+1} - side_{t=i})^2 + (vert_{t=i+1} - vert_{t=i})^2}$$

Inertial movement analysis (IMA) was used to detect jumps and decelerations (DEC) during 3x3 games. Tri-axial accelerometer and gyroscope data (100 Hz) were taken into consideration to evaluate the magnitude of the athlete's movements. To differentiate between athlete and device movement, an advanced gravity filtering model (Kalman filtering technique) was used. IMA accelerations contain, based on the direction of sensor movement, positive accelerations, while IMA decelerations summarize negative acceleration values.

TMG raw data were saved in Microsoft Excel (Version 16.5, Microsoft Corporation, Redmont, USA) for each athlete. Each measurement was visualized and compared to other trials to exclude possible erroneous measurements. Only the values of the curve with the highest maximum radial displacement were used for analysis. In addition to Dm, Vc was calculated using MATLAB® R2019b (MathWorks, USA) and was defined as the calculated slope of the displacement curve over time. Vc was calculated as: $(90\%Dm - 10\%Dm) / (\text{contraction time from 10 to } 90\%Dm)$. To analyze changes of TMG parameters, ΔDm and ΔVc were calculated for each game by subtracting post-game values from pre-game values for each athlete in each measurement. Therefore, when ΔDm and ΔVc had positive values, there was an increase in contractility, when values were negative, contractility decreased.

For analysis of the muscular reactions on the external load of a single 3x3 game, athletes were grouped calculating the percentage of change in Dm, since we assumed that athletes might respond in both directions. Group allocations are displayed in Table 2.

Table 2
TMG analysis of a single game. Group allocation of all athletes who had a baseline measurement and a TMG measurement after game 1. GC = M. Gastrocnemius medialis, RF = M. Rectus femoris.

	Day 1				Day 2			
Muscle	GC	RF	GC	RF	GC	RF	GC	RF
Group	ΔDm	ΔDm	ΔDm	ΔDm	ΔDm	ΔDm	ΔDm	ΔDm
	> 0	> 0	< 0	< 0	> 0	> 0	< 0	< 0
<i>N</i>	1	5	4	4	0	4	6	7

2.4 Statistics

Statistical analyses were performed using IBM SPSS (version 26, IBM Corporation, Armonk, New York). Descriptive statistics included means, standard deviations, minimum, and maximum. Graphs were generated using Microsoft Excel (Version 16.5, Microsoft Corporation, Redmont, USA).

All data were analyzed within the groups (GC and RF). When investigating differences of contractility within a single game, the first games of each day were taken into account since TMG values can be directly compared to the baseline measurement of each day. Therefore, bivariate correlations (Pearson's r) were calculated with PL, DEC, jump count, ΔDm , and ΔVc . The level of significance was set to $\alpha < 0.05$.

For further analysis, athletes were grouped according to their muscular load response. This allowed group comparisons, which were conducted using the athletes' performance in jumping and COD tasks. We aimed to describe group differences which muscular responses might be based on.

3 Results

The average PL of a single 3x3 game is 126.0 (± 35.9) arbitrary units (a.u.). 23.6 (± 7.8) DEC and 21.7 (± 8.4) jumps are performed per game. The average time between the end of the game and the TMG measurement was 19:18 ($\pm 04:45$) min. Athletes rated the games as being more and more exhausting as the tournament progressed (5.8 ± 1.6 to 7.3 ± 1.8).

Regarding correlations between external and internal load parameters, a significant correlation can be reported in ΔVc and PL in the GC group ($r = 0.58$, $p = 0.04$). In RF, external load does not correlate with TMG values (Table 3).

Furthermore, ΔDm and ΔVc correlate significantly in the RF group ($r = 0.91$, $p < 0.01$). External load parameters also show significant correlations in RF and GC for DEC and PL (GC: $r = 0.7$, $p = 0.01$; RF: $r = 0.7$, $p < 0.01$). Jump count correlates with DEC in GC group ($r = 0.57$, $p = 0.04$).

Table 3

Correlation matrix of external load and TMG response following a single 3x3 game. PL = Player Load, DEC = deceleration, GC = M. Gastrocnemius medialis, RF = M. Rectus femoris.

		GC					RF				
		PL	DEC	Jumps	ΔDm	ΔVc	PL	DEC	Jumps	ΔDm	ΔVc
PL	Pearson	1	0.7*	0.33	-0.01	0.58*	1	0.7*	0.16	-0.07	-0.12
	<i>p</i>		0.01	0.27	0.98	0.04		< 0.01	0.47	0.74	0.6
	<i>N</i>	13	13	13	13	13	23	22	22	23	23
DEC	Pearson	0,7*	1	0.57*	0.22	0.28	0,7*	1	0.21	-0.08	-0.22
	<i>p</i>	0.01		0.04	0.47	0.36	< 0.01		0.36	0.71	0.32
	<i>N</i>	13	13	13	13	13	22	22	22	22	22
Jumps	Pearson	0.33	0,57*	1	0.45	0.33	0.16	0.21	1	-0.18	-0.16
	<i>p</i>	0.27	0.04		0.12	0.27	0.47	0.36		0.42	0.47
	<i>N</i>	13	13	13	13	13	22	22	22	22	22
ΔDm	Pearson	-0.01	0.22	0.45	1	0.47	-0.07	-0.08	-0.18	1	0.91*
	<i>p</i>	0.98	0.47	0.12		0.11	0.74	0.71	0.42		< 0.01
	<i>N</i>	13	13	13	13	13	23	22	22	23	23
ΔVc	Pearson	0,58*	0.28	0.33	0.47	1	-0.12	-0.22	-0.16	0.91*	1
	<i>p</i>	0.04	0.36	0.27	0.11		0.60	0.32	0.47	0	
	<i>N</i>	13	13	13	13	13	23	22	22	23	23
* significant correlation ($p < 0.05$)											

Since the athletes' TMG response is independent of game load and is either positive (increasing) or negative (decreasing), performance parameters were analyzed to test if differences in the athletic performance can explain different TMG responses. There is only one athlete in the GC group who showed a positive response after playing one 3x3 match. Slight differences in the performance parameters of this person (higher jumping height and DJ index, but longer COD duration) can be shown when comparing the values to the other persons of the GC group. Within the RF group, 11 athletes showed a negative response, nine showed increased TMG values (see Table 2, 4). There are small differences between the performance parameters in this group. Since *SD* is larger than the group differences, we do not assume that the athletic state influences contractility of the muscle after a 3x3 game.

Table 4
Means and standard deviation of the athletes' performance parameters grouped by the muscular response in game one of each day. *SD* = standard deviation, Neg = negative, Pos = positive, GC = M. Gastrocnemius medialis, RF = M. Rectus femoris.

		CMJ			DJ		COD	
		<i>N</i>	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>
GC	Neg. response	10	46.98	4.09	0.19	0.2	6.91	0.15
	Pos. Response	1	49.84	0.17	0.22	0	7.2	0
RF	Neg. response	11	40.9	5.30	0.16	0.2	7.17	0.19
	Pos. Response	9	39.84	5.58	0.15	0.51	7.45	0.2

Because 3x3 is played in a tournament mode, we aimed to report changes in the individual TMG response during the tournament. Although data was captured in all 23 participants, TMG measurements after every single game could only be acquired in three athletes of the GC group and six athletes of the RF group. TMG and load data for each athlete are displayed in Fig. 2. There is no clear trend to be reported regarding both, load and TMG parameters. Some athletes rather show potentiation of contractility, some show only small changes during the tournament. A high decrease in contractility can only be seen after single games but not during the course of a game day.

4 Discussion

External load, which can be quantified by microsensor technology, leads to reactions of both the cardiovascular and musculoskeletal systems⁶. We aimed to investigate the effect of mainly eccentric load parameters on muscular tissue by analyzing its contractility. A significant correlation between load and TMG parameters can be reported between *Vc* and external load in GC. Out of 13 athletes only two responded with increased contraction velocity post game. All others showed decreased *Vc* values – unexpectedly, the decreases were higher when game load was lower. However, there is no significant correlation of load parameters and *Dm* in GC group. Therefore, the significance in *Vc* might be driven by the small sample size and high variance within the data or by differences in physical fitness. In the RF group, neither *Vc* nor *Dm* were correlated with external load parameters occurring during a 3x3 game. While most athletes in the GC group responded with decreased *Dm* and *Vc* values, athletes in the RF group showed both increased as well decreased TMG values. Since, in some cases, athletes responded with increased values in one game and decreased values in another game, the question is whether there is an individual threshold after which potentiation turns into muscular fatigue. Rassier and McIntosh (2000) stated that the contractile response is dependent on the amount and intensity of muscular work with brief repetitive stimulations leading to a potentiation of the contractile response and continued stimulations resulting in impaired contractile response (fatigue)³⁵. This can be explained by the common mechanisms of PAP and fatigue, which are caused by a change in calcium sensitivity³⁵. Primarily, PAP is driven by the increase in calcium sensitivity of the muscle due to the phosphorylation of the myosin regulatory light chain¹⁴. Due to a lower basal calcium sensitivity and myosin light chain kinase activity, the effect of PAP is

greater in Type II fibers than in Type I fibers^{36,37,38}. Since more type II fibers are reported to be in the superficial area of the RF than the GC^{39,40,41}, larger PAP effects can be assumed in the RF. This is in line with our results, where in the GC group, only one athlete showed potentiation, while in the RF group, PAP and fatigue occurred with equally high incidence.

In contrast to PAP mechanisms, muscular fatigue is driven by phosphate accumulation which leads to decreased calcium sensitivity³⁵ and, therefore, a depression of contractile response. The question arises, whether or to what degree the athletes' external load is critical to the muscular response. We hypothesized that external load parameters correlate with the muscular response. This could not be supported by our analysis. One problem might have been an insufficient reference concerning the athletic state. The effect of external load on internal load depends on physical fitness - untrained and trained individuals are supposed to show a different response in contractility given the same external load. What is potentiation for some would be fatigue for others, who would therefore show a decrease in Dm.

When analyzing the athletic state of the subjects included within this study, no group differences in CMJ, DJ, or COD tests could be shown with regard to TMG response. One reason for the result may be the demands of the tasks given. When performing a COD movement or jumps, not only the muscular response but also intra- and intermuscular coordination and neural mechanisms determine the performance output⁴². An association between DJ contact time and Dm in rectus femoris of elite soccer players was already reported⁴². Even though TMG results are moderately related to factors linked with a stretch-shortening cycle related task in their study, the authors state that TMG parameters are no predictors for power-dependent motor tasks⁴². Regarding the results of this investigation, again, there is only small variance within the data, especially regarding the COD test duration. One explanation for the lack of variance might be the expertise level of the athletes tested within this study. All athletes competed at national state level and therefore did perform well in the performance tests. Since no major differences were seen, it could be assumed that due to the high training status, even a 3x3 game does not result in any significant changes in the contractility of the musculature. In their review, García-García et al. (2019) reported changes in TMG parameters in diverse sports (e.g., endurance athletes, sport games, and gymnastics) provoked by diverse stimuli (training periods, competition, rehabilitation)⁴³. When analyzing professional soccer and rugby players, altered TMG values were reported for both, Dm and Vc in RF. However, these results were reported after an 8- to 10-week training period or during a season. This raises the question of whether the external load of a single match is not high enough to affect muscle contractility in highly trained athletes.

As described above, one may assume that external load can have a two-way influence on TMG parameters – either showing a potentiation or a decrease in contractility. We would assume the relation of load and muscular response to be of an inverted-U type with an individual optimum load, leading to great PAP and even higher load leading to fatigue. The work of Peterson and Quiggle (2016) supports this theory⁴⁴. The authors also investigated the internal-external load response in female basketball players during one entire season using TMG and accelerometer-based load analysis. They found significant positive correlations between contraction time and the external load (accumulated count of ACC and DEC in all directions). More interestingly, the authors stated that a decrease of external load (13%) led to substantial decreases in internal load (20%). Also, an increase in external load (40%) led to an increase in internal load (18%)⁴⁴. However, the sample size in their study was quite low, which is why further analysis has to be conducted. Regarding the data of this investigation,

we cannot show proof for an inverted-U-theory since the variance within the load data is small. This might also be the reason for missing correlations between external load and TMG response. To further investigate a possible dose-response relationship of external and internal load, the external load would have to be varied systematically and TMG values would have to be collected accordingly.

Because in 3x3 two to three games are played per day in multiple-day tournaments², it is important not only to analyze a single game but also to focus on the whole tournament. Three athletes from the GC group and four athletes from the RF group were measured seven times during a two-day tournament. Neither changes between the baseline measurements on day one and day two, nor clear changes during the course of the tournament can be shown. However, there are quite high interindividual differences concerning the muscular response which might act in favor of the above-mentioned inverted-U theory.

There are some limitations regarding the practicability of the study design and the data interpretation. Since data were collected at an official tournament, the teams' main goal was to reach a successful outcome. Therefore, we aimed to conduct our measurements as quickly and accurately as possible without disturbing the athletes' usual routines. We instructed them to come to us as soon as possible after the game to collect the sensors and to carry out the TMG measurement. Also, the athletes of each team were measured in the same order on each measurement. However, in some cases, the teams used the time directly after the match to analyze the game. Then, it was not possible to capture TMG data directly after the termination of the game. For this reason, the time delay of the TMG measurement was not the same after each match. When the teams were not able to get to the measurement setup before the following game ended, we were not able to conduct TMG analyses for each team member. This is why the sample size of those persons for whom every measurement could be conducted is quite low. Even though sometimes it took longer until the athletes could be measured, the time delay between the end of the game and the TMG measurement was less than 20 min. It is therefore expected that possible changes in contractility can still be measured^{14,20,21}. Furthermore, in the context of the transferability of the research results into practice, it is questionable whether effects that show up only very shortly after the load have relevance for practice (concerning game tactics and regeneration) since the breaks between games are longer than 20 min in 3x3.

Although TMG measurements are sensitive to detecting changes in contractility of the muscle after specific motor tasks^{16,21,45,46}, other authors are questioning the reliability of the method. Wiewelhove et al. (2017) state that TMG markers are not sensitive enough to detect muscular performance changes after a 4-day HIT microcycle²⁵. One possible explanation might be the mechanism of fatigue, which can be peripheral (within the muscle, beyond the neuromuscular junction) or central, involving CNS and neural pathways⁴⁷. When mainly central fatigue occurs as a result of physical exercise, peripheral mechanisms might not be impaired and, therefore, contractility of the musculature is unchanged. Especially in young athletes, higher central than peripheral fatigue was reported after repeated maximal contractions⁴⁸. This effect might also be explained by a greater reliance on slow-twitch muscle fibers in youth athletes^{49,50}. Within this study, only adults were included, however, when analyzing the rating of perceived exhaustion, the athletes rated the games to be "hard" to "very hard". Because a systematic decrease of contractility could not be shown within this study, it might be assumed that mechanisms of central fatigue might be dominant in the participating elite athletes.

Because there are no systematic changes of contractility of the musculature after a single 3x3 game and during the tournament, one may assume that a specific focus on muscular regeneration is not necessary to succeed in a 3x3 tournament in elite 3x3 athletes. Analysis of less trained athletes as well as a systematic variation of the load to investigate the relationships between increased and decreased contractility might be advantageous.

5 Conclusion

3x3 is a sport with a high amount of jumps, COD, ACC, and DEC. However, it seems that top athletes are well prepared for this kind of external load and there is no local muscular fatigue or that the break between games is sufficient to return to the initial level. Nevertheless, athletes report that the games are perceived as more strenuous as the tournament progresses, which could be explained by global fatigue.

Abbreviations

COD	Change of direction
Dm	Maximal radial displacement
GC	M. Gastrocnemius medialis
HR	Heart rate
RF	M. Rectus femoris
SD	Standard deviation
Session RPE	Rate of perceived exhaustion per Session
TMG	Tensiomyography

Declarations

Ethics approval and consent to participate: Each participant provided written consent for participation in the study, which was approved by the local ethics committee of the Goethe-University Frankfurt (FB 05 -Grant Number: 2021-30).

Consent for publication: not applicable

Availability of data and materials: The datasets for this study can be found in Open Science Framework [OSF, DOI 10.17605/OSF.IO/HXF8G].

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Figures

Figure 1

Study design. TMG measurements are marked yellow (square), games of the tournament are marked blue (rough). The time delay of TMG measurements = time of TMG measurement – time of the end of the related game. GC = M. Gastrocnemius medialis, RF = M. Rectus femoris.

Figure 2

TMG and load parameters during a 3x3 tournament. Dm = radial displacement of the muscle belly, Vc = contraction velocity, PL = Player load, GC = M. Gastrocnemius medialis, RF = M. Rectus femoris.