BALNEO RESEARCH Balneo and PRM Research Journal
English Edition
e ISSN 2734 - 8458 p ISSN 2734 - 844X ROMANIAN ASSOCIATION OF BALNEOLOGY

Research article

Effects of post warm-up short-term inactivity on physical and physiological parameters in female elite team handball players

Carmen Gheorghe [1], Lars Bojsen Michalsik [2], Dana Bădău [3], Adela Bădău [4], Claudiu Mereuță [5*]

1 "Dunărea de Jos" University of Galati, Faculty of Physical Education and Sport, Galati, Romania; carmen.gheorghe@ugal.ro;
2 Department of Sport Science and Clinical Biomechanics, Muscle Physiology and Biomechanics Research Unit, University of Southern Denmark, Denmark; lb@michalsik.dk
3 Transilvania University of Brasov, Romania, Faculty of Physical Education and Mountain Sports; dana.badau@unitbv.ro
4 Transilvania University of Brasov, Romania, Faculty of Physical Education and Mountain Sports; adela.badau@unitbv.ro
5 " Dunărea de Jos" University of Galati, Faculty of Physical Education and Sport, Galati, Romania; claudiu.mereuta@ugal.ro

* Correspondence: Claudiu Mereuță- claudiu.mereuta@ugal.ro;

Citation: Gheorghe C.,Michalsik L.B., Bădău D., Bădău A., Mereuță C. - Effects of post warm-up short-term inactivity on physical and physiological parameters in female elite team handball players
Balneo and PRM Research Journal ***2024**, 15(1): 652*

Academic Editor(s):
Constantin Munteanu

Reviewer Officer:
Viorela Bembea

Production Officer:
Camil Filimon

Received: 12.02.2024
Published: 31.03.2024

Reviewers:
Constantin Munteanu
Mariana Rotariu

Publisher's Note: Balneo and PRM Research Journal stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: In team handball, coaches can make unlimited substitutions, allowing players to enter the game at any time, even if they haven't been active on the bench. The aim of this study was to investigate the impact of inactivity following a warm-up on the physical performance and physiological responses of female elite team handball players. The secondary aim of the study was to examine a possible connection between the examined parameters. Twelve female adult elite field handball players (n = 12; age, 31.9 ± 4.05 years; weight, 66.1 ± 5.8 kg; height 173 ± 3.8 cm and body mass index, 2.2 ± 0.2 kg/cm2) were examined. All tests were assessed in two distinct situations: (a) immediately after warm-up (T1-AW) and (b) after a 15-minute inactivity period (T2-IP). The physical tests performed were: countermovement jump with arms fixed (CMJ AF), squat jump (SJ), medicinal ball rotational throw test right (MBTT-R) and medicinal ball rotational throw test left (MBTT-L) and 10 m acceleration test (TA 10m). Heart rate (HR) was measured during warm-up and at T2-IP, while body temperature (BT), lactic acid (LA), serum glucose (G), and blood oxygen saturation (SpO2) were measured at T1-AW and T2-IP. Significant differences were found at T2-IP for RSI1 ($t= 2.88$, $p < 0.01$) and PP ($t= 2.24$, $p < 0.05$), specific to CMJ AF and RSI1 ($t= 3.88$, $p < 0.01$), and for PP specific to SJ ($t= 2.28$, $p < 0.05$). All physical indices correlated positively with the physiological ones. In addition, two significant correlations were identified, one between the decrease in the RSI 1-CMJ AF index and the PP-CMJ AF index ($r=0.59$, $p<0.05$) and another between the decline in the PP- SJ and Tc ($r=0.60$, $p<0.05$). The results obtained from the present study indicate that short-term inactivity can negate some of the physical and physiological benefits that players gain from warming up. The study revealed a significant reduction in certain parameters related to jump tests after a 15-minute period of inactivity. Moreover, it was observed that there is a direct correlation between the decrease in body temperature and the reduction in peak power specific to squat jump performance. This implies that lower body temperatures that result from a short period of inactivity can have a negative impact on jumping performance just before players enter the game.

Keywords: female team handball, warm-up, inactivity, physical performances, physiological parameters.

Introduction

Handball is a fast-paced team sport involving frequent jumps, accelerations, decelerations, changes in direction, physical contact, and various technical game actions tailored to the shifting dynamics of game tactics [1–3]. Team handball requires excellent muscular strength, relatively high aerobic capacity and high anaerobic power [4–6].

Understanding players' physical characteristics and their impact on performance and development can be helpful for youth academies in selecting players and promoting long-term performance [7,8].

In both male and female handball competitions, internal and external factors can lead to fatigue [13–16]. Specialists use measurements of external and internal load to determine an athlete's level of adaptation to exertion [17–19]. On the one hand, the external load represents the visible physical effort, expressed by volume and intensity parameters. It is quantified by the specific units of measurement for distances covered, the number of accelerations, the number of jumps, and the frequency of physical impacts. On the other hand, internal loads are the body's psychophysiological responses to external physical efforts, such as maximum oxygen consumption, heart rate, blood pressure, respiratory rate, temperature, blood lactate, and glucose. Properly monitoring both loads is essential to predicting and reducing the risk of overwork, illness, and injury [20]. The relative workload during match play can be determined as a percentage of VO_2-max, although absolute HR-max measurements say very little about team handball's intensity and physical demands [2].

In elite team handball, full-time players can cover an average distance of about 4700m during a game [9]. During a game, female players can make almost 700 activity changes, out of which 2.5% are at maximum intensity, 47.8% are at average intensity, and 49.7% are at low power [2]. Additionally, research has shown that players can perform 0.7 ± 0.4 accelerations, 2.3 ± 0.9 decelerations, and 1.0 ± 0.4 changes in direction within a minute [10]. Due to the new demands of the handball game, the intensity of the exerted effort reaches average values of around 85% of HR_{max} [11,12]. Evidence shows that more than 70% of game time can lead to decreased physical capacity, considering the number of low-intensity activities can increase. In contrast, high-intensity activities can decrease in the second half of the game [2].

Blood lactate concentration is a commonly evaluated metric in athletes' exercise and performance testing [21]. Lactate analysis is an accurate method to determine an athlete's exercise tolerance and fatigue [22–24]. The lactate level in the body can help determine the anaerobic threshold. This threshold is the point where the accumulation of lactic acid in the muscles starts until the upper limit of physical activity is reached. When this limit is exceeded, the body turns to the glycolytic system for energy, which can result in muscle fatigue. A high lactate threshold indicates better resistance to exertion, especially at intensities of 80-90% of VO_2-max or HR max. Researchers have reported that the average resting blood lactate levels range from 1 to 1.8 mmol·L−1. However, these levels can increase dramatically after strenuous exercise and go above 25 mmol·L−1 [25]. According to a recent study, female adult handball players on the top elite field team had values around 10 mmol·L−1 when their blood lactate levels were measured during a handball match-based performance test [26].

The warm-up program optimises the body for training and competition [27]. Warming up is an essential practice to prepare the body for physical activity. It helps activate and maximize players' physical potential and prevent injuries. Increasing muscle and body temperature during warm-up results in reducing muscle and joint stiffness, increasing muscle oxygenation, improving anaerobic metabolism, and optimizing the rate of muscle contraction. These benefits reflect the importance of warming up before any physical activity [28,29]. During warm-up, certain aerobic gymnastics techniques may have an impact on the development of motor skills indices [30].

Before handball games, all players must undergo the same warm-up routine. The inactivity after warm-up refers to the period following the warm-up session where players may experience a decrease in physical activity levels before the game officially begins. This period could include moments such as the pre-game team talks, player introductions, or waiting for the referees to start the match. Moreover, substitutes who do not start the game need to remain on the sidelines and sit on the bench until they enter the field. If space permits, warming up is possible behind the benches. Unfortunately, the infrastructure of many sports halls in Romania makes it almost impossible to have a proper warm-up behind the benches. In this context, the effects of post-warm-up short-term inactivity on physical and physiological parameters in female elite team handball players need to be investigated.

Very few studies have examined the effects of inactivity after a standard game warm-up in competitive handball, and none of them have been conducted on elite women's handball. Some studies have suggested that interrupting exercise can lead to decreased core and muscle temperatures, lower blood sugar levels, and reduced physical and cognitive performance in soccer players [31,32]. In basketball, it has been suggested that post-warm-up inactivity may decrease substitutes' physiological and performance-related responses during competitions [33,34]. In addition, sitting is less favourable than standing, leading to a faster drop in basketball players' explosive power and speed test results, mainly due to the sitting posture [35]. Furthermore, studies suggest that the lack of preparation during half-time could be a reason for the reduced number of high-intensity runs in the second half of the game [36–38]. This is because players only warm up before the game and not during half-time.

Handball coaches have the freedom to make multiple player substitutions during a game. However, it's crucial to have a player rotation plan that takes into account the duration of the physical and physiological benefits of the pre-game warm-up and the impact of a player's inactivity while sitting on the bench.

Our experiment recommended simulating player substitutions at the 15th-minute mark of the first half. This is because there is often a brief period of inactivity while players take a break on the bench. Such changes between players are common in both the first and second halves of elite handball games.

The primary purpose of this research was to examine how inactivity after a match warm-up impacts elite team handball players' physical performance and physiological responses. A secondary goal of the study was to identify any potential correlation between the analysed parameters through comparative analysis.

This study addresses a topic that has not been thoroughly investigated in the literature, so we think we can make a meaningful contribution to the scientific community.

2. Materials and Methods

2.1. Subjects

Twelve elite female players from the first Romanian Female Team Handball League team participated in the study. Only female court players (n = 12; age, 31.9 ± 4.05 years; weight, 66.1 ± 5.8 kg; height, 173 ± 3.8 cm and body mass index, 2.2 ± 0.2 kg/cm2) were included in the study, goalkeepers being excluded due to their different positional physical demands. The team was divided into groups of six players each (Group 1 and Group 2), in pairs for each position (left-wing, right-wing, left back, right back, centre and pivot). We allocated two sessions to familiarise players with the tests and measurement tools needed for the experiment. Each group was tested separately on two different days. All players were informed about the implementation of the test and the possible risks and gave their written consent. The study was approved by the Ethics Committee of the University of Galati, Romania and the Ethics Committee of the Galati Community. The study was conducted in accordance with the accepted ethical standards and with the principles of the Declaration of Helsinki in Sport and Physical Activity Research.

2.2. Procedures

2.2.1 Warm-Up

Before the evaluation protocols, all players underwent a 30-minute warm-up routine similar to a typical match. The warm-up consisted of two distinct parts: the general warm-up and the handball-specific warm-up. The general warm-up comprised individual or collective exercises without the ball and was guided by the team's physical trainer. The handball-specific warm-up involved repeating the usual technical-tactical actions under the guidance of the head coach. The detailed match warm-up schedule is presented in Table A1 (see Appendix A, p. 12).

2.2.2 Short-term inactivity

After the initial physical and physiological evaluation (T1-AW), each group was instructed to sit on the bench and remain inactive, just as they would in an official game, until the second test was called (T2-IB). We chose 15 minutes of inactivity to mimic the players' work and rest times during official matches, and during this time, the players wore jerseys and shorts.

2.2.3 Physical evaluation

After the warm-up, players underwent four physical tests to assess their combined strength-speed qualities and determine anaerobic power output. The results served as a reference for each player.

The Countermovement Jump with Arms Fixed (CMJ AF) without additional load is a test used to measure lower body strength. It is a simple, valid, and practical method that is widely used compared to other jumping tests. The results obtained from CMJ tests are associated with parameters like maximum speed, maximum power and maximum explosive power. Several studies have found a strong correlation between CMJ and acceleration speed [28].

The squat jump (SJ) was used to assess the ability to produce explosive force during concentric movements [39].

For both CMJ and SJ, we measured jump height, reactive strength index, power, and speed. These measurements provide insights into players' explosive leg power, which is crucial in team handball.

The Medicine Ball Toss Test (MBTT) determines a player's maximal anaerobic and explosive power in the upper limbs. It involves a rotational throw from the right side (MBTT-R) and the left side (MBTT-L). The most important parameter for evaluating performance in the MBTT is the peak throwing velocity (PV), measured with the PUSH band when the ball is released from the hands. To perform the exercise, the player stands to the side of the wall, with their left or right shoulder forward, and holds the medicine ball with both hands. They then make an explosive upper body twist and throw the ball against the wall. The test is conducted three times, and the best result is recorded. The MBTT provides valuable information about a player's upper body power, particularly relevant in sports such as handball involving throwing or striking movements.

We carried out the **TA 10m (10-meter acceleration) Test** to evaluate handball players' ability to accelerate over short distances, which is crucial in a game involving approximately 663.6 ± 99.7 actions of varying intensities [1], with the most demanding being acceleration, deceleration, and changes of direction over short distances (<15m). Instead of the traditional 30m sprint test, we used the TA 10m test to measure players' speed over shorter distances. We used a stopwatch, which is a reliable method for assessing short-distance sprints [40,41], to conduct the test.

The PUSH tape device (version 2.0) was used to conduct jump and medicine ball tests. Once the sensor was properly placed, the device was connected via Bluetooth to the laptop and smartphone used in the study. The tests measured jump height (JH), reactive strength index (RSI 1), peak jumping power (PP), and peak jumping velocity (PV) for both the countermovement jump (CMJ) and squat jump (SJ). In the medicine ball throw test (MBTT), peak-throwing power (PP) and peak-throwing velocity (PV) were assessed. By incorporating technology into sports and physical education, coaches and teachers can create more inclusive and engaging learning environments [42].

2.2.4 Physiological Evaluation

The physiological assessment consisted of five measurements to identify potential physiological changes between the standard warm-up (SW) and the period of inactivity (IP).

As part of our **heart rate (HR)** study, we provided Garmin Fenix 5S smartwatches to the players before the warm-up. We recorded HR values during the standard warm-up and at T2-IP. Additionally, we measured **body temperature (BT)** immediately at T1-AW and T2-IP using the Veroval DS 22 infrared thermometer. To measure **biochemical parameters, including blood lactate and serum glucose**, we used the Accutrend Plus device. The club's medical team took capillary blood samples, and we followed strict hygienic-sanitary conditions according to the Accutrend Plus device user manual instructions. The Accutrend Plus device is a viable alternative to laboratory testing [43]. Capillary blood sampling provides quick and accurate information similar to what is obtained from arterial blood in medical analysis laboratories [44]. In this study, a finger puncture was performed using the VivaChek Eco-lancing device to collect blood lactic acid samples, which were taken three minutes after warm-up and at T2-IP. The blood sample for BL was collected first, as the Accutrend Plus instrument takes 60 seconds to analyse this measurement. Another blood sample was taken for serum glucose during this interval, and it was analysed within 12 seconds. **Blood oxygen saturation (SpO2)** was measured at T1-AW and T2-IP by placing the IMDK pulse oximeter (Model C101A2, Version V1.1) on the player's finger. The device was disinfected with antiseptic sanitary alcohol after each use.

2.3. Experimental design

The chosen tests were intended to determine the physical and physiological scores achieved after completing the standard match warm-up. They also aimed to identify the changes caused by 15 minutes of inactivity in the neuromuscular and cardiorespiratory systems. The tests used in each assessment protocol were selected based on the physical exertion of the handball players [45–49].

The players' physical tests were conducted twice, as shown in Figure 1. The first test (T1-AW) was done immediately after the standard warm-up, before a short period of inactivity. The second test (T2-IP) was done immediately after the 15-minute inactivity period. The team was divided into groups of 6 players based on their playing position. Group 1 included the first-line players, and Group 2 included the substitutes. We opted for this strategy because if the warm-up had ended simultaneously, evaluating the entire team would have taken a long time, resulting in some players being tested towards the end, thereby impacting the results. Group 1 was tested in the first week of September, and Group 2 was tested in the second week, using the same testing protocol. CMJ AF was assessed on Tuesdays, SJ test was evaluated on Thursdays, and MBTT and TA 10m tests were performed on Saturdays. For physiological measurements, players were tested on the following two Tuesdays. We conducted a session three days before the experiment to familiarize all the players with the methodology. During this session, we instructed players not to have any food or coffee, only water, on the morning of the physiological measurements.

Following the standard warm-up, the players were called to the designated testing area per the predetermined plan. Each player was given a maximum of one minute for the test. However, to preserve the benefits of the warm-up, players waiting for their turn were instructed to perform dynamic stretching exercises. Meanwhile, the other group continued with their training session as scheduled.

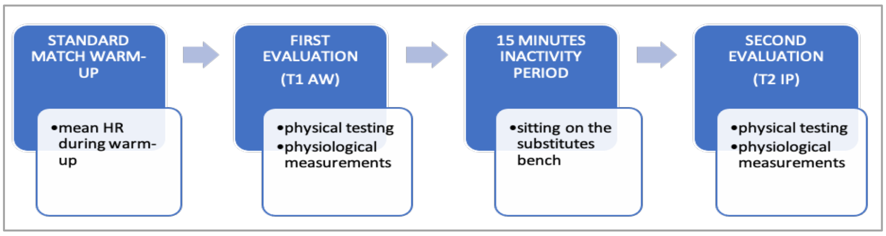

Figure 1. The overall evaluation study model used

2.4. Statistical analysis

IBM SPSS Statistics for Macintosh, version 25 (IBM Corp., Armonk, NY, USA) and Microsoft Excel were used to process and organise the collected data.

The results are presented as arithmetic group means (standard deviations and coefficient of variation). To identify statistically significant differences between the subjects' performances, in the case of applying the inactivity protocol between the initial (T1-AW) and the second (T2-IP) testing, the t-test for dependent samples (repeated measurements) was used, where a value of the statistical significance coefficient $p < 0.05$ was considered significant. Correlations between physical and physiological performance were assessed using the Pearson correlation coefficient.

3. Results

3.1 Physical tests

Descriptive data, group means, standard deviations (±SD) and the coefficient of variation (Cv), *p*-values of the t-test for dependent samples for all variables are presented in Table 1.

Table 1. Results obtained in the physical tests, before and after the short-term inactivity

Test	Parameter	T1 AW (N=12)		T2 IP (N=12)		t	Sig. (2-tailed)
		Mean ± SD	Cv%	Mean ± SD	Cv%		
CMJ AF	JH (cm)	34.57 ± 2.04	5.89	33.00 ± 3.36	10.19	1.38	0.180
	RSI1 (cm/s)	0.43 ± 0.06	14.53	0.35 ± 0.07	21.00	**2.88**	**0.009***
	PP (w)	2.71 ± 0.22	8.04	2.55 ± 0.11	4.21	**2.24**	**0.039****
	PV (m/s)	2.39 ± 0.13	5.44	2.46 ± 0.14	5.50	1.20	0.242
SJ	JH (cm)	29.99 ± 3.49	11.63	28.50 ± 3.34	11.71	1.07	0.298
	RSI1 (cm/s)	0.90 ± 0.06	6.81	0.79 ± 0.08	9.58	**3.88**	**0.001***
	PP (w)	2.49 ± 0.21	8.53	2.32 ± 0.16	6.92	**2.28**	**0.033****
	PV (m/s)	2.31 ± 0.12	5.31	2.40 ± 0.13	5.51	1.81	0.084
MBTT-R	PP (w)	10.59 ± 3.78	35.67	9.97 ± 3.54	35.50	0.42	0.682
	PV (m/s)	6.77 ± 1.09	16.17	6.83 ± 1.17	17.10	- 0.13	0.894
MBTT-L	PP (w)	9.63 ± 2.55	26.50	8.36 ± 2.35	28.11	1.27	0.219
	PV (m/s)	6.15 ± 0.96	15.68	6.69 ± 1.06	15.85	- 1.31	0.204
TA	10 m (s)	2.14 ± 0.10	4.67	2.19 ± 0.10	4.37	- 1.25	0.223

Abbreviations: CMJ AF= countermovement jump arms fixed; SJ= squat jump; MBTT-R= medicinal ball right throw; MBTT-L= medicinal ball left throw JH= (jump height); RSI1= (reactive strength index); PP= (peak power); PV= (peak velocity);
t = t value;
Sig. (2-tailed) = t significance level;
**= p<0.01 differences between T1-AW and T2-PI are highly significant statistically;*
***= p<0.05 differences between T1-AW and T2-PI are statistically significant.*

Short-term inactivity after warm-up caused a decrease in RSI1 CMJ AF ($p<0.01$) and PP CMJ AF ($p<0.05$), as shown in Table 1. Regarding the SJ, there were significant decreases in RSI1 SJ ($p<0.01$) and PP SJ ($p<0.05$). Standard deviation values indicate a significant central value, and Cv values show that groups are homogeneous and that the means obtained are representative at their level. No significant differences were found for the MBTT and the TA 10m test.

3.2 Physiological measurements

Changes in all physiological measurements are shown in Table 2. Mean HR was higher after warm-up than after inactivity (121±8 vs 87.6±7 beats·min^{-1}, $p<0.001$). Significant changes also occurred in body temperature after 15 minutes of inactivity (37.8 °C vs. 36 °C, $p<0.001$). The values for BL, G and S O_2 did not differ between the two situations.

Table 2. Results from the physiological tests before and after the inactivity period

Physiological Parameter	T1 AW (N=12)		T2 IP (N=12)		t	Sig. (2-tailed)
	Mean ± SD	Cv%	Mean ± SD	Cv%		
HR (bpm)	*121.75 ± 8.07*	*6.56*	*87.58 ± 6.97*	7.96	11.10	***0.001****
BL (mmol/L)	*1.72 ± 0.43*	*25.19*	*1.57 ± 0.31*	20.06	0.97	0.342
G (mg/dL)	*89.58 ± 3.99*	*4.45*	*88.17 ± 4.30*	4.88	0.84	0.412
T_c (°C)	*37.73 ± 0.24*	*0.49*	*36.09 ± 0.49*	0.65	18.84	***0.001****
S O_2 (SpO_2)	98.67 ± 0.49	0.50	98.75 ± 0.45	0.46	- 0.43	0.670

Abbreviations: T1 AW= first evaluation after warm-up (or during warm-up for HR values); T2 IP=second evaluation after inactivity period; HR= heart rate; BL= lactic acid; G= glycaemia; T_c= body temperature; S O_2= oxygen saturation in the blood;
t = t value;
Sig. (2-tailed) = t significance level;
**= p<0.01 differences between T1-AW and T2-IP are highly significant statistically.*

3.3 Correlations

Only variables whose changes showed significant differences between the initial and final tests (identified with t-tests) were included in this analysis.

After multivariate correlation analysis, based on Pearson's r-correlation coefficient, we found that statistically significant positive correlations exist between all analysed variables at a significance level of $p < 0.01$ (see Table 3).

Table 3. Correlations between values (R-values) of variables that underwent significant changes between the first and second test.

			1	2	3	4	5
Physiological	**1**	HR.					
	2	T_c	***0.93****				
Physical	**3**	RSI 1- CMJ AF	***0.87****	***0.71****			
	4	PP- CMJ AF	***0.94****	***0.91****	***0.82****		
	5	RSI 1- SJ	***0.96****	***0.92****	***0.79****	***0.96****	
	6	PP- SJ	***0.94****	***0.91****	***0.83****	***0.98****	***0.95****

***** The correlation is significant at a significance threshold of 0.01 (2-tailed).***

Table 4 shows the associations between changes recorded for each parameter between T1-AW and T2-IP. Two significant correlations were identified, one between the RSI 1-CMJ AF index and the PP-CMJ AF index ($r=0.59$, $p<0.05$) and another between the PP-SJ and T_c ($r=0.60$, $p<0.05$).

Table 4. Correlations between the decrease in the values (R-values) of physical and physiological indices after the short-term inactivity period.

			1	2	3	4	5
Physiological	**1**	HR Evolution					
	2	T_c Evolution	0.52				
Physical	**3**	RSI 1- CMJ AF Evolution	-0.3	-0.51			
	4	PP- CMJ AF Evolution	0.26	-0.27	***0.59****		
	5	RSI 1- SJ Evolution	-0.15	-0.24	0.02	-0.02	
	6	PP- SJ Evolution	0.38	***0.60****	-0.52	-0.24	0.02

**** The correlation is significant at a significance threshold of 0.05 (2-tailed).***

4. Discussion

To our knowledge, this is the first study to address the effects of inactivity on both physical and psychological aspects in female team handball. We investigated the impact of 15 minutes of rest on players' performance and biochemical parameters after completing a standard match warm-up.

Warming up is recognised worldwide as a standard procedure to prepare the body for subsequent exertion and prevent injury [50,51]. In competitive handball, there is a time immediately after the warm-up for tactical advice, equipment adjustments, or first-player picks. The game begins with the kick-off, and from that point, the players face two different scenarios: some play on the field (the first-line players), and the rest of the players become inactive on the sidelines (the substitutes). The unlimited substitutions permitted in the handball game allow coaches to control the intervals at which players play or rest. Proper substitution management can reduce players' physiological stress and determine the later onset of fatigue [6]). Players can only achieve physical recovery by restoring energy potential and performance during the game through an optimal balance between effort and recovery, made possible by efficient player rotation.

Maintaining a proper balance between rest and work is crucial for optimizing individual or collective performance [13]. To achieve this, rotating players during competition is recommended, as it helps keep the body functioning at the optimal effort parameters specific to the handball game [13,47]. Additionally, proper transition management is essential to reduce players' physiological stress and subsequent fatigue [6]. It is often overlooked that substitute players must perform at a high level when they enter the game so that the team can play at its best. Our study was necessary to highlight this aspect.

We identified that short-term inactivity in a sitting position, as substitutes would do in official handball games, can decrease physiological parameters and physical performance. As a result, when players enter the field from the bench, it would take them a certain amount of time to reach the same level of performance as they did during the pre-game warm-up.

We have found that when substitutes in official handball games sit for short periods of time, their physiological parameters and physical performance decrease. As a result, when these players would enter the field from the bench, it would take them some time to reach the same level of performance they had during the pre-game warm-up.

To our knowledge, this is the first study in women's handball to examine the effects of short-term player inactivity after a standard game warm-up and the relationship between them.

4.1 Physical testing

Vertical jumps are valid methods to evaluate neuromuscular function and anaerobic peak performance in the lower limbs [52]. Previous research has shown that players' performance in handball games is influenced by various factors such as balance and precise throwing of explosive power [53]. This study used the medicine ball rotational throw test to provide relevant data on maximal anaerobic performance [54]. In team sports games that require intermittent efforts, players' inadequate preparation for explosive tasks could reduce the amount of high-intensity running performed in the second half's first 15 minutes compared to the first half [32]. This is a crucial aspect as the game's pace is essential to their competitive advantage in game situations.

The effects of inactivity after a warm-up on physical performance have not been adequately studied in women's handball. In our study, after 15 minutes on the substitution bench, RSI 1 and PP decreased by 19% and 6%, respectively, in the case of CMJ AF and by 15% and 7%, respectively, in the case of SJ. Our results confirm the negative impact of inactivity on explosive loads, such as lower-limb jumping, which has been identified in previous studies. Although we could not find any study on women's team handball, we could identify, through a wider literature review, that our results are consistent with similar findings reported in basketball. According to Galazoulas et al. (2012), 40 minutes of inactivity reduces jumping performance by 20% and sprint performance by 6%. Other reports have also shown that performance on the countermovement jump test (CMJ) was reduced by 15% compared to performance after the match warm-up [33]. The performance loss may be due to the associated drop in body temperature and decreased resting plasma glucose concentration after warm-up.

We found that short-term inactivity mainly affected lower-limb explosive force tests, while upper-limb tests remained unaffected. However, we found no significant effects in MBBT tests and TA 10m. This indicates that the short period of inactivity did not impact upper body performance and speed-related performance. The reason for this is still unclear to us.

On the one hand, a previous study in basketball showed that inactivity or passive rest has a significant impact on explosive tasks but not so much on speed-related ones [34]. On the other hand, a correlation between lower muscle and core temperature and the decrease in sprint performance was observed in soccer after a passive half-time period [32]. Some other studies also found significant differences in running performances after inactivity [31,34,55]. However, our speed test results were different from these findings, perhaps due to the different methodology used. The latter authors performed a repeated sprint test while we used the TA 10m test.

4.2 Physiological measurements

4.2.1 Heart rate

Heart rate is a valuable tool for measuring exercise intensity during physical activity. It helps individuals to gauge their effort and adjust their intensity levels accordingly [56–59]. This study used HR to predict exercise intensity based on the mean HR_{max} (176.5 bpm) recorded during the two friendly games held before the present study. The low mean HRmax of the players (age 31.9 ± 4.05 years) could be attributed to the lack of motivation during friendly games or poor fitness levels. During the standard warm-up in our experimental design, the mean HR was 122 bpm (69% of HR_{max}). Based on Harre's (1982) exertion intensity scale, as cited by Bompa (2002), the study found that during warm-up, the players' exertion level was moderate (69% HRmax). However, after 15 minutes of inactivity, their heart rate significantly dropped to 49% HRmax (87.58 ppm), which falls into the low-intensity effort category. Therefore, it can be concluded that the players were not adequately prepared for the intense demands on their cardiac system during games, as previous studies have reported: 86% of HR_{max} [12], 84.4 ± 5.1% HR_{max} [11], 191.1± 8.417 ppm [60], 162 ± 8 ppm [1], 195 ± 9 ppm at the elite level, 188 ± 6 ppm at the top elite level and 182 ± 12 ppm at world-class level [61].

4.2.2 Body temperature

Various studies have demonstrated that increased body temperature can accelerate metabolic processes, providing the neuromuscular system with the necessary resources to amplify nerve impulses, thereby increasing muscle contraction speed [50,51]. Moreover, it has been suggested that enhanced muscle activation is one of the reasons for improved exercise performance after a warm-up or re-warm-up [32,62,63].

In this study, we measured mean whole-body skin temperature, not muscle temperature, because we didn't have the necessary equipment. Our results show that a short period of inactivity leads to a significant decrease in T_c values, 4% below the initially achieved value. In a similar basketball study, Crowther et al. (2017) found that after only 6 minutes of inactivity, physiological outcomes indicated a ~0.5 °C decrease in body temperature (T_c) and a ~2.0 °C decrease in abdominal temperature (T_a).

Warm-up and re-warm-up protocols can lead to increased blood flow and associated temperature in the leg muscles, thus an increased ability to sprint [37]. It has been suggested that the dependence of neuronal transmission rate and muscle contraction speed on temperature are possible mediators for the influence of temperature on performance [32]. Since the generation of explosive energy relies on high-frequency nerve impulses and the ATP-phosphocreatine system in the muscle, it is interesting to speculate that one or both were primarily affected by the drop in muscle temperature. It has been found that a single °C decrease in body temperature can result in a 3% decrease in lower-body performance [64]. So, having identified regressions, particularly in jump tests, we can say that our results support these statements.

4.2.3 Blood lactate

Blood lactate measurements, also known as lactate testing or lactate analysis, are a way to assess lactate concentration in the blood. Blood lactate data can be used in combination with other physiological measurements such as blood glucose, heart rate and skin temperature to derive training thresholds and prescribe accurate training intensities for specific sports [21]. The lactate threshold is the exercise intensity at which lactate production exceeds its clearance, leading to an accumulation in the blood. It is well known that intensity during warm-up should be challenging enough to elicit physiological responses but should not cause excessive fatigue or impair subsequent performance [50,51,62]. Knowing that resting lactate levels in healthy individuals are usually low (<2.2 mmol/L), we hypothesised that during the standard game warm-up protocol, lactate levels will rise and continue to rise during the short 15-minute inactivity period.

Our findings contradicted our initial hypothesis. We examined the capillary lactate dynamics between the first and second tests and found that the results fell within the typical mean values at rest (T1-AW: 1.72 ± 0.43 mmol/L and T2 IP: 1.57 ± 0.31 mmol/L). Before interstitial lactate reaches a steady-state exchange with the bloodstream, a significant portion can be metabolised in other muscles or organs [47]. The blood lactate concentration (BLC) depends on the intensity of the physical activity performed minutes before the blood sample was taken. In our study, BLC could have been higher immediately after exercise, reflecting the immediate production of lactate during anaerobic metabolism. This raises doubts about our results, and we can speculate that the timing of lactate measurement after physical effort might be a reason for this. The blood samples were collected 3 minutes post-exercise and not immediately after the warm-up.

It is possible that the low blood lactate concentration during the standard match warm-up was due to the low exercise intensity (69% HR_{max}) during this time. The intensity of the warm-up was low in the last part, which included tactical combinations and one-goal play, leading to a higher blood lactate peak during warm-up than the value measured after 3 minutes post-warm-up (1.72 mmol/l). However, the blood lactate concentration values measured after 15 minutes of rest were too low to explain the drop in performance, and they were lower than the values registered after warm-up. Therefore, the changes in performance observed are unlikely to be related to the concentration of lactate in the blood (and probably also in the muscles).

It is essential to accurately determine the lactate level in the muscles to obtain more precise results. However, no study has yet determined the exact amount of lactate produced in muscles or capillaries during or after a warm-up in team handball. This is an important topic that needs to be addressed in future research.

4.3 Correlations

Another aim of our research was to investigate the association between the changes in the physical and physiological indices values after implementing the short-term inactivity period protocol. Furthermore, it was interesting to observe if we could find any links between these indices' magnitude of the modification in the values (R-values).

This study presents a new approach to analyzing physical parameters corresponding to jumping exercises and their correlation with physiological indices. While previous studies have mainly focused on jump height, our study delves into multiple physical indices, including CMJ AF and SJ (RSI 1 and PP), which we found to be significantly associated with physiological indices such as HR and T_c.

The main finding of this study is that resting for 15 minutes after a standard warm-up in handball resulted in a rapid decrease in performance in vertical jumping. Moreover, results show a significant relationship between the evolution of T_c values and the evolution of peak jumping power SJ values after 15 minutes of inactivity ($r=0.60$, $p<0.05$). These findings are consistent with the results of other studies on ball games, which identified a strong connection between the decrease in body temperature and the reduction in athletic performance in jumping [33,34].

It is possible for a player's vertical jump to be affected for various reasons after sitting on the substitution bench. However, there has not been extensive research done on the direct correlation between jump performance and body temperature. It is known that body temperature can have an impact on physical performance in general [65,66]. Previous studies have shown that lower-body exercise performance decreases by 3% with every one degree Celsius lost [64] and that a one degree Celsius increase in muscle temperature can lead to a 2-5% improvement in muscle power performance [67].

Although we didn't measure muscle temperature, the drop in body temperature we observed could be linked to a potential drop in muscle temperature. The reduction in jumping ability could be due to the sitting posture or the interruption of exercise leading to a decrease in muscle temperature [32]. However, more detailed studies are required to better understand the association between waiting on the bench and vertical jump performance.

We discovered that when players' physiological values decreased after 15 minutes, their physical performance scores in jumping tests were lower. Since jumping is a crucial skill in handball, both CMJ AF and SJ can offer valuable insights into an individual's explosive leg power and how it directly relates to the physical demands of match-play. This suggests that reduced lower body temperatures after even a short period of inactivity can impair jumping performance just before players enter the game. Future studies should further explore these possibilities.

5. Practical applications

Due to the restrictions imposed by the rules, which do not allow the movement of players on the sidelines, it is recommended to use passive strategies to maintain the beneficial effects of warming up. For example, one could wear full tracksuits or thermal compression sports clothing that could benefit both thermoregulation and muscle support [66,68]. Consistent with previous studies and based on our results, this strategy alone is insufficient to maintain the benefits players derive from the game's warm-up. Therefore, we suggest complementing passive warm-up strategies with active warm-up or re-warm-up protocols. The challenge is to find a suitable place in the substitutes' area to implement these protocols since players are not allowed to stand during official handball matches, and the space behind the substitutes' bench in most of Romania's sports halls is either too small or inexistent.

6. Limitations of the study

It is essential to keep in mind that there are certain limitations when interpreting our findings. This study is a one-group design, which means that there is no control group for comparison. We measured physical and physiological parameters for a single group of players before and after a brief 15-minute inactivity. We chose this method because we considered each player's specific physical and physiological condition, which would provide a more accurate comparison.

We measured the body's skin temperature instead of muscle temperature due to the lack of necessary equipment. It is essential to consider multiple factors that can affect body temperature and jump performance to understand the relationship between the two correctly.

We used tests that lasted only a few seconds, despite the fact that the game requires physical actions of longer duration. However, the short duration of these tests couldn't have affected the player's overall performance. Nonetheless, it is advisable to exercise caution when selecting the evaluation methods before a second test round.

Future studies where handball players can be tested in active situations after the first round of testing should be addressed. In this case, one could see possible differences in the test results and compare them directly.

8. Conclusions

In handball, the players who are not playing remain seated on the sideline and wait on the bench until they are called to enter the field. If there is enough space, substitutes may warm up behind the benches. However, in Romania, due to insufficient infrastructure in many sports halls, it is almost impossible for players to warm up behind the benches.

The main idea of this study is that sitting on a bench for 15 minutes without any movement or activity can cause a drop in body temperature and heart rate, both critical in preparing the body for physical activity. This can then lead to a decline in jumping performance. The study found that lower body temperature resulted in lower jumping capacity after sitting on the bench in complete inactivity for 15 minutes immediately after the handball game warm-up. Previous studies have looked at similar circumstances in ball games, such as men's soccer or basketball, but they focused on the effects of passive rest during half-time breaks on players' performance in the second half.

This is the first study to demonstrate that inactivity negatively affects the physical and physiological function of female handball players.

In conclusion, we strongly recommend including warm-up activities for substitute handball players in the bench area to help them maintain the benefits gained during the standard game warm-up. It is essential for players to maintain their physical readiness and mental focus, as the transition from low activity to high-intensity gameplay can be abrupt.

Author Contributions: Conceptualisation, CG and CM; methodology, CG..; software, CG; validation, CG and CM; formal analysis, CG; investigation, CG; resources, CG; data curation, CG; writing—original draft preparation, CG; writing—review and editing, CM; visualisation, CG; supervision, CM; project administration, CM; funding acquisition, CM. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Galati, Romania and the Ethics Committee of the Galati Community.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A 1. The model of the warm-up for the competition, specific to the CSM Galati team.

General warm-up (12 minutes)
- Individual: variants of walking and running. - Collective: dynamic stretching under the guidance of the team's physical trainer. - Collective: variants of running and jumping on the coordination ladder, followed by accelerated runs to the centre of the court and walking to the end of one's line.
Specific warm-up (18 minutes)
- In pairs, face to face - passing the ball with two hands above the head, two hands from the chest, and one arm above the shoulder, special passes (with a progressive increase in distance). - The team divided equally, arranged on the left back (LB) and right back (RB) positions - passing the ball with one arm above the shoulder, then moving to the end of one's line. - The collective was divided equally, arranged on the LB and RB positions - passing the ball with one arm above the shoulder, followed by moving to the end of the opposite line. - In the warm-up program for goalkeepers, each player with the ball throws according to the instructions of the physical trainer. - Throws from the positions: each player with the ball throws at the goal 2-3 times depending on the position or positions she is specialised in (the backcourt players throw from all the 9-meter positions, and the players from the wing and pivot throw from both positions). - Throws following counter-attack: passes are alternately launched by the substitute goalkeeper to the players who leave the specific defensive position and receive the ball in the area of the centre line, after which they return while dribbling and shooting at the goal (2-3 repetitions). - In pairs of positions: individual actions of meeting the opponent with the ball by quickly exiting the defensive zone, physical contact on the throwing arm and chest, followed by quick withdrawal. After three repetitions, the defender performed an accelerated run to the centre, retreats with her back to the practice area, and changed places with her colleague in the attack (2-3 repetitions each). - One group was on the attack, and the other was on defence: 2-3 tactical combinations and one goal play (each half of 1-2 minutes).

References

1. Michalsik, L.B.; Madsen, K.; Aagaard, P. Match Performance and Physiological Capacity of Female Elite Team Handball Players. *Int. J. Sports Med.* **2013**, *35*, 595–607, doi:10.1055/s-0033-1358713.
2. Michalsik, L.B.; Madsen, K.; Aagaard, P. Match Performance and Physiological Capacity of Female Elite Team Handball Players. *Int. J. Sports Med.* **2014**, *35*, 595–607, doi:10.1055/s-0033-1358713.
3. Michalsik, L.B.; Aagaard, P.; Madsen, K. Technical Activity Profile and Influence of Body Anthropometry on Playing Performance in Female Elite Team Handball. *J. Strength Cond. Res.* **2015**, *29*, 1126–1138, doi:10.1519/JSC.0000000000000735.
4. Buchheit, M.; Al Haddad, H.; Millet, G.P.; Lepretre, P.M.; Newton, M.; Ahmaidi, S. Cardiorespiratory and Cardiac Autonomic Responses to 30-15 Intermittent Fitness Test in Team Sport Players: *J. Strength Cond. Res.* **2009**, *23*, 93–100, doi:10.1519/JSC.0b013e31818b9721.
5. Granados, C.; Izquierdo, M.; Ibañez, J.; Bonnabau, H.; Gorostiaga, E.M. Differences in Physical Fitness and Throwing Velocity among Elite and Amateur Female Handball Players. *Int. J. Sports Med.* **2007**, *28*, 860–867, doi:10.1055/s-2007-964989.
6. Karcher, C.; Buchheit, M. On-Court Demands of Elite Handball, with Special Reference to Playing Positions. *Sports Med. Auckl. NZ* **2014**, *44*, 797–814, doi:10.1007/s40279-014-0164-z.
7. Čaušević, D.; Rani, B.; Gasibat, Q.; Čović, N.; Alexe, C.I.; Pavel, S.I.; Burchel, L.O.; Alexe, D.I. Maturity-Related Variations in Morphology, Body Composition, and Somatotype Features among Young Male Football Players. *Children* **2023**, *10*, 721, doi:10.3390/children10040721.
8. Postelnicu, M.G.; Mihaila, M.I. Study on the Importance of Physical Training for Junior Female Handball Teams from Romania. *Bull. Transilv. Univ. Braşov Ser. IX Sci. Hum. Kinet.* **2022**, 9–16, doi:10.31926/but.shk.2022.15.64.1.1.
9. Michalsik, L.B.; Aagaard, P. Physical Demands in Elite Team Handball: Comparisons between Male and Female Players. *J. Sports Med. Phys. Fitness* **2015**, *55*, 878–891.
10. Luteberget, L.S.; Spencer, M. High-Intensity Events in International Women's Team Handball Matches. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 56–61, doi:10.1123/ijspp.2015-0641.

11. Kniubaite, A.; Skarbalius, A.; Clemente, F.M.; Conte, D. Quantification of External and Internal Match Loads in Elite Female Team Handball. *Biol. Sport* **2019**, *36*, 311–316, doi:10.5114/biolsport.2019.88753.
12. Manchado, C.; Tortosa-Martínez, J.; Vila, H.; Ferragut, C.; Platen, P. Performance Factors in Women's Team Handball: Physical and Physiological Aspects--a Review. *J. Strength Cond. Res.* **2013**, *27*, 1708–1719, doi:10.1519/JSC.0b013e3182891535.
13. Moss, S.L.; Twist, C. Influence of Different Work and Rest Distributions on Performance and Fatigue During Simulated Team Handball Match Play: *J. Strength Cond. Res.* **2015**, *29*, 2697–2707, doi:10.1519/JSC.0000000000000959.
14. Póvoas, S.C.A.; Ascensão, A.A.M.R.; Magalhães, J.; Seabra, A.F.T.; Krustrup, P.; Soares, J.M.C.; Rebelo, A.N.C. Analysis of Fatigue Development During Elite Male Handball Matches: *J. Strength Cond. Res.* **2014**, *28*, 2640–2648, doi:10.1519/JSC.0000000000000424.
15. Ronglan, L.T.; Raastad, T.; Børgesen, A. Neuromuscular Fatigue and Recovery in Elite Female Handball Players. *Scand. J. Med. Sci. Sports* **2006**, *16*, 267–273, doi:10.1111/j.1600-0838.2005.00474.x.
16. Thorlund, J.B.; Michalsik, L.B.; Madsen, K.; Aagaard, P. Acute Fatigue-Induced Changes in Muscle Mechanical Properties and Neuromuscular Activity in Elite Handball Players Following a Handball Match. *Scand. J. Med. Sci. Sports* **2008**, *18*, 462–472, doi:10.1111/j.1600-0838.2007.00710.x.
17. Impellizzeri, F.M.; Marcora, S.M.; Coutts, A.J. Internal and External Training Load: 15 Years On. *Int. J. Sports Physiol. Perform.* **2019**, *14*, 270–273, doi:10.1123/ijspp.2018-0935.
18. McLaren, S.J.; Macpherson, T.W.; Coutts, A.J.; Hurst, C.; Spears, I.R.; Weston, M. The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. *Sports Med. Auckl. NZ* **2018**, *48*, 641–658, doi:10.1007/s40279-017-0830-z.
19. Martoma, A. The Influence of Acute Exposure to Moderate Altitude upon the Oxidants/Antioxidants Balance and upon the Effort Capacity. *Int. J. Biol. Biomed. Eng.* **2011**, *5*, 114–120.
20. Halson, S.L. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Med.* **2014**, *44*, 139–147, doi:10.1007/s40279-014-0253-z.
21. Goodwin, M.L.; Harris, J.E.; Hernández, A.; Gladden, L.B. Blood Lactate Measurements and Analysis during Exercise: A Guide for Clinicians. *J. Diabetes Sci. Technol. Online* **2007**, *1*, 558–569.
22. Ahmaidi, S.; Granier, P.; Taoutaou, Z.; Mercier, J.; Dubouchaud, H.; Prefaut, C. Effects of Active Recovery on Plasma Lactate and Anaerobic Power Following Repeated Intensive Exercise. *Med. Sci. Sports Exerc.* **1996**, *28*, 450–456, doi:10.1097/00005768-199604000-00009.
23. Dodd, S.; Powers, S.K.; Callender, T.; Brooks, E. Blood Lactate Disappearance at Various Intensities of Recovery Exercise. *J. Appl. Physiol.* **1984**, *57*, 1462–1465, doi:10.1152/jappl.1984.57.5.1462.
24. Martoma, A. Statistical and Experimental Methods Used in Medical Education Related to the Aerobic and Anaerobic Effort Capacity at Athletes. In Proceedings of the Proceedings of the WSEAS international conferences, Iwate Prefectural University, Japan, October 4-6, 2010; Iwate Prefectural University, Japan, 2010; pp. 102–108.
25. Ionescu, A. Capacitatea de efort. In *Medicină sportivă*; Editura Medicală: Bucure□ti, 2002; p. 797 ISBN 973-39-0494-5.
26. Michalsik, L.B.; Fuchs, P.; Wagner, H. The Team Handball Game-Based Performance Test Is Better than the Yo-Yo Intermittent Recovery Test to Measure Match-Related Activities in Female Adult Top-Elite Field Team Handball Players. *Appl. Sci.* **2021**, *11*, 6551, doi:10.3390/app11146551.
27. McCrary, J.M.; Ackermann, B.J.; Halaki, M. A Systematic Review of the Effects of Upper Body Warm-up on Performance and Injury. **2015**, 9.
28. Markström, J.L.; Olsson, C.-J. Countermovement Jump Peak Force Relative to Body Weight and Jump Height as Predictors for Sprint Running Performances: (In)Homogeneity of Track and Field Athletes? *J. Strength Cond. Res.* **2013**, *27*, 944–953, doi:10.1519/JSC.0b013e318260edad.
29. Wisløff, U.; Castagna, C.; Helgerud, J.; Jones, R.; Hoff, J. Strong Correlation of Maximal Squat Strength with Sprint Performance and Vertical Jump Height in Elite Soccer Players. *Br. J. Sports Med.* **2004**, *38*, 285–288, doi:10.1136/bjsm.2002.002071.
30. Zaharia, A.-M. THE CONTRIBUTION OF AEROBIC GYMNASTICS MEANS TO THE IMPROVEMENT OF MOTOR DEVELOPMENT INDICES. *GYMNASIUM* **2014**, *15*.
31. Lovell, R.; Midgley, A.; Barrett, S.; Carter, D.; Small, K. Effects of Different Half-Time Strategies on Second Half Soccer-Specific Speed, Power and Dynamic Strength. *Scand. J. Med. Sci. Sports* **2013**, *23*, 105–113, doi:https://doi.org/10.1111/j.1600-0838.2011.01353.x.
32. Mohr, M.; Krustrup, P.; Nybo, L.; Nielsen, J.J.; Bangsbo, J. Muscle Temperature and Sprint Performance during Soccer Matches--Beneficial Effect of Re-Warm-up at Half-Time. *Scand. J. Med. Sci. Sports* **2004**, *14*, 156–162, doi:10.1111/j.1600-0838.2004.00349.x.
33. Crowther, R.; Leicht, A.; Pohlmann, J.; Shakespear-Druery, J. Influence of Rest on Players' Performance and Physiological Responses during Basketball Play. *Sports* **2017**, *5*, 27, doi:10.3390/sports5020027.
34. Galazoulas, C. Gradual Decline in Performance and Changes in Biochemical Parameters of Basketball Players While Resting after Warm-Up. *Eur J Appl Physiol DOI 101007s00421-012-2320-* **2012**, doi:10.1007/s00421-012-2320-1.

35. Alberti, G.; Annoni, M.; Ongaro, L.; Scurati, R.; Michielon, G. Athletic Performance Decreases in Young Basketball Players after Sitting. *Int. J. Sports Sci. Coach.* **2014**, *9*, 975–984, doi:10.1260/1747-9541.9.5.975.
36. Hammami, A.; Zois, J.; Slimani, M.; Russel, M.; Bouhlel, E. The Efficacy and Characteristics of Warm-up and Re-Warm-up Practices in Soccer Players: A Systematic Review. *J. Sports Med. Phys. Fitness* **2018**, *58*, 135–149, doi:10.23736/S0022-4707.16.06806-7.
37. Russell, M.; West, D.J.; Harper, L.D.; Cook, C.J.; Kilduff, L.P. Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players: A Review and Recommendations. *Sports Med. Auckl. NZ* **2015**, *45*, 353–364, doi:10.1007/s40279-014-0297-0.
38. Silva, L.M.; Neiva, H.P.; Marques, M.C.; Izquierdo, M.; Marinho, D.A. Effects of Warm-Up, Post-Warm-Up, and Re-Warm-Up Strategies on Explosive Efforts in Team Sports: A Systematic Review. *Sports Med. Auckl. NZ* **2018**, *48*, 2285–2299, doi:10.1007/s40279-018-0958-5.
39. Van Hooren, B.; Zolotarjova, J. The Difference Between Countermovement and Squat Jump Performances: A Review of Underlying Mechanisms With Practical Applications. *J. Strength Cond. Res.* **2017**, *31*, 2011–2020, doi:10.1519/JSC.0000000000001913.
40. Hetzler, R.K.; Stickley, C.D.; Lundquist, K.M.; Kimura, I.F. Reliability and Accuracy of Handheld Stopwatches Compared with Electronic Timing in Measuring Sprint Performance. *J. Strength Cond. Res.* **2008**, *22*, 1969–1976, doi:10.1519/JSC.0b013e318185f36c.
41. Mayhew, J.L.; Houser, J.J.; Briney, B.B.; Williams, T.B.; Piper, F.C.; Brechue, W.F. Comparison between Hand and Electronic Timing of 40-Yd Dash Performance in College Football Players. *J. Strength Cond. Res.* **2010**, *24*, 447–451, doi:10.1519/JSC.0b013e3181c08860.
42. Pârvu, C.; Ungurean, B.; Zamfir, C.; Khamraeva, Z.; Daniel, A. The Impact of Technology on Improving the Learning Process in Physical Education Lessons for Medically-Exempt Pupils. *Balneo PRM Res. J.* **2023**, *14*, doi:10.12680/balneo.2023.551.
43. Coqueiro, R. da S.; Santos, M.C.; Neto, J. de S.L.; Queiroz, B.M. de; Brügger, N.A.J.; Barbosa, A.R. Validity of a Portable Glucose, Total Cholesterol, and Triglycerides Multi-Analyzer in Adults. *Biol. Res. Nurs.* **2014**, *16*, 288–294, doi:10.1177/1099800413495953.
44. Seoane, L.; Papasidero, M.; De Sanctis, P.; Posadas-Martínez, L.M.; Soler, S.; Rodríguez, M. Capillary Lactic Acid Validation in an ED. *Am. J. Emerg. Med.* **2013**, *31*, 1365–1367, doi:10.1016/j.ajem.2013.06.015.
45. Barbero-Álvarez, J.; Granda, J.; Calleja Gonzalez, J.; Del Coso, J. Physical and Physiological Demands of Elite Team Handball Players. *Int. J. Perform. Anal. Sport* **2014**, *14*, 921–933, doi:10.1080/24748668.2014.11868768.
46. Krüger, K.; Pilat, C.; Uckert, K.; Frech, T.; Mooren, F.C. Physical Performance Profile of Handball Players Is Related to Playing Position and Playing Class. *J. Strength Cond. Res.* **2014**, *28*, 117–125, doi:10.1519/JSC.0b013e318291b713.
47. Michalsik, L.B. On-Court Physical Demands and Physiological Aspects in Elite Team Handball. In *Handball Sports Medicine*; Laver, L., Landreau, P., Seil, R., Popovic, N., Eds.; Springer Berlin Heidelberg: Berlin, Heidelberg, 2018; pp. 15–33 ISBN 978-3-662-55891-1.
48. Moss, S.L.; McWhannell, N.; Michalsik, L.B.; Twist, C. Anthropometric and Physical Performance Characteristics of Top-Elite, Elite and Non-Elite Youth Female Team Handball Players. *J. Sports Sci.* **2015**, *33*, 1780–1789, doi:10.1080/02640414.2015.1012099.
49. Weber, J.; Wegner, M.; Wagner, H. Physical Performance in Female Handball Players According to Playing Position. *Ger. J. Exerc. Sport Res.* **2018**, *48*, 498–507, doi:10.1007/s12662-018-0541-0.
50. Bishop, D. Warm Up I: Potential Mechanisms and the Effects of Passive Warm Up on Exercise Performance. *Sports Med.* **2003**, *33*, 439–454, doi:10.2165/00007256-200333060-00005.
51. Bishop, D. Warm Up II: Performance Changes Following Active Warm Up and How to Structure the Warm Up. *Sports Med.* **2003**, *33*, 483–498, doi:10.2165/00007256-200333070-00002.
52. Markovic, G.; Dizdar, D.; Jukic, I.; Cardinale, M. Reliability and Factorial Validity of Squat and Countermovement Jump Tests. *J. Strength Cond. Res.* **2004**, *18*, 551–555, doi:10.1519/1533-4287(2004)18<551:RAFVOS>2.0.CO;2.
53. Raeder, C.; Fernandez-Fernandez, J.; Ferrauti, A. Effects of Six Weeks of Medicine Ball Training on Throwing Velocity, Throwing Precision, and Isokinetic Strength of Shoulder Rotators in Female Handball Players. *J. Strength Cond. Res.* **2015**, *29*, 1904–1914, doi:10.1519/JSC.0000000000000847.
54. Stockbrugger, B.A.; Haennel, R.G. Validity and Reliability of a Medicine Ball Explosive Power Test. *J. Strength Cond. Res.* **2001**, *15*, 431–438.
55. Edholm, P.; Krustrup, P.; Randers, M.B. Half-Time Re-Warm up Increases Performance Capacity in Male Elite Soccer Players. *Scand. J. Med. Sci. Sports* **2014**, doi:10.1111/sms.12236.
56. Karvonen, M.J.; Kentala, E.; Mustala, O. The Effects of Training on Heart Rate; a Longitudinal Study. *Ann. Med. Exp. Biol. Fenn.* **1957**, *35*, 307–315.
57. Londeree, B.R.; Moeschberger, M.L. Effect of Age and Other Factors on Maximal Heart Rate. *Res. Q. Exerc. Sport* **1982**, *53*, 297–304, doi:10.1080/02701367.1982.10605252.

58. Navalta, J.W.; Montes, J.; Bodell, N.G.; Salatto, R.W.; Manning, J.W.; DeBeliso, M. Concurrent Heart Rate Validity of Wearable Technology Devices during Trail Running. *PLoS ONE* **2020**, *15*, doi:10.1371/journal.pone.0238569.
59. Shargal, E.; Kislev-Cohen, R.; Zigel, L.; Epstein, S.; Pilz-Burstein, R.; Tenenbaum, G. Age-Related Maximal Heart Rate: Examination and Refinement of Prediction Equations. *J. Sports Med. Phys. Fitness* **2015**, *55*, 1207–1218.
60. Karpan, G.; Škof, B.; Bon, M.; Šibila, M. Analysis of Female Handball Players' Effort in Different Playing Positions during Official Matches. *Kinesiology* **2015**, *47.*, 100–107.
61. Wagner, H.; Fuchs, P.; Michalsik, L.B. On-court Game-based Testing in World-class, Top-elite, and Elite Adult Female Team Handball Players. *Transl. Sports Med.* **2020**, *3*, 263–270, doi:10.1002/tsm2.139.
62. McGowan, C.J.; Pyne, D.B.; Thompson, K.G.; Rattray, B. Warm-Up Strategies for Sport and Exercise: Mechanisms and Applications. *Sports Med. Auckl. NZ* **2015**, *45*, 1523–1546, doi:10.1007/s40279-015-0376-x.
63. Yanaoka, T.; Hamada, Y.; Kashiwabara, K.; Kurata, K.; Yamamoto, R.; Miyashita, M.; Hirose, N. Very-Short-Duration, Low-Intensity Half-Time Re-Warm up Increases Subsequent Intermittent Sprint Performance. *J. Strength Cond. Res.* **2018**, *32*, 3258–3266, doi:10.1519/JSC.0000000000002781.
64. Sargeant, A.J. Effect of Muscle Temperature on Leg Extension Force and Short-Term Power Output in Humans. *Eur. J. Appl. Physiol.* **1987**, *56*, 693–698, doi:10.1007/BF00424812.
65. Hills, S.; Aben, H.; Starr, D.; Kilduff, L.; Arent, S.; Barwood, M.; Radcliffe, J.; Cooke, C.; Russell, M. Body Temperature and Physical Performance Responses Are Not Maintained at the Time of Pitch-Entry When Typical Substitute-Specific Match-Day Practices Are Adopted before Simulated Soccer Match-Play. *J. Sci. Med. Sport* **2020**, doi:10.1016/j.jsams.2020.11.013.
66. West, D.J.; Russell, M.; Bracken, R.M.; Cook, C.J.; Giroud, T.; Kilduff, L.P. Post-Warmup Strategies to Maintain Body Temperature and Physical Performance in Professional Rugby Union Players. *J. Sports Sci.* **2016**, *34*, 110–115, doi:10.1080/02640414.2015.1040825.
67. Racinais, S.; Oksa, J. Temperature and Neuromuscular Function. *Scand. J. Med. Sci. Sports* **2010**, *20 Suppl 3*, 1–18, doi:10.1111/j.1600-0838.2010.01204.x.
68. Kilduff, L.P.; West, D.J.; Williams, N.; Cook, C.J. The Influence of Passive Heat Maintenance on Lower Body Power Output and Repeated Sprint Performance in Professional Rugby League Players. *J. Sci. Med. Sport* **2013**, *16*, 482–486, doi:10.1016/j.jsams.2012.11.889.