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Article *in* Isokinetics and Exercise Science · August 2019

DOI: 10.3233/IES-193178

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Isokinetics and Exercise Science -1 (2019) 1–6
DOI 10.3233/IES-193178
IOS Press

Skeletal muscle fatigue does not affect shooting accuracy of handball players

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Received 1 January 2019
Accepted 8 July 2019

Abstract.
BACKGROUND: Shooting accuracy and ball speed are important factors relating to scoring in handball that could be affected by skeletal muscle fatigue.
OBJECTIVE: To explore the effects of muscle fatigue on male handball players' shooting accuracy and ball speed.
METHODS: Sixteen elite handball players ($M_{age} = 17.1 \pm 1.7$ years) participated in the laboratory and the field-testing sessions. Running speeds equal to 75% of participants' maximal oxygen uptake (VO2max) values from laboratory tests were used as the initial velocity for the 30–15 intermittent fitness test ($30–15_{IFT}$) in the fatigue protocol. Participants shot to the target at random visual signals placed behind the target before and after fatigue. We used an accelerometer and a radar gun to measure wrist acceleration and ball speed, respectively. We also recorded numbers of accurate and inaccurate shots.
RESULTS: There were no significant differences between pre-fatigue and post-fatigue protocols in terms of accurate and inaccurate shots, and ball speed. Only wrist acceleration in the Y axis ($M_{pre-fatigue} = 33.12$, SD = 1.17msec; $M_{post-fatigue} = 34.50$, SD = 1.21msec) was affected by the fatigue protocol in inaccurate shots ($p = 0.042$).
CONCLUSIONS: Muscular fatigue does not affect shooting accuracy and ball speed in male handball players.

Keywords: Handball, shooting accuracy, fatigue, $30–15_{IFT}$, ball speed, wrist acceleration

1. Introduction

Team handball is a competitive sport including full speed running, changes in speed and direction, jumping and overhead throwing [1,2]. Overhead performance including speed and accuracy has critical importance in handball players, which is a determining factor of scoring goals [3]. Successful shooting requires maximum ball velocity; however shooting the ball fast is not enough to beat a good goalkeeper. Accuracy is also essential for optimum results. Passing accuracy provides either pace or continuity of the play or keeps pressure on the defense by allowing each attacker to be a scoring threat [4,5]. In that point, Freeston et al. optimized the accuracy at the range of expert players' shooting speeds at between 75% and 85% of their maximum speed [6].

Training with appropriate intensity is a key factor in improving performance and prevention from injuries. Maximal oxygen uptake (VO2max), maximal heart rate (HRmax) and individual lactate threshold are used as physiological breakpoints in the determination of exercise intensity. Meyer et al. [7] stated that 60 and 75% of VO2max as well as 70 and 85% of the HRmax considerably in relation. In that point during whole match, handball players' mean heart rate was reported

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ISSN 0959-3020/19/$35.00

between 75–80% of maximum heart rate by Chirosa et al. [8]. By the way Michalsik et al. [9], stated relative work load during match-play on average 70.85 ± 6.00% of VO2max for elite team handball players and they also added individual variations in relative work load were observed, since players showed transient periods with a relative work load corresponding over 90% of VO2max. Therefore, in the current study, relative fatigue protocol was set to 75% of VO2max values.

Shooting performance in handball could be affected by fatigue. The term fatigue has been defined as any reduction in maximal force generating capacity, irrespective of the force required for a specified task [10–12]. Neuromuscular fatigue affects the nerve and muscle physiology and biomechanical processes to produce muscle force and it depends on type of exercise performed [13]. A previous study [11] indicates that cumulative fatigue influences range of motion, isometric strength and kinematics and kinetics of throwing a ball of handball players. Fatigue decreases joint position sense in the shoulder and hip joints that may impair the accuracy in throwing and speed [14]. On the other hand, two studies [15,16] showed that skeletal muscle fatigue did not affect ball throwing velocity, muscular balance and kinematics of shooting in handball and basketball. We therefore wondered whether shooting accuracy and ball speed would be affected after fatigue in male handball players. However, in variance with previous studies, we induced skeletal muscle fatigue in the laboratory and evaluated shooting accuracy and ball speed in the field setting.

2. Methods

2.1. Participants

Sixteen elite young male handball players (M_{age} = 17.1 ± 1.7 years, $M_{training\ age}$ = 9.1 ± 1.4 years, M_{height}: 185.3 ± 7.2 cm, M_{weight}: 78.9 ± 11.1 kg, $M_{percent\ body\ fat}$: 9.7 ± 3.2%, M_{BMI}: 22.9 ± 2.3 kg/m^2) participated. All players and their families were informed on the procedures, potential risks and discomfort associated with tests, and they signed a written informed consent form prior to the study. The Ethics Committee of the Middle East Technical University approved the study (13.04.2011/13.30.2ODT.O.70 AH.00.00/126/119-1184).

2.2. Study design

The current study was made up of two sessions: laboratory and field test. Upon arrival at the laboratory participants underwent a treadmill test in order to determine VO2max values (75% of VO2max) for setting relative running speed of each participant for 30–15 intermittent fitness test [17] as the fatigue protocol. Field test session composed of pre-fatigue shooting test and post-fatigue shooting test. After determination of the optimal shooting velocities of the participants shooting to target procedure was applied. After that, the 30–15_{IFT} test was performed to induce fatigue and immediately after the participants repeated the shooting to target procedure. During this session, the acceleration of the wrist and the shooting velocities of participants were simultaneously recorded. Heart rate monitoring and blood lactate measurements were performed both at the laboratory and at the field test sessions (pre-fatigue and post-fatigue conditions).

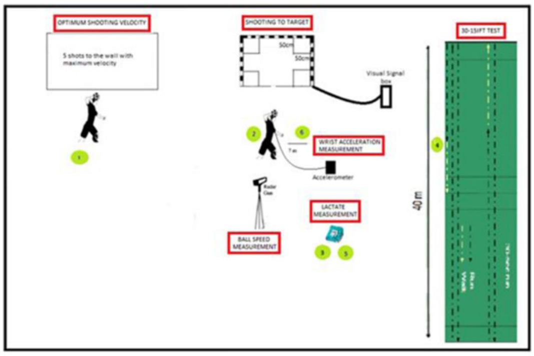

Fig. 1. The field test design.

Blood lactate concentration over 8 mmol/L, 90% of HRmax values were calculated according to age, RER values > 1 obtained from the gas analysis system and the participants' exhaustion were accepted as ending criteria for the tests [18].

Handball players' height measurement was performed with a stadiometer (Holtain, England, sensitivity ± 1 mm). Body mass and percentage body fat measurement were performed with a body composition analyser (Tanita TBF 300, Japan).

A heart rate (HR) monitoring system was fitted to each player before a treadmill test and the 30–15 intermittent fitness test (30–15_{IFT}). During all sessions, both laboratory and field tests, each participant's resting HR and maximum HR values were recorded. In addition, every 3 minutes during the treadmill test and at the end of every 30-s running session during the 30–15_{IFT} test, participants' HR values were recorded by the Polar S 810I (Polar Electro OY, Finland) heart rate monitoring system.

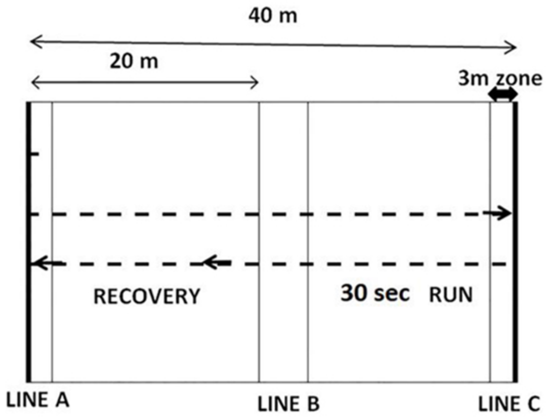

Fig. 2. 30-15 Intermitted Fitness Test (30-15_{IFT}) Footnote: 30-15_{IFT} consists of 30-second shuttle runs interspersed with 15-second walking recovery periods. Running speed start with 8 km h–1 for the first 30 second run and increased by 0.5 km·h–1 every 45 second stage [25].

2.3. Pre-fatigue condition

In order to obtain the VO2max values of the participants, pulmonary maximum oxygen uptake was measured by a breath-by-breath gas analyzing system (JAEGER MasterScreen CPX; Viasys Healthcare GmbH, Hoechberg, Germany) and the Jager LE 200 CE treadmill. The analyzer was calibrated before each test. The participants performed an incremental test on a treadmill with 0.5% slope. Treadmill speed began at 8 km.h^{-1} as a warm-up session, continued with 9 km.h^{-1} and increased 1 km.h^{-1} every 3 m. Each 3-m stage was separated by a 30-s passive rest period, during which both HR values were recorded [19,20]. Breath-by-breath data were stationary time averaged over 5 sec. The highest VO_2 obtained during the graded exercise test's last 40 s was considered maximal oxygen consumption (VO2max) [21]. Seventy five percent of VO2max value is accepted as relative running speed for 30–15_{IFT} as relative fatigue protocol because of the physiological demands about HRmax and VO2max of handball players during competition [7–9].

In order to measure participants' blood lactate levels, 25 μl capillary blood sample was jhhtaken from the participants' earlobe and analyzed using YSI Sport 1500, Yellow Springs Instrument Co, USA, lactate analyzer which was calibrated every five subjects. Before the tests and for each calibration sessions membrane and solution, 5.0 mmol/L and 30.0 mmol/L standard lactate solutions were used.

Before shooting to target test procedure, optimum shooting velocities of participants are determined and want them to shot at least with their optimal shooting velocity to prevent the athlete from developing a tactical method that will influence shooting accuracy during shooting. After a warm-up session, participants shot the ball as fast as possible to the entire goal area from a 7-m line without a target. Ball velocity was measured by Sports Radar Gun (SR 3600, USA) placed behind the participant and arranged to align with the height of his throwing arm. Except for minimum and maximum speeds, mean values of three shots were calculated, and 80% of shooting speed was accepted as optimum shooting velocity. During shooting procedures, a standard handball (diameter = 58–60 cm, weight = 425–475 gr) and goal (width = 3 m, height = 2 m) specified by international Handball Federation guidelines were used.

2.3.1. Shooting to target procedure

Four equal-sized targets (50 cm× 50 cm) hollow and made of iron, were mounted at each of the goal's corners. To hold balls shot into the targets, cone-shaped fishnets were affixed to them. Target areas were chosen as the goal area extreme points and hence most likely to give rise to differences in players' movement form [22]. Targets were labelled in the following manner: top right, bottom right, top left and bottom left relative to participants' perspective. Visual stimuli designating targets were four separate light panels with 15 × 15 green LEDs at 3 mm gaps, attached 1 m behind the goal, where they appeared to participants at each target's centre. Visual stimulus was provided manually; according to the randomised order determined before the trials; a researcher pressed a control unit's designated button to turn on the appropriate light.

2.3.2. Shooting to target measurements

Each participant has shot four times at each of the four target locations, completing 16 shots. Participants had to maintain their feet in contact with the ground just behind the 7-m line; they had to use correct techniques and shoot with optimum velocity during 16 consecutive trials. Between trials, after being given a ball by a designated person standing 1 m away, the participant could handle the ball for 3 s, assume a standardized shooting position and be ready to react to the next visual stimulus. Accurate and inaccurate shots, shooting velocity and successes for each target were all recorded.

Table 1
Paired sample t-test results for accurate and inaccurate shots before and after fatigue protocol

Variables	Pre-test		Post-test		t	p
	M	SD	M	SD		
Accurate shots	5.31	2.08	5.87	2.06	−0.83	0.415
Inaccurate shots	10.68	2.08	10.18	1.97	0.76	0.459

2.3.3. Wrist acceleration measurement

To determine wrist acceleration during shooting performance, a tri-axial accelerometer range, Biopac, USA) was used. Acceleration signals were acquired using an analogue-to-digital converter card (USB-1608FS, Measurement Computing, USA) at a sample rate of 1000 Hz per channel. The accelerometer was attached on the extensor retinaculum (dorsal carpal ligament) on the back of the wrist just proximal to the hand, where x, y and z axes correspond, respectively to lateral (X, from right to left), horizontal (Y, from back to forward) and vertical (Z, from up to down) directions of the forearm. Double-sided adhesive tape and elastic straps affixed the accelerometer to avoid undesired movement due to skin movement and vibration artefacts. The acceleration data recording was begun before initiation of the 16 consecutive trials. Acceleration signals were acquired using an analogue-to-digital converter card at a sample rate of 1000 Hz per channel. Response times were calculated for each shooting action by using synchronized recordings of acceleration and light trigger signals.

2.4. Fatigue protocol

As a fatigue protocol, a 30–15_{IFT} test was used, consisting of 30-s shuttle runs interspersed with 15-s passive recovery periods [15]. Velocity was set equal to 75% of velocity at participants' maximal oxygen uptake (vVO2max) values. Initial velocity changed from one subject to another, depending on differences in each participant's VO2max value for the first 30-s run and increased by 0.5 km.h^{-1} for every 45-s stage thereafter. The 30–15_{IFT} was performed over a 40-m shuttle distance, within which participants had to run at a pace governed by a pre-recorded beep. At each short beep, participants needed to be within 3 m zones at either the extreme or the middle of the course. During the 15-s recovery period, athletes walked forward to join the closest line, where they began the next stage from a standing position. Exhaustion was defined as the inability to match the covered distance according to the audio signal on three consecutive occasions, or until each participant reached 90% of his maximal HR. The velocity of the last completed stage (VIFT) was used to predict VO2max using the equation below, proposed by Buchheit [23–25].

VO2max30-15_{IFT} (ml.-1min.kg-1) = 28.3 – 2.15 G-0.741 A −0.0357 W + 0.0586 A × VIFT + 1.03 VIFT, where G stands for gender (female = 2; male = 1), A for age, and W for weight.

2.5. Post-fatigue condition

After the completion of the 30–15_{IFT} fatigue protocol, following lactate measurements, shooting was repeated with the same procedure as at the beginning of the 30–15_{IFT} test, with the same measurement methods.

2.6. Statistical analysis

Paired sample t-test was used to determined differences in the shooting accuracy, ball speed and wrist acceleration before and after the fatigue protocol.

3. Results

Paired sample t-test results indicated no significant differences on shooting accuracy before and after the fatigue protocol (Table1). Similarly, paired sample t-test results revealed no significant differences on axes of wrist acceleration in the accurate shots. For inaccurate shots, results showed no fatigue effects on axes of wrist acceleration, with the exception of Y axis values ($t_{(15)} = -2.25$, $p < 0.05$) shots before and after the fatigue protocol (Table2). In addition, ball speed values of accurate and inaccurate shots did not change before and after the

4. Discussion

This study primarily assessed the effects of muscle fatigue on male handball players' shooting accuracy. As further research questions, we examined muscle fatigue's effects on ball speed and wrist acceleration.

With respect to our results the fatigue condition did not change handball players' shooting accuracy.

Table 2
Paired sample t-test results for X, Y, Z axis values (msec) of wrist acceleration during shooting before and after fatigue protocol

	Pre-test		Post-test		t	p
	M	SD	M	SD		
Accurate shots						
Acceleration (X)	36.05	1.13	37.24	1.03	−1.40	0.184
Acceleration (Y)	33.25	1.23	33.81	1.02	−0.62	0.542
Acceleration (Z)	3.43	0.44	2.68	0.33	1.47	1.630
Inaccurate shots						
Acceleration (X)	36.11	0.99	37.35	1.11	−1.76	0.101
Acceleration (Y)	33.12	1.17	34.50	1.21	−2.25	0.042*
Acceleration (Z)	3.45	0.34	3.22	0.35	0.54	0.597

*$P < 0.05$.

Table 3
Paired sample t-test results for ball speed (km/h) values in accurate and inaccurate shots before and after fatigue protocols

	Pre-test		Post-test		t	p
	M	SD	M	SD		
Ball speeds (Accurate shots)	66.75	5.83	67.02	4.66	−0.40	0.693
Ball speed (Inaccurate shots)	66.94	5.95	67.48	4.48	−0.76	0.458

In other words, accurate and inaccurate shot performances before and after the fatigue protocols were similar. According to related literature about team handball's match profiles, effective playing time for an entire match was reported over approximately 70% of total effective playing time [26] and the number of attacks (57.5 ± 3.8) and mean time of one attack (23.0 ± 1.9 sec.) were also reported [27]. Obviously, then, players must shoot accurately many times during an entire match and without opposing defensive players' obstruction; thus, they must cope with fatigue in highly intense game situations.

On the other hand, Tillar and Ettema compared novices and experts in terms of speed – accuracy trade-off in overarm throwing. They reported that, while novices may show a trade-off, expert players could control their techniques and manage optimized throwing patterns without showing effects of fatigue [28]. Parraga, Sanchez and Ona also reported that throwing speed did not affect accuracy [29]. In addition, García et al. reported that ball speed did not affect throwing accuracy [30]. Enoka stated that unless athletes were highly motivated, most terminated exercise before their muscles became physiologically exhausted; thus, elite athletes highly motivate themselves, especially for match conditions, and although they do reach fatigue, they can continue top performance [31]. In another supporting study, Andrade asserted that ball speed did not change at the end of the fatigue condition both for accurate and inaccurate shots [15]. In other words, experienced players, especially, better able to cope with fatigue conditions and still optimize their throwing velocity and techniques. In this situation, related studies supported the current results.

For wrist acceleration, this study's results show that only movement in the Y axis (from back to forward) only was affected by the fatigue condition for inaccurate shots. In handball throwing technique, mechanical energy transfers in sequence from the starting point to the ball release, respectively, for the hip, trunk, shoulder, upper arm, forearm and hand. Therefore, the part of the mechanical energy generated in and around the shoulder is transferred to the hand [31]. From that point, throwing motion follows an orbit from back to forward. In the current study, chances of movement pattern of Y axis during or inaccurate shots after the fatigue condition can be explained by players attempting to optimize their technique to avoid effects of fatigue.

The study was restricted by the elite young male handball players. If the same study design was performed on female handball players or if local fatigue protocol was applied instead of general fatigue protocol, the result could be different. In addition, the number of each target was limited to four shots in order to avoid elimination of fatigue effects during shooting.

5. Conclusion

The results of this study suggest that muscle fatigue has no effect on shooting accuracy and ball speed in elite male handball players. Further studies that focus on the effects of various local fatigue protocols on the variables analyzed are recommended.

Conflict of interest

The authors declare no conflict of interest regarding publication of this manuscript.

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