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ORIGINAL ARTICLE

Effect of different physical stressors on soldier's psychophysiological response and marksmanship

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Abstract: *Shooting impairment may occur whereas there is either central or peripherical fatigue. However, the effects of different physical stressor stimuli on fine motor skills as shooting are yet not fully understood. The present research aimed to analyze the effect of endurance and resisted physical stressors on the psychophysiological response and pistol marksmanship of novel soldiers, and the possible differences in gender and BMI. Variables of heart rate, isometric hand strength, rate of perceived exertion, and pistol marksmanship were analyzed in 56 soldiers in endurance and resisted stress protocols. Isometric hand strength, heart rate, and RPE were significantly higher in both resisted and endurance physical stress protocols than in the basal sample. Gender differences were seen in strength, cardiovascular and RPE values. Also, subjects with larger BMI presented significantly higher isometric hand strength and higher marksmanship in all moments evaluated. We conclude that an endurance stress protocol produced a higher cardiovascular and perceived exertion than a resisted one, not affecting hand strength, shooting heart rate, and marksmanship. Females presented lower hand strength and marksmanship while higher rated of perceived exertion and heart rate during the endurance and resisted stress protocols than males. Overweight participants presented higher heart rates during both physical stress protocols, but higher hand strength and marksmanship while similar shooting heart rates than normal-weight participants.*

Keywords: *marksmanship; stress; heart rate; fine motor skills; fatigue*

INTRODUCTION

The effect of different stressor stimuli on fine motor skills is an area with wide applications, yet not highly developed. The stress effects may differ regarding the characteristics of the stressor stimuli. In the case of physical exercise, the intensity, duration, and type of exercise have a direct impact either on fine or gross motor skills [1].

Authors found how after a bout of high-intensity, lower-body resistance training passing accuracy was decreased [2]; after cycling in an ergometer at 100% of maximal capacity, significant attenuation on reaction times was found, like at lower intensities (70%) [3], suggesting an inverted-U function between exercise intensity and motor control.

Specifically, in combat, previous researchers found no effect on marksmanship despite the increased combat stress, neither with rifles and pistols independently of the caffeine ingestion [4,5]. The physiological mechanisms underlying the decrease of performance on fine motor skills may be related to i. the accumulation of hydrogen ions, which affect glycolytic enzymes due to low Ph, impairing ATP production and compromising the contractile capacity of the muscle [6]; ii. the high inorganic phosphate concentration, which inhibits Ca ++ reuptake increasing its concentration in the sarcoplasm and hindering muscle contraction; and iii. the ammonia concentration, which is related to the affection of neurobiological processes, affecting the quality of neural connections and electrical activity of the muscle [7].

In addition, all these acute metabolic responses are directly modulated by the intensity and type of exercise [8]. Related to shooting accuracy and marksmanship, previous authors showed that high-intensity exercise affected central aspects

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of shooting performance, shooting accuracy, shooting precision, and stability of hold, being accentuated when shooting in a standing position, compared with shooting in a prone position [9]. Acute protocols designed to fatigue the upper body flexor muscle groups (muscles involved in stabilizing and supporting a firearm), such as lifting, climbing, and pulling, presented significant decreases in rapid-fire rifle shooting performance in the standing position in soldiers immediately after these exercises [10]. In this line, independently of the type of exercise (concentric, eccentric, or a combination of both) or the location (knee, ankle, or entire lower extremity), acute fatigue may induce a loss of stability[11]. This fact, directly affects postural, standing, and gun stability, key factors connected to rifle shooting accuracy 12 since body sway and imbalance has been directly correlated with poor shooting score[13,14]. Superior shooting performance requires good postural balance, as well as, an ability to steady the gun while aiming[12]. However, the effect of different acute stress exercise-induced peripheral fatigue on fine motor skills such as shooting is yet not well documented. Most of the studies have focused either on soldiers or experienced subjects, showing how lower fitness levels, experience, and training increased fatigue and decrease marksmanship [15,16]. In addition, previous studies were the focus on the rifle, showing lower research on pistols, leading to greater muscular fatigue due to the farther center of mass to the shooter's body and the increase in joint angle [17]. Thus, we proposed the present research to analyze the effect of endurance and resisted physical stressors on the psychophysiological response and pistol marksmanship of non-experienced shooters. As a second aim, we aimed to analyze differences in gender and weight. We hypothesized that i. resisted physical stressor would produce a higher psychophysiological stress response, decreasing the marksmanship more than the endurance exercise stressor; ii. Subjects with higher body mass index (BMI) would present higher psychophysiological response and lower marksmanship; iii. There would be gender differences in the psychophysiological stress response and marksmanship.

MATERIALS AND METHODS

Participants

A total of 56 soldiers belonging to light military forces (23.6±3.7 years; 175.8±9.1 cm; 71.3±8.7kg; 23.1±2.2 BMI) were analyzed. Inclusion Criteria were: Professional Experience in the army. Exclusion Criteria for were: Presence of any medical condition or injury that would be a limiting factor for intense physical activity and the use of firearms (e.g. cardiovascular diseases) at the moment or during the protocol, intake of any dietary supplement, stimulants, or other ergogenic aids. Participants were informed of the characteristics of the study and the potential risks derived from those who were exposed. All the procedures were conducted following the Helsinki Declaration (as revised in Brazil, 2013), all the participants filled out an informed consent form previous to starting the research, and all the procedures were approved by the University Ethic Committee.

Methods

Procedures

Before the research started all the subjects received instructions/familiarization regarding the protocol and tests. Then 3 days of evaluation were distributed as follows: 1º Day: basal sample of all the variables measured in the study; 2º Day: 48h after, subjects performed randomly an endurance or resisted physical stress protocol; 3º Day: 48h after, subjects performed the remaining protocol.

For both physical stress protocols, participants conducted a warm-up composed by:

i) 2 min of joint mobility

ii)5 min of light aerobic running (50-60% Maximum Heart Rate)

iii) 2 series of 20 m of progressive running intensity

After the warm-up, participants performed the physical stress protocol, which was supervised and encouraged by sports science professionals:

Resisted Physical Stress Protocol

- 20 sets of burpees at maximum intensity

Endurance Physical Stress Protocol

- 5 min maximal running test in a track field.

Before the research, body weight was assessed with a SECA scale model 714 with a precision of 100 grams (range 0.1-130 Kg), located on a flat and smooth surface and calibrated at zero. Subjects were barefoot and with minimal clothes. Once located in the center of the platform, they remained without their body being in contact with surrounding objects, with the weight evenly distributed on both feet facing forward. Height, with a SECA scale model 714 with a precision of 0.1 mm (range 60-200 cm). The subject stood up, barefoot with the head oriented in the Frankfurt plane. Arms on both sides of the trunk and fully extended with palms touching the external face of the thighs, heels together touching the lower end of the vertical surface with the inner edge of the feet, occipital area, scapular, buttocks, posterior face of the knees and calves touching the vertical surface of the anthropometer.

Before and after the exercise stress protocols, we measured:

- Rating of perceived exertion (RPE), 6–20 scale.

- Isometric hand-grip strength using a TKK 5402 dynamometer (Takei Scientific Instruments CO. LTD). Each participant's grip strength was measured on the shooting hand. Participants were standing with 0 degrees of shoulder flexion, 90 degrees of elbow flexion, and the forearm in neutral. Idem, was done pre-post and among series.

- Heart Rate (HR) was measured before and during the entire protocol by a Polar V800 HR monitor (Kempele, Finland).

- Marksmanship was measured by the sum of three airsoft pistol shots to a target at a distance of 7 m, following procedures of previous research [4,5]. A gas blowback Beretta 92X Centurion airsoft gun (450 fps) was used.

Statistical analyses

To analyze the data, we used the SPSS statistical package (version 24.0; SPSS, Inc., Chicago, Ill.). Means and standard deviation (SD) were calculated using traditional statistical techniques. Normality and homoscedasticity assumptions were checked with a Kolmogorov-Smirnov test. To analyze differences between pre and post a T-test was administered, and to analyze differences between experimental groups (gender and BMI) and differences between moments of evaluation, an ANOVA test was conducted since variables presented a parametric distribution.

RESULTS

The results are reported as mean±SD. Isometric hand strength, HR, and RPE were significantly higher in both Resisted and Endurance physical stress protocols than in basal samples (Table 1).

According to gender differences, males present significantly higher isometric hand strength at all moments evaluated. HR at shooting at Basal and Endurance physical stress protocol of females was statistically higher than males. Female RPE was higher than males at Resisted and Endurance physical stress protocols (Table 2) (between parenthesis significant differences (p≤0.05) between males vs females).

Subjects with larger BMI (BMI ≥25 overweight) presented significantly higher isometric hand strength at Basal and Resisted physical stress protocol than subjects with lower BMI (BMI<25). Subjects with larger BMI also presented higher marksmanship in all moments evaluated (Table 3) (between parenthesis significant differences (p≤0.05) between BMI<25 vs BMI≥25).

Table 1: Psychophysiological parameters analyzed before and after the physical stress protocols

	Basal	Resistance Training	Endurance Training	F	P	η2	Moment comparison
Isometric Hand Strength	42.8 ± 8.4	44.9 ± 6.4	42.7 ± 2.1	8.481	.001	.239	2>1
Marksmanship	12.8 ± 9.5	14.5 ± 10.6	15.2 ± 10.1	1.844	.168	.068	-
Heart rate during protocol	-	166.1 ± 13.3	178.9 ± 11.7	68.156	.013	.711	3>2
Shooting Heart Rate	90.3 ± 17.5	125.2 ± 19.0	124.3 ± 17.6	50.122	.000	.650	2>1; 3>1
Rated of Perceived Exertion	6.6 ± 1.1	15.2 ± 2.0	16.8 ± 1.8	739.846	.000	.965	3>2>1; 3>1

Table 2: Psychophysiological gender differences of the parameters analyzed before and after the physical stress protocols

		Basal	Resistance based exercise	Endurance based exercise	F	P	η2	Moment comparison
Male	Isometric Hand Strength	44.8±7.8	46.3±6.2	43.9±9.5	3.973	.026	.153	2>1
	Marksmanship	13.6±9.5	16.0±10.8	15.7±10.7	1.940	.156	.081	-
	Heart rate during protocol	-	165.8±9.2	178.9±6.1	71.012	.021	.781	3>2
	Shooting Heart Rate	87.7±17.0	128.4±16.0	121.6±16.5	65.007	.000	.747	2>1;2>3;3>1
	Rated of Perceived Exertion	6.6±1.1	14.9±2.0	16.5±1.8	604.148	.000	.965	3>2>1; 3>1
Female	Isometric Hand Strength	33.4±2.4 (.000)	38.2±1.0 (.000)	36.9±2.1 (.025)	53.399	.000	.930	3>1; 2>1
	Marksmanship	9.2±9.1 (.011)	7.4±5.5 (.018)	13.2±7.3 (.024)	2.533	.141	.388	-
	Heart rate during Protocol	-	174.4±8.2 (.011)	191.2±7.1 (.006)	71.231	.000	.961	3>2
	Shooting Heart Rate	102.6±15.0 (.014)	113.6±27.1	136.6±17.9 (.014)	69.514	.000	.946	3>1; 3>2
	Rated of Perceived Exertion	6.6±1.2	16.2±1.8 (.009)	18.2±1.0 (.007)	392.302	.000	.990	3>1; 2>1

Table 3: Psychophysiological body mass index differences of the parameters analyzed before and after the physical stress protocols

		Basal	Resistance based exercise	Endurance based exercise	F	P	η2	Moment comparison
BMI <25	Isometric Hand Strength	41.7±3.5	43.7±7.0	42.9±7.7	1.197	.318	.238	-
	Marksmanship	11.4±9.7	12.4±10.6	12.5±8.8	.380	.686	.019	-
	Heart rate during protocol	-	163±8.5	178±7.2	67.145	.032	.631	3>2
	Shooting Heart Rate	91.8±15.2	125.9±14.7	126.8±17.2	28.322	.000	.685	1<2; 1<3
	Rated of Perceived Exertion	6.5±1.0	14.7±1.9	16.8±1.5	910.743	.000	.979	1<2; 1<3; 2<3
BMI ≥25	Isometric Hand Strength	44.5±2.8 (.019)	48.5±5.5 (.011)	39.7±12.9	22.960	.000	.793	1<2
	Marksmanship	16.8±7.8 (.001)	20.8±7.7 (.009)	23.4±9.8 (.000)	2.169	.157	.266	-
	Heart rate during Protocol	-	171±9.7 (.031)	188±9.1 (.021)	79.256	.038	.720	3>2
	Shooting Heart Rate	92.7±23.5	122.2±24.3	118.4±16.9	3.996	.047	.400	1<2; 1<3
	Rated of Perceived Exertion	7.0±1.3	16.4±1.7 (0.007)	18.8±2.4 (0.021)	112.325	.000	.949	1<2; 1<3

DISCUSSION

The present research aimed to analyze the effect of endurance and resisted physical stressors on the psychophysiological response and pistol marksmanship of non-experienced shooters. Our hypotheses were partially completed since i. There were no significant differences in stress protocols in the psychophysiological stress response or marksmanship. ii. A similar psychophysiological response was found independently of the BMI, but subjects with larger BMI presented higher marksmanship values. iii. There were gender differences in the psychophysiological stress response and marksmanship.

The cardiovascular response monitored at the basal time was higher than the considered standard for the population evaluated (60-70 bpm) [18]. This was consistent with an anticipatory anxiety response, a defense organic response modulated by the activation of the sympathetic nervous system that prepares individuals for any uncontrolled or new stimuli [19]. Previous authors reported a significant increase in the heart rate from a standing resting position to a standing position firing a gun, in line with the results obtained in the present research [20].

The cardiovascular response has a direct impact on fine motor skills as shooting, the higher HR shortens the diastolic phase and increases the systolic one, increasing body tremor [21], which in addition to the one produced by physical activity, marksmanship could be compromised [22,23]. After resisting and endurance physical stress protocols we found a significant increase in the cardiovascular response to shooting (38.6% and 46% respectively), however, marksmanship was not affected, suggesting no negative effect on shooting HR and fine motor skills.

In this line, previous authors obtained similar cardiovascular results, without a marksmanship compromise in archers [22] and pistol shooters [24]. The lack of significant differences in marksmanship between the two stress protocols highlighted the no effects of peripheral fatigue on shooting performance.

There are three possible hypotheses which would explain this: i) Subjects performed both resisted and endurance physical stress protocols with an optimal arousal level [25,26], in accordance with the Inverted-U hypothesis which predicts that performance is best at a moderate optimal level and becomes progressively worse with either increases or decreases in arousal, and comes to confirm that incorporating psychological factors in training (e.g. pressure), may enhance performance [27,28]; ii) Since subjects have none previous experience and despite performing a familiarization, as consequence of low total acquired experience, fatigue did not affect their marksmanship values; iii) Among the familiarization, breathing and holding techniques were taught to the subjects, which are essential to attenuate the postural tremors created by possible high HR at the moment of shooting, technique which has proven essential for rifle, pistol [15] and arch [22], the use of these techniques could be another possible explanation.

The ability to stabilize a gun is crucial for performance in pistol shooting, being related to the shooter's muscular strength [29]. The maintenance of isometric hand strength can play an important role in this fact, highlighting the importance of physical fitness for athletes and professionals that have to use fire weapons (such as biathlon athletes, or police and military respectively).

Previous authors proposed integrated operative high-intensity interval training as one of the best training tools for this aim since it allows participants to improve both, muscular and cardiovascular performance, two factors directly related to shooting performance [30,31]. In this line, both protocols elicited a significant increase in HR during its execution, being higher in the endurance stress protocol.

This cardiovascular response could be related to the continuous impact, load, and physiological demand of this type of work, a fact consequent with previous studies which compared similar exercise-based protocols [31,32]. The HR reached during the two stress protocols is associated with a decrease in fine motor abilities and specifically in shooting, a fact basic for any shoot actions independently performed by arch [33] pistol or rifle [24].

Nevertheless, at the shooting moment the HR decreased below 140 bpm, HR is not related to this fine motor abilities impairment.

These results highlighted the importance of cardiovascular stress response control in these activities, emphasizing the importance of a good aerobic physical condition for these activities. Females presented lower isometric hand strength values at all moments evaluated. This could be explained due to the female phenotype since they present lower body and muscle mass than males, lower baseline testosterone levels, and lower strength in the upper body muscles [34]. Previous authors also found similar results when comparing the hand grip of active handball and judo female athletes with healthy male subjects, presenting males with higher hand grip strength than females [35].

RPE seems to be also influenced by gender. Females presented higher RPE in the endurance and resisted physical stress protocols. These gender differences were also found in weight-bearing as treadmill [36,37,38], partial weight-bearing as ski machine [38], and non-weight-bearing as cycle [39]. Mechanisms underlying this apparent gender difference cannot be specified, however, there are several hypotheses as information processing [40] and physiological [41] differences as plausible explanations. In this line, previous authors suggested that gender differences in RPE may exist in the fact that females rate exercise as more effortful than males at absolute levels of power output [42].

Finally, a higher cardiovascular response during the protocols and while shooting at basal and endurance stress protocol was presented by females. These differences are related firstly to their smaller myocardium, beating slightly faster to make up for its size. While the average basal male heart beat is around 70-72 bpm, women's beats are 78-82 bpm [43]. Secondly, the increased basal heart rate would explain the aforementioned anticipatory anxiety response, which increases the heart rate due to perceived stress and novelty of the stimuli [19]. The response has been also evaluated in sports competition tasks [44] or novel paratroopers before jumping [45] with a similar physiological response. Thirdly, the lower recovery capacity after short burst high-intensity endurance activities of females [46], may explain the significantly higher shooting heart rate than males after the endurance stress protocol. BMI cutline was established at normal-weight (<25 BMI) and overweight (25 BMI >).

Overweighed subjects presented greater significant values of isometric hand strength, probably explained due to the larger body mass, consequent with previous studies comparing the strength of obese and non-obese subjects of either upper [47] and lower body [48] strength. In addition, overweighed subjects present greater marksmanship values evaluated at all moments, reinforcing the relationship between hand strength and shooting marksmanships [49].

However, the cardiovascular response of overweighed subjects was significantly higher during both physical stress protocols, explained due to inferior cardiovascular performance, since for the same stimuli and intensity greater cardiovascular output is needed compared to normal-weight subjects.

Nevertheless, during shooting actions their HR was similar to the normal-weight group, decreasing to HR values related with no negative effect on fine motor skills. In addition, RPE was also higher in overweighed subjects after both protocols, suggesting greater effort and exposing inferior fitness, explained due to worst physical conditioning, or the fact that being overweight is an added organic stressor 50. In this line, previous authors correlated larger BMI with reduced cardiovascular output and lower performance, showing greater sympathetic, stress, and RPE baseline values [51], supporting our present data.

CONCLUSIONS

An endurance stress protocol produced a higher cardiovascular and perceived exertion than a resisted one, not affecting hand strength, shooting heart rate, and marksmanship. Females presented lower hand strength and marksmanship while higher rated of perceived exertion and heart rate during the endurance and resisted stress protocols than males.

Overweight participants presented higher heart rates during both physical stress protocols, but higher hand strength and marksmanship while similar shooting heart rates than normal-weight participants.

Limitations of the study practical applications

The small number of subjects is one of the main limitations of the present study, however, there were no more available subjects at the moment. A second limitation was the lack of evaluation of hormones such as testosterone, alpha-amylase, and cortisol to control the hormonal stress response. These limitations were subjected to financial and technological lack.

Practical applications

The information of the present research could be used for specific training, allowing further individualization of the training stimulus according to gender, anthropometric and experience characteristics. In addition, soldiers, police, and other security crops, as well as those sport modalities in which shooting is present, for example, biathlon, could potentially benefit from this information.

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