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**EFFECTS OF SHIVERING ON RIFLE  
SHOOTING PERFORMANCE IN U.S. MARINES**

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND  
BETHESDA, MARYLAND

The Effects of Shivering on Rifle  
Shooting Performance in U.S. Marines

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## SUMMARY

### Problem

Marksmanship is an integral part of military training. It requires a combination of fine and gross motor skills and visual-motor components. Muscular shivering, induced by acute cold exposure, makes fine motor skills difficult to perform. Therefore, prolonged intensive shivering would be predicted to cause a decrease in rifle shooting performance.

### Objective

The objective was to examine the effect of muscular shivering, as measured by analysis of root mean square (RMS) and mean power frequency (MPF) of electromyographic (EMG) signals on rifle shooting accuracy (RSA).

### Approach

Six subjects wore U.S. Marine standard issue boots, pants, and T-shirts while exposed for 120 min to both a cold (40°F), and a neutral (75°F) condition. Mean-weighted skin temperature ( $T_{sk}$ ), rectal temperature ( $T_{re}$ ), and heart rate (HR) were monitored at 5 min intervals. Blood was analyzed for catecholamines before and after both exposures. RSA was determined by a laser acquisition system (Noptel Training System ST-1000PC). RSA, horizontal (X), and vertical (Y) deviations were measured. Muscular shivering was determined visually, by EMG signals analyzed for mean power frequency (MPF), and root mean square (RMS) and oxygen consumption ( $\dot{V}O_2$ ). A repeated measures multivariate analysis of variance was performed to determine significant ( $p < 0.05$ ) main and interaction effects. A Tukey's post hoc test was performed when a significant difference occurred.

## Results

$\dot{T}_{sk}$  decreased significantly (32.8°F vs. 23.8°F) and catecholamines increased (norepinephrine pre 41.5 to post 324.3 pg/ml) during cold exposure. However,  $T_{re}$  temperature in either condition did not significantly change. X deviation exhibited a significant difference between cold and neutral conditions (1.42 and 1.26 cm, respectively). Y deviation and RSA did not show any significant change. Analysis of the MPF for the trapezius and middeltoid muscles revealed a significant temperature effect. Neither the EMG from the pectoralis major or rectus femoris showed any significant temperature effect. There was no significant difference for the RMS in any of the muscles. A significant metabolic response occurred as indicated by the increase in  $\dot{V}O_2$  over time in the cold condition (0.309 L·min<sup>-1</sup> vs. 0.727 L·min<sup>-1</sup>).

## Conclusion

RSA was not adversely affected by 120 min of mild cold exposure. Some shivering of neck and shoulder muscles occurred but overall body shivering was not documented. It is concluded that the cold stress was not sufficient to induce whole-body shivering and hence compromise RSA.

## INTRODUCTION

Exposure to cold has played a major role in compromising military operations for many years (Hanson & Goldman, 1969; Hawryluk, 1977; Vaughn, 1980). Cold injuries such as frostbite and trench foot have plagued military personnel in this country since the American Revolution and were critical to military losses (Hanson & Goldman, 1969; Grandberg, 1988). The effects of cold exposure on exercise performance, nutrition, and physiological parameters have been extensively studied throughout the years (Dauncey, 1990; Dauncey, 1981; Doubt, 1991; Edwards & Roberts, 1991; LeBlanc, 1987; Martineau & Jacobs, 1988).

Shivering is defined as an increase in reflex, nonlocomotor muscular tone attributable to exposure to cold, with and without visible tremor (Kleinebeckel & Klussmann, 1990). Shivering has been associated with the clonus of spastic muscles and has been noted to have overt tremor-like movements (Israel & Pozos, 1989; Pozos & Iaizzo, 1991). Askew (1989) and Shephard (1985) reported that coordinated motor skills were impaired while shivering, and Kleinbeckel and Klussman (1990) stated that a typical cold tremor involved almost all body parts but mainly the extremities. Thus, Rifle Shooting Accuracy (RSA), which is a crucial part of military field operations, would be predicted to decrease due to intense muscular shivering.

Maintenance of internal body temperature by shivering is a vital physiological reaction induced by cold exposure. However, the direct effect of shivering on performance tasks during military field operations has been largely ignored.

The objective of this study was to investigate the effects of cold-induced muscular shivering, measured by electromyography (EMG) analysis, on RSA of military personnel. In addition, a secondary objective was to quantify muscular shivering as measured by frequency; median power frequency (MPF) and intensity or amplitude; root mean square (RMS).

## MATERIALS AND METHODS

### *Subjects*

Six male U.S. Marine marksmen signed informed consent and volunteered as subjects. Physical characteristics of the subjects were: (mean  $\pm$  SD) height (174.0  $\pm$  4.1 cm); weight (77.86  $\pm$  5.75 kg); and body fat (14.9  $\pm$  3.2%).

### *Measurements*

**Shooting performance.** Shooting performance was determined by the Noptel Laser Rifle Training System ST-1000PC which consists of an optical target and tripod [Fig. 1 (A)], a laser transmitter attached to the barrel of an M-16A2 rifle [Fig. 1 (B)], and a control switch interfaced with a desktop computer.

The subjects aimed and fired at a solid black bull's-eye surrounded by three outer rings from a distance of 2.86 m for a total of 10 shots (trials) per series. One series of 10 shots was completed at minutes 25, 55, 85, and 115 of cold and neutral conditions. Mean RSA was determined by averaging the score (hit) of all 10 shots at a specific time (0, 25, 55, 85, 115 min), in the cold or neutral condition. The score obtained for each shot (0-10.9) was determined by distance to center mass (bull's-eye). Horizontal deviation was defined as the distance along the X axis from the center of the shot group to the center of the target. Vertical deviation was defined as the distance along the Y axis from the center of the shot group to the center of the target.

**Muscle activity.** Shivering was monitored by EMG activity using Ag-AgCl surface electrodes attached to the skin with sterile adhesive electrode washers. Four muscle sites were chosen to represent upper and lower body shivering: the trapezius, miltoid, pectoralis major, and rectus femoris (Bell et al., 1992; Israel & Pozos, 1989). Electrodes were placed 1 cm apart above the belly of the muscle. EMG signals were amplified using Grass AC Pre-amplifiers P5

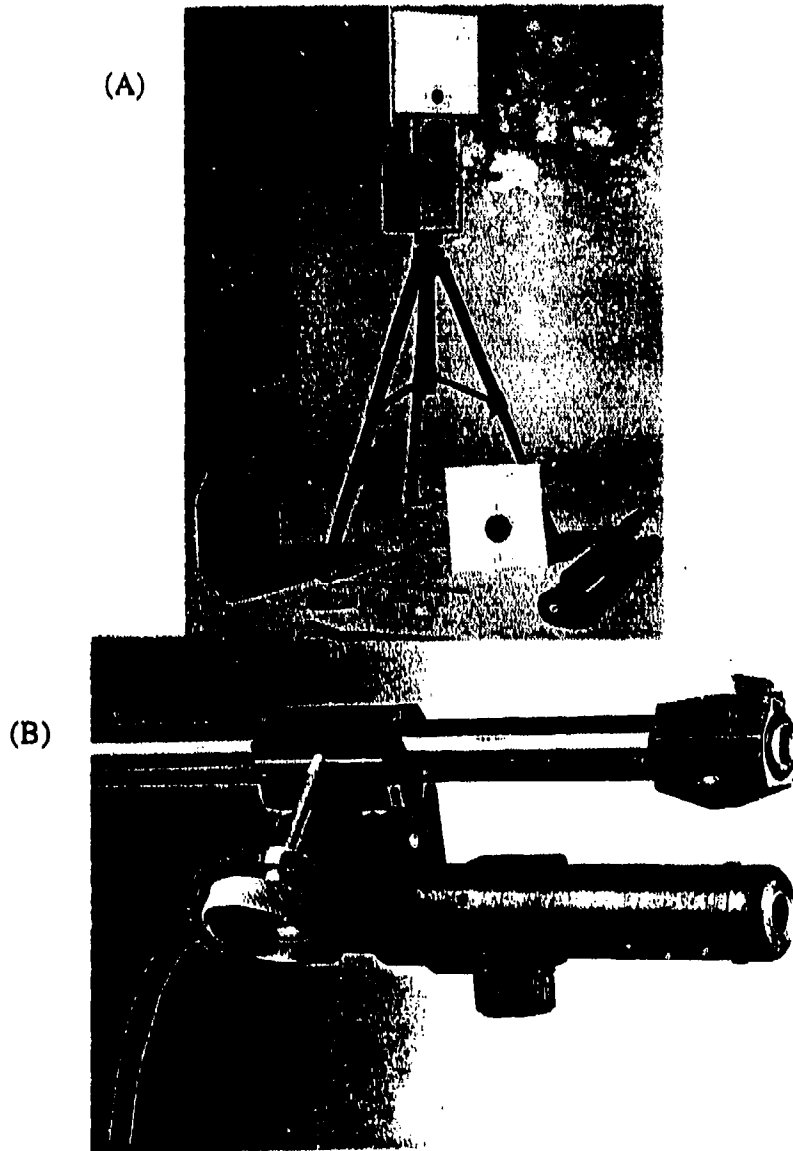


Figure 1. (A) Tripod with optical target and shooting target.  
(B) Laser transmitter attached to barrel of M-16 rifle.

series and recorded on a TEAC RD130T PCM data recorder. A 60-sec recording was taken at baseline and after 20 and 110 min of each trial. The recorded EMG signal was digitized at a sampling rate of 1024 samples/sec. Data were divided into three 10-sec windows and analyzed for RMS and MPF. The averaged values for each window were reported as the RMS and MPF for each rifle series.

Physiological Measurements. Height and weight were measured using standard medical procedures. Percent body fat was determined by skinfold measurements taken with Harpenden calipers at the chest, abdomen, and thigh. Body density was calculated utilizing the three-site equation proposed by Jackson and Pollock (1978). Siri's equation (1961) was used to determine relative body fat.

Oxygen consumption ( $\dot{V}O_2$ ) was determined by collection of expired air into 100 L Collins bag for a period of 2 min. The expired air was analyzed for carbon dioxide using SensorMedics Carbon Dioxide Medical Gas Analyzer LB-2, and for oxygen by using AMETEK Oxygen Analyzer S-3A/1. The volume of expired air was measured by a dry gas meter. For each trial,  $\dot{V}O_2$  was measured at baseline and immediately after each shooting series. Heart rate (HR) was monitored by a Polar Advantage-XL heart rate watch. The heart rate watch was set to record HR at one minute intervals. Pre-and post venous blood was drawn from an antecubital vein and analyzed for catecholamines on a Waters HPLC with ESA Electro Chemical Detector.

Mean-weighted skin temperature ( $\bar{T}_{sk}$ ) was measured using silver skin thermistors taped at four sites: the chest (CH), biceps (B), front of the thigh (TH), and back of the calf (CF).  $T_{re}$  was measured using sterile disposable rectal thermistors. A Grant Squirrel/Meter logger was used to record all temperature measurements at 1-min intervals.  $\bar{T}_{sk}$  was calculated as:  $.35 \cdot (T_{chest} + T_{biceps}) + .15 \cdot (T_{thigh} + T_{calf})$ , using the techniques proposed by Ramanathan (1964) and adapted by Mitchell and Wyndham (1969).



## *Procedures*

On two separate days with at least 1 day between days, seated subjects were exposed to 120 min of 40°F (cold) and 120 min of 75°F (neutral) environment, with a relative humidity of 35% in a sealed environmental chamber. Subjects were clothed in the standard issue camouflage pants, boots, and undershirt for both experimental conditions. The order of exposure was counterbalanced among subjects.

At the beginning of each session, the same qualified personnel sighted and calibrated the Noptel laser rifle system. On the initial visit, each subject was instructed on how to use the laser rifle system and was given 30 practice shots broken into 3 blocks of 10 shots to become familiar with the system. Next, the subject's height, weight, and body fat were determined. Prior to entering the environmental chamber, each subject was instrumented with a heart rate monitor, rectal thermistor, surface skin temperature thermistors, and surface EMG electrodes. After 15 min of rest in a sitting position, baseline measurements of HR,  $\dot{T}_{sk}$  and  $T_{re}$ , blood pressure (BP),  $\dot{V}O_2$ , and EMG samples were recorded.

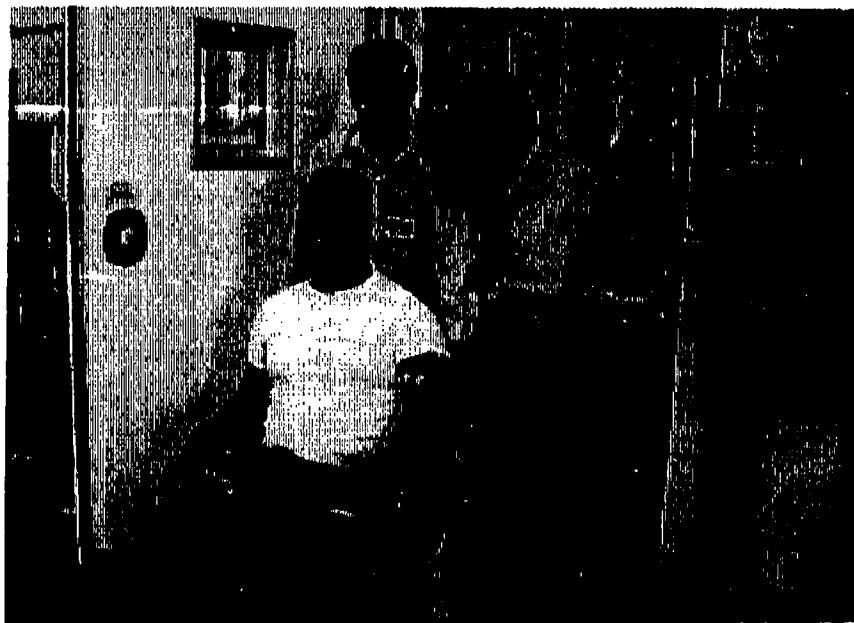


Figure 2. Subject being rolled into environmental chamber.

Subjects were seated in a standard desk chair and wheeled into the environmental chamber to minimize unnecessary movements (Fig 2). The subjects remained seated in the chair for the entire 120 min exposure. Subjects were in the chamber for 25 min before firing the first series. One series of 10 shots was completed at minutes 25, 55, 85, and 115 of cold or neutral conditions. Immediately after each shooting series, HR,  $\dot{T}_{sk}$ ,  $T_{re}$ , blood pressure, and  $\dot{V}O_2$  were recorded.

**Statistics.** A repeated-measures multivariate analysis of variance (MANOVA) was used to assess the difference in means of RSA, X deviation, Y deviation,  $\dot{V}O_2$ ,  $\dot{T}_{sk}$ ,  $T_{re}$ , and EMG samples for the two experimental conditions. Statistical significance was accepted at  $p < 0.05$ . Tukey's multiple comparison test was used for *post hoc* analysis.

## RESULTS

**Shooting performance.** Table 1 contains the values for mean RSA, X and Y deviations for both environmental conditions. There were no significant differences in RSA between cold or neutral conditions. Horizontal (X) deviation was significantly increased due to cold exposure. There were no significant differences in vertical (Y) deviation.

TABLE 1  
Rifle Shooting Accuracy (RSA), Horizontal (X) and Vertical (Y) Deviations  
in Cold and Neutral Conditions

T (min)	RSA neut.	RSA cold	X neut.	X cold	Y neut.	Y cold
0	6.6±1.6	6.6±1.6	1.5±0.1	1.5±0.1	1.5±0.0	1.5±0.0
30	7.0±0.5	7.0±1.0	1.3±0.4	1.2±0.2	1.3±0.4	1.3±0.3
60	6.7±1.3	6.8±1.1	1.2±0.3	1.5±0.4	1.4±0.3	1.6±0.4
90	7.3±1.3	6.3±0.9	1.2±0.3	1.6±0.4	1.2±0.4	1.6±0.3
120	6.8±1.6	6.2±2.1	1.1±0.3	1.4±0.3	1.2±0.4	1.5±0.3

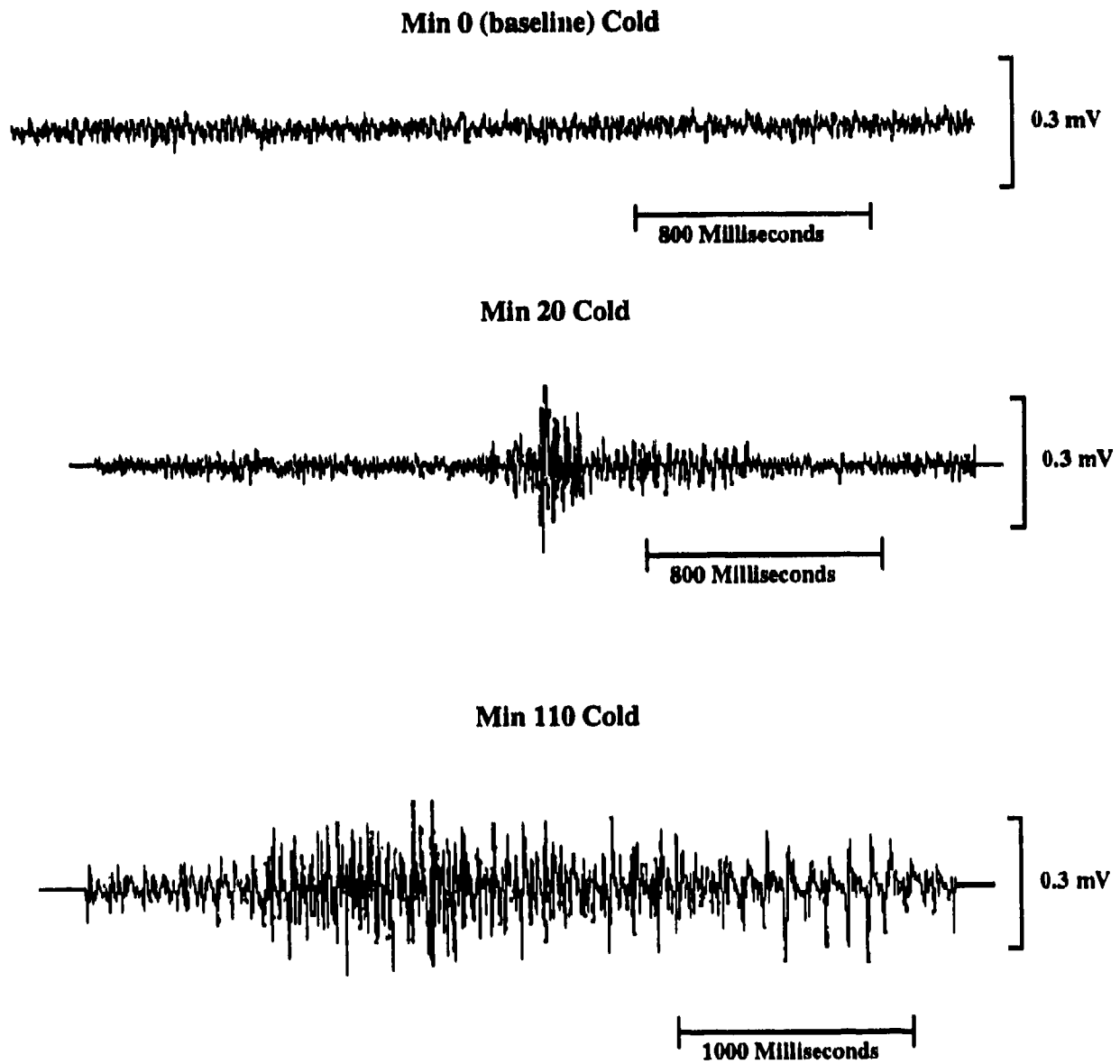


Figure 3. EMG samples of a subject's trapezius muscle at 0, 20, and 110 min of cold exposure.

**EMG Analysis.** The initial shivering response, as noted by an increase in myoelectric activity and visual observation, began 5 to 30 min after exposure to the cold environment, indicating substantial individual differences in shivering response. A typical representative EMG sample of the trapezius during shivering is seen in Fig. 3. There were no significant differences for the RMS in any muscles. For the MPF, increases were exhibited in the trapezius and mid-deltoid due to cold exposure. There were no significant main effects for MPF of the rectus femoris or pectorales muscle.

**Physiological.** Table 2 shows the mean values for  $\dot{V}O_2$ ,  $\bar{T}_{sk}$ , and  $T_{re}$  for both cold and neutral environmental conditions.  $T_{re}$  remained relatively constant for all subjects throughout

TABLE 2

Mean Values of Physiological Variables Measured in Cold and Neutral Conditions

	PRE	30	60	90	120
$\dot{V}O_2$ (L/min)					
Neutral	0.29±0.06	0.36±0.06	0.37±0.07	0.38±0.10	0.43±0.14
Cold	0.31±0.07	0.47±0.15	0.53±0.22	0.65±0.08	0.73±0.18*
$\bar{T}_{sk}$ (°C)					
Neutral	32.9±0.7	31.2±1.1	30.9±0.8	30.6±0.8	30.9±1.0
Cold	32.8±0.4	25.8±0.7	24.6±0.3	24.1±0.4	23.8±0.7*
$T_{re}$ (°C)					
Neutral	36.9±0.4	36.9±0.5	36.8±0.5	36.7±0.5	36.7±0.5
Cold	37.3±0.2	37.3±0.2	37.1±0.3	36.9±0.5	36.8±0.6

\*  $p < 0.05$

both environmental conditions. During the cold exposure,  $\bar{T}_{sk}$  decreased significantly with an average decrease of 9.0°F. In the first 30 min, 77% of the  $\bar{T}_{sk}$  drop occurred. There was a significant increase in  $\dot{V}O_2$  across time in the cold condition while  $\dot{V}O_2$  remained relatively constant throughout the neutral condition. The mean absolute change during the cold exposure was 0.42 L/min or a 42.5% increase over baseline values. A significant increase in norepinephrine ( $41.5 \pm 25.5$  pre to  $324.3 \pm 40.8$  pg/ml post) occurred from cold exposure while norepinephrine remained constant ( $46.3 \pm 16.1$  pre to  $64.3 \pm 40.8$  pg/ml post) from neutral condition. There were no differences in epinephrine and dopamine.

## DISCUSSION:

Exposure to cold weather causes variations in many physiological and cognitive functions (Bergh & Ekblom, 1979). The purpose of this study was to investigate whether muscular shivering has an impact on RSA.

The results of this study indicated that shivering caused by 120 min of exposure to 40°F air had an adverse effect on the horizontal (X) deviation but not on RSA. The MPF of both the trapezius and middle deltoid muscles were significantly different between temperature conditions. The pectoralis major and rectus femoris muscles did not exhibit significant increases in MPF. In addition, since the RMS in any of the muscles did not increase over time, the muscles were not contracting maximally. The metabolic response, measured by  $\dot{V}O_2$ , increased significantly during cold exposure while  $\dot{T}_{re}$  was significantly decreased.

Since core temperature did not fall over time, it was concluded that the subjects were maintaining their core temperature by tensing and shivering the trapezius and deltoid muscles. Since the pectoralis and rectus femoris were not shivering, it is concluded that the cold stress was not sufficient to induce whole-body shivering.

It is well known that the percent of body fat can have varying effects on cold-stressor responses. Studies have confirmed that morphological characteristics, such as body fatness, are related to the extent of body cooling during cold exposure. Lean subjects exhibit a greater increase in metabolic heat production than subjects with greater amounts of body fat (Bittel et al., 1988; Buskirk et al., 1963). The subjects in this study had an average percent body fat of 14.9% ( $\pm 3.2$ ) which is equal to the average (15%) for young healthy males (McArdle et al., 1991). This amount of body fat may have served to decrease the intensity of the cold stimulus, thereby suppressing a maximal shivering response.

Askew (1989), McCarroll et al. (1979), and Shephard (1985) have reported that shivering can produce metabolic increases up to five times resting values. The average increase reported in the present study was only 2.4 times over baseline values, which is similar to the response reported in previous investigations (Israel & Pozos, 1989; Muza et al., 1986). Bittel et al. (1988) reported that the magnitude of thermoregulatory response was directly related to the intensity of the cold stress. This fact suggests that the cold stress used in this study was of insufficient duration and/or intensity to produce a maximal metabolic response. EMG data of shivering activity supports this conclusion. The trapezius and middeltoid muscles were the only two muscles that exhibited a significant change in MPF due to cold exposure.

Shivering suppression techniques were not controlled in the present study, however, they may have served to buffer the shivering response. Glickman et al. (1967) reported that most subjects may cease shivering for short periods of time with only a small amount of electrical activity in the skeletal muscles. Israel et al. (1993) found similar results when comparing several different types of shivering suppression methods: breath holding, mental arithmetic, relaxation, and ingestion of warm water. These authors found a significant decrease in shivering response after the suppression techniques of mental arithmetic, relaxation, and breath holding. Experienced marksmen hold their breath when sighting a firearm (Tharion et al., 1992), and champion shooters are able to coordinate firing with their heartbeat (Helin et al., 1987) to minimize involuntary muscular movements. The Marines in the present study are trained to hold their breath when firing, therefore invoking a central inhibitory mechanism that overrides peripheral stimuli and allows the subject to suppress shivering. Therefore, trained shivering suppression techniques may have influenced this study.

In summary, the mild shivering exhibited by the subjects in this study did not have an adverse effect on RSA. X deviation was adversely effected. RSA and Y deviation were maintained, suggesting that maximal shivering was not present even though the significant decrease in  $\dot{T}_{sk}$ , as well as a significant increase in  $\dot{V}O_2$ , were indicative of shivering.

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13. ABSTRACT (Maximum 200 words) Rifle-shot accuracy (RSA) is important to biathletes, marksmen, and military personnel, and may be compromised by shivering induced by acute cold exposure. Therefore, the effect of shivering on RSA, using a laser acquisition system (Noptel Training System), was examined in six male U. S. Marines. The subjects wore camouflage pants, T-shirts, and boots during a 120 min exposure to both cold, (40°F) and neutral, (75°F) ambient temperatures. Shivering was measured by electromyographic activity of the pectoralis major, trapezius, middeltoid, and rectus femoris muscles. Statistical analysis included the calculation of Root Mean Square (RMS) and Mean Power Frequency (MPF). RSA was based on four blocks of 10 shots each at 25, 55, 85, and 115 min. Data included horizontal (X) and vertical (Y) deviation and shot score. Mean-weighted skin temperature ( $\bar{T}_{sk}$ ), rectal ( $T_{re}$ ) temperatures, and oxygen consumption ( $\dot{V}O_2$ ) were measured before and during exposure. RSA was maintained over 120 min during the neutral conditions, but horizontal deviation was significantly greater over time with cold exposure. The trapezius, and middeltoid muscles exhibited significant increases in MPF of shivering activity. The RMS did not differ between the two conditions. $\bar{T}_{sk}$ decreased significantly in the cold condition, $32.8 \pm 0.4^\circ\text{F}$ , baseline; $23.8 \pm 0.7^\circ\text{F}$ , 120 min. $\dot{V}O_2$ was significantly increased (42.5%) over baseline values in the cold. In conclusion, RSA was not affected by muscular shivering induced by 120 min of exposure to 40°F.			
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