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The Effect of acute exercise-induced fatigue on pistol shooting performance in police officers

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THE EFFECT OF ACUTE EXERCISE-INDUCED FATIGUE ON PISTOL
SHOOTING PERFORMANCE IN POLICE OFFICERS

by

Melissa Jean Brown

Bachelor of Science
University of Nevada, Las Vegas
2007

A thesis submitted in partial fulfillment
of the requirements for the

**Masters of Science Degree in Exercise Physiology
Department of Kinesiology and Nutrition Sciences
School of Allied Health Sciences
Division of Health Sciences**

**Graduate College
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THE GRADUATE COLLEGE

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Melissa Jean Brown

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The Effect of Acute Exercise-Induced Fatigue on Pistol Shooting Performance in Police Officers

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May 2011

ABSTRACT

The Effect of Acute Exercise-Induce Fatigue on Pistol Shooting Performance in Police Officers

by

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Duties of police officers include apprehending suspects, which may involve foot pursuit and firing a weapon at a suspect. Previous studies in biathletes and soldiers suggest that shooting performance is compromised when fatigue is present. Purpose: To investigate the effects of exercise-induced fatigue on shooting performance in police officers. Methods: Nine police officers fired five rapid-fire shots at three targets each with a fifteen second rest period in between each trail. Officers then exercised on a cycle ergometer to 85% maximum heart rate or voluntary fatigue. The pretest shooting was repeated post-exercise. Distances of 4 shots from the center of the target and diameters of tightest 4-shot grouping were measured. Results: No significant differences in distance or diameter were found. Conclusions: Fatiguing exercise had no effect on shooting accuracy or precision in the subject population.

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“I can do all things through Christ which strengtheneth me.”

Philippians 4:13

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CHAPTER 1

INTRODUCTION

Duties of police officers include apprehending suspects, which may involve foot pursuit and in some cases firing a weapon at a suspect. Accuracy in shooting is obviously important for the officer's safety as well as for the safety of others. Postural sway and changes in heart rate may contribute to diminished shooting performance (Evans, Scoville, Ito, & Mello, 2003). A high level of physical fitness may counteract these effects of exercise-induced fatigue. However, since police work is largely sedentary and not physically demanding, physical fitness can decline if the officers and/or police departments do not make physical activity a priority.

Bonneau & Brown (1995) reported on a survey conducted in 1991-1992 that only 17% of Royal Canadian Mounted Police (RCMP) engaged in regular physical activity at least three times a week. The greatest decline in physical fitness occurred between the ages of 20 and 30 for males. A 15-year follow-up study of Finnish police found that physical activity in early adulthood strongly predicts physical fitness of middle-aged police officers (Sorensen, Smolander, Louhevaara, Korhonen, & Oja, 2000). It has been consistently found that as years of service increase, fitness levels of most police officers decrease (Bonneau & Brown, 1995). If physical fitness is allowed to deteriorate in young police officers, optimal physical fitness is very unlikely subsequently in the officers' careers.

Multiple studies have shown that the physical demands of police work are insufficient to maintain physical fitness (Stamford, Weltman, Moffatt, & Fulco, 1978; Pollock, Gettman, & Meyer, 1978; Smolander, Louhevaara, & Oja, 1984; Bonneau & Brown

1995). Thus, when an officer is faced with a situation where he/she must speedily pursue a suspect on foot, the officer's physical fitness status may be a determining factor in the outcome of the situation. Specifically, exercise-induced fatigue may have a negative impact on the officer's shooting performance.

A study examining the effects of prior exercise intensity on rifle shooting performance in biathletes found that prior exercise intensity affected central aspects of shooting performance, namely, shooting accuracy, shooting precision, and stability of hold (Hoffman, Gilson, Westenburg, & Spencer, 1992). The adverse effect of fatigue on shooting performance was accentuated when shooting in the standing position, compared with shooting in the prone position (Hoffman et al, 1992). Peripheral muscular fatigue provoked by short-duration exercise effects postural stability, the ability to maintain a steady upright position (Dickin & Doan, 2008). Shooting performance is compromised when fatigue is present and thus will adversely affect shooting performance of police officers since this is the position most often assumed in pursuit.

Purpose of the Study

It has been previously shown that shooting performance decreases after fatiguing exercise in biathletes and military soldiers, but this has not been studied in police officers. The purpose of this study is to investigate the effects of exercise-induced fatigue on shooting performance in police officers.

Research Hypotheses

1. Shooting performance will be higher prior to exercise fatigue compared to shooting performance after exercise fatigue.
2. Shooting performance will recover more quickly in fitter individuals who recover more quickly from exercise fatigue.

Null Hypotheses

1. There will be no difference in shooting performance before and after exercise fatigue.
2. There will be no difference in shooting performance recovery between individuals with different fitness levels.

Limitations

1. Testing was conducted at an indoor shooting range, and the exercise was performed on a cycle ergometer. A field test conducted outdoors with an exercise better simulating a foot pursuit would be a more desirable and possibly more accurate way to study the effects of exercise-induced fatigue on shooting performance in police officers.
2. There were no emotional or psychological factors that would have affected hormone levels and stress as there was no exchange of gun fire as might be the case in an actual officer involved shooting.
3. Ages of participants ranged from 24 to 40. Officers over 40 years of age were not permitted to participate as a safety precaution due to the exercise test demands.

Assumptions

1. As all of the participants in this study are professional police officers, the assumption is made that all are proficient shooters due to their training and experience. Any deviation in shooting performance is attributed to exercise induced-fatigue and not a lack of shooting skill.
2. The sample subject group is representative of the general officer population.
3. All participants are practiced in using their own service weapons.
4. All officers gave maximal exercise efforts.

Definition of Terms

The following definitions are given for the purpose of clarification:

1. Fatigue: The inability to maintain force production with repeated contractions or decrement in force with a sustained contraction.
2. Shooting Performance: An overall assessment of marksmanship comprised of two factors, shooting precision and shooting accuracy.
3. Shooting Precision: The closeness or tightness of a group of shots measured by the diameter of the smallest possible circle encompassing all shots. Also referred to as “group shot tightness” or “shot variability.”
4. Shooting Accuracy: The distance of each shot from the center of the target.
5. VO₂max: Maximal Oxygen Consumption. The highest rate of oxygen uptake by the body measured during maximum exercise. Measured on a cycle ergometer or treadmill. VO₂max is accepted as an indicator of aerobic fitness.

CHAPTER 2

REVIEW OF RELATED LITERATURE

Fatigue

Fatigue is defined as the inability to maintain a given level of power output during repeated muscular contractions. Muscular fatigue is characterized by a reduced ability to generate maximal force or perform work. Effects of fatigue may include any or all of following: muscular weakness and tremor, loss of reaction speed, loss of visual perception, lassitude. In general, fatigue adversely affects performance. Causes of fatigue vary and are usually specific to the type of physical activity being performed.

There are two types of fatigue: peripheral and central. Central fatigue takes place prior to the neuromuscular junction, while peripheral fatigue takes place beyond the neuromuscular junction. Central fatigue involves psychological aspects. Both exercise duration and intensity influence the onset of fatigue (Powers & Howley, 2007, p. 409). While the average duration of a foot pursuit is currently unknown, police officer foot pursuits are rarely long-duration, multi-hour events. As such, fatigue experienced during and after a foot pursuit is primarily peripheral. Interval cycling at high and low resistance until volitional exhaustion was the exercise protocol used to induce fatigue in the present study. Energy deficit, ATP production not keeping up with ATP demand, is a key source of peripheral fatigue (Powers & Howley, 2007, p. 411-412).

During early, low-intensity exercise (such as a warm-up), most of the ATP that is fueling muscle contractions comes from aerobic sources. As exercise intensity increases, there is a sudden increase in blood lactic acid, showing an increased reliance on anaerobic metabolism (Power & Howley, 2007, p. 59). This point, the anaerobic

threshold or lactate threshold, occurs around 50-60% of VO_2max in untrained individuals and around 65-80% VO_2max in trained individuals (Gollnick, Bayly, Hodgson, 1986), or around 85% maximum heart rate in general. Fatigue quickly occurs after reaching anaerobic threshold (Nardone, Taratola, Giordano, Schieppati, 1997). Officers in the current study will be exercising to 85% maximum heart rate or until voluntary termination of the exercise. All officers will reach anaerobic threshold and experience fatigue to some degree. Individuals who are not trained, or as physically fit, will likely experience fatigue to a greater degree than individuals who are trained, or more physically fit, and will recover from exercise slower than those who are more fit (Powers & Howley, 2007, p. 192).

Both lower body and upper body fatiguing exercises have been shown to adversely affect shooting performance. Hoffman, et al. (1992) conducted a study utilizing fatiguing lower body exercise on a cycle ergometer. Exercise intensity increased over the course of five exercise conditions, ranging from rest to maximal effort. Maximal effort was determined to occur at volitional termination by the biathletes or when biathletes' heart rates no longer increased with an increase in workload (peak VO_2). This indicates that each biathlete reached or surpassed their anaerobic threshold. Each workload was followed by a 5-shot shooting bout. Hoffman et al. (1992) found that exercise intensity had a significant effect on shooting performance in the standing position. As exercise bouts increased in intensity, muscular fatigue increased and shooting performance declined.

Evans et al. (2003), implementing fatiguing upper body exercises such as lifting, climbing, and pulling, found significant decreases in rapid fire rifle shooting performance

in the standing position in soldiers immediately after exercise. The exercises were specifically designed to fatigue the upper body flexor muscle groups, as these muscles are involved in stabilizing and supporting a rifle. Soldiers performed the exercise circuit until fatigue prevented them from keeping the required pace, at which point exercise was terminated. Five rapid fire tests were completed: pre-exercise, immediately after exercise, 5 minutes post-exercise, 10 minutes post-exercise, and 15 minutes post-exercise. Immediately following the fatiguing upper body exercises, precision (shot group tightness) scores were 71% of pre-exercise values, mean number of hits was 46% lower than pre-exercise values, and mean number of misses was 55% higher than pre-exercise values. Shooting performance only temporarily decreased post-exercise, however, showing recovery of precision and number of hits to pre-exercise values within five minutes and number of misses to pre-exercise values within ten minutes post-exercise. None of the fitness measures, VO_2 peak, Army physical fitness test score, or duration of exercise to fatigue, were correlated with any of the marksmanship parameters. Still, Evans et al. (2003) state that “fit soldiers can recover shooting accuracy following exhausting lifting, climbing, and pulling activities and can accurately and effectively engage the enemy by small arms fire after a very brief rest period,” (p. 456). Although the fitness levels of the soldiers in this study were not stated it can be assumed that the effects of fatigue on shooting performance would be magnified in untrained individuals. If these findings can transfer to police officers, as officers do similar activities during foot pursuits (such as climbing walls), shooting performance may only temporarily suffer after fatiguing upper body exercise.

The length and weight of a fire arm can also lead to muscular fatigue and adversely impact shooting performance. Kemnitz, Johnson, Merullo, & Rice (2001) found this to be true for both male and female soldiers in rifle shooting in the standing position. Reducing the stock length of a rifle may reduce fatigue and preserve shooting performance. Shortening the rifle's stock length brings the weapon's center of mass nearer to the shooter's body and decreases elbow joint angle, allowing the shooter to hold the rifle in a more comfortable, maintainable, and less fatiguing position (Kemnitz et al., 2001). Rifles and pistols are common tools for police officers; however, pistols are used more often. While pistols do not have stocks and shooting techniques require a pistol to be held far away from the shooter's body, pistol barrel length can vary and affect the weight of the weapon.

A heavier weapon has more resistance and leads to fatigue more quickly than a lighter weight weapon. The physical strength of the shooter may be a factor in compensating for added weight and resistance of a weapon. Shooters with less upper body strength may have more difficulty steadying a weapon over time. According to Johnson and Merullo (2000), women, having less upper body strength than men, may fatigue faster than men after extended bouts of shooting (1.5 hours), resulting in reduced shooting accuracy and precision (as cited in Kemnitz et al., 2001, p. 480). Kemnitz et al. (2001) did not observe a difference in shooting performance between women and men in testing periods under 30 minutes, however. Regardless of gender, decreasing the weight and length of a fire arm will help to minimize fatigue and maintain shooting performance (Kemnitz et al., 2001).

Postural Stability

Pistol shooting is a precision activity requiring a high control of postural sway. Fatigue, specifically lower body muscular fatigue, increases postural sway which in turn has an effect on shooting performance. Dickin and Doan (2008) found that regardless of type (concentric, eccentric, or a combination of both) or location (knee, ankle, or entire lower extremity) of lower body exercise fatigue, an individual is at increased risk for loss of stability. After reaching fatigue, postural control continued to recover more than 30 minutes post-exercise. Dicken and Doan also found that effective training helps to reduce fatigue. This suggests that reduced fatigue would improve postural balance and stability, and thus, shooting performance.

The majority of shooting research focuses on the effects of exercise on rifle shooting, as opposed to pistol shooting. Mononen, Kontinen, Viitasalo, & Era (2007) found that increased body sway could cause an increase in rifle barrel movement, resulting in a poor shooting score. Stability of hold on a fire arm may be a determining factor of shooting success (Hoffman et al., 1992). According to Mononen and colleagues (2007), superior shooting performance requires good postural balance as well as an ability to steady the gun while aiming. This requirement is not contingent upon skill level, making it applicable to both elite and novice shooters. Shooters with repeatedly low variability in postural balance, demonstrating an ability to control his/her posture, may consequently elicit a more consistent shooting performance as a whole (Mononen et al., 2007). Furthermore, postural stability, or standing stability, and gun stability are factors connected to rifle shooting accuracy (Mononen et al., 2007, Niinimaa & McAvoy, 1983).

More experienced rifle shooters have been shown to produce significantly smaller body sway movements while aiming compared to less experienced rifle shooters while aiming, with and without prior exercise (Niinimaa & McAvoy, 1983). When comparing body sway during aiming after exercise to aiming without prior exercise, Niinimaa and McAvoy (1983) found body sway to be significantly greater after exercise in experienced and inexperienced shooters alike. Significant improvement in standing stability takes longer than 60 seconds post-exercise. These findings indicate that effects from exercise, such as exercise induced fatigue, decrease postural stability and thus negatively affect shooting performance in shooters of all skill levels.

Even though these conclusions were based on rifle shooting, the general findings likely apply to pistol shooting. Goonetilleke, Hoffmann, and Lau (2009) concluded that “the difference in performance due to levels of experience appears to lie...in the errors due to body sway or tremor while aiming [pistols]” and that “improving aiming performance appears to be in learning to control body motion during the aiming and triggering movement phases,” (p. 507). This is consistent with the rifle research findings that more experienced, accurate shooters are able to better control body sway while aiming compared to novice, less accurate shooters.

Rifles are held against the upper body for support, while pistols are held out in front of the body by one hand, or possibly two hands for added stability. Even with a double-handed grip, fully extended arms offer less stability than a rifle supported against the shooter’s body. Extended arms can move independently from the core of the body, yet can be affected by the body’s postural stability concurrently (Mononen et al., 2007). Unlike rifle shooting where only body tremor is a factor, in pistol shooting, the effects of

arm tremor and body tremor are additive (Goonetilleke et al., 2009). This indicates that postural stability is of even greater importance when shooting a pistol as opposed to a rifle.

Tang, Zhang, Huang, Young, and Hwang (2008) define a postural tremor as movement occurring when attempting to maintain a stable position against gravity and used accelerometers to document postural tremors during pistol shooting. An inverse relationship between tremor amplitude and shot performance was established (Tang et al., 2008). Success in shooting appeared to be determined greatly by the increased ability to control postural tremors. It is thought that an increased capacity for exercise, and fatigue tolerance, would accordingly withstand postural tremors more effectively and improve shot performance, as demonstrated in the study by Tang and colleagues.

Similarly, Hoffman et al. (1992) found that shooting performance in the standing position was significantly affected by prior intense lower body exercise. This suggests that exercise-induced body sway impairs shooting performance. Conversely, Nardone, Tarantola, Giordano, and Schieppati (1997) found that exercise fatigue induced by cycle ergometer produced minimal effects on body sway. Non-fatiguing exercise, performed below the estimated anaerobic threshold, resulted in no significant change in body sway. Although body sway was affected by strenuous exercise, the effects were moderate and short-lasting and appear to be dependent on the type of exercise performed, i.e. fatiguing lower body exercises. Therefore, the effect of body sway from strenuous exercise on shooting performance is not clear. If body sway has a significant effect on shooting performance, it most likely would be short-lasting.

Automaticity, Attention, Arousal

Automaticity, attention, and arousal are often related and integrated into the same studies. Each plays a role in shooting performance. Exercise-induced fatigue and physiological arousal can cause distractions to the shooter and are common causes of “choking”, or performing below expectations.

Automaticity

Early models of skill acquisition state that athletes pass through three phases of learning when developing a skill: cognitive, associative, and autonomous (Fitts and Posner, 1967). The athlete moves from consciously analyzing the new task (internal focus) and mechanically performing each step to fluidly performing the task automatically and thinking of the final outcome, rather than the process itself (external focus). Cognitive processing may be beneficial when learning a new skill; however, after the skill has been learned and the performer has moved on to the automaticity phase, cognitive processing may hinder performance. It is widely believed that focusing on the target or goal of a well-learned task (external focus) while automatically going through the motions of the skill at hand, rather than thinking of the mechanics, generates better performance.

However, a more recent model of skill acquisition states that there is a phase beyond automaticity that must be obtained by athletes before they can consistently achieve the highest levels of expertise. Ericsson (2003) concluded that “expert performers counteract automaticity by developing increasingly complex mental representations so they can attain higher levels of control of their performance....” Vickers and Williams (2007) use this more recent model to explain the findings in their study, pointing out that the elite

biathletes that increased their cognitive control during high pressure conditions (HP), compared to cognitive control levels during low pressure (LP) conditions, were able to overcome the difficult conditions and avoid choking.

Despite this more recent model focusing on the importance of increased mental involvement during performance, studies still focus on the importance of automaticity during performance. Kerick, Douglass, and Hatfield (2004) concluded that the reduction in cortical activity measured in novice pistol shooters over a 12-14 week training period was likely due to automaticity, which involves less cognitive effort. The decrease of cortical activation indicates that less cognitive effort is required for the task and that shooting skills are becoming more automatic over the course of time with training. Walmsley and Williams (1994) found that highly skilled and trained rapid-fire marksmen are consistent in form, movement, and shot location.

Considering the findings by Kerick et al. (2004) and Walmsley and Williams (1994), shooting performance in well trained police officers would be consistent and automatic. Therefore, if an officer is well trained, changes in shooting performance would then be attributed to outside factors, such as a lack of fitness causing physiological impairments during a foot pursuit or increased pressure causing choking during a stressful scenario, rather than inexperience or delayed reactions due to cognitive effort.

Attention

The direction of attentional focus, either internal or external, can determine the outcome of a given task, such as pistol shooting required of police officers or rifle shooting in a biathlon competition. An internal focus is one in which the performer dwells on their own thoughts, feelings, physiological state, or techniques relating to the

task. An external focus is one in which the performer cues in on outside information, such as the target, goal, or outcome. An external focus is indicative of an absence of distraction. This allows the shooter to direct the body's systems to better meet the task constraints that are present. Internal focusing could be considered a distraction. When a performer, such as a marksman, is distracted with self-consciousness and unable to fully focus on the external task, he or she is focusing inward and thus not able to have a performance-enhancing external focus.

Schmidt and Wrisberg (2004) state that “research examining the optimal attentional focus for skill learning suggests that people who are instructed to focus on the intended effects of their actions (i.e., an external focus) perform and retain target skills significantly better than those who are told to focus on the action itself (i.e., an internal focus),” (p. 215, 217). Wulf, Shea and Park (2001) suggest that once a motor skill is learned, attention shifts from an internal to an external focus, meaning that skilled or elite shooters focus externally. Tremayne and Barry (2001) found this to be true in elite pistol shooters. Better shooting performance occurred when shooters had a more efficient narrowing of attentional focus prior to shooting, demonstrated by heart rates decelerating earlier and more systematically during best shots compared to worst shots. Decreased heart rate has been found to be an indication of external attentional focus (Salazar et al., 1990).

In a study by Vickers and Williams (2007) to determine why some individuals choke under pressure and others are able to overcome the negative effects of pressure, it was found that shooting accuracy in elite biathlon shooters was dependant on an increase in external focus. External focus was determined by measuring quiet eye gaze with a

mobile eye tracking device that records “vision-in-action” data. A shift in gaze to a new location corresponds to a shift in attention. At the highest bicycle ergometer exercise intensity level (100% VO_2 max), directing visual attention externally to critical task information appeared to shield the biathletes from choking during the HP condition. Typically debilitating effects from extreme exercise, pain, and anxiety were overcome by focusing attention externally, allowing biathletes to maintain or increase shooting performance above those shooting scores recorded during reduced quiet eye gaze durations.

Vickers and Williams (2007) related their findings to the Setchenov Phenomenon which showed that individuals who were exhausted could do more physical work when their attention was diverted to an external target or activity (p. 392). This phenomenon suggests that external focus of attention can aid in an individual’s ability to overcome the normally debilitating effects of fatiguing exercise, effects that can be distractions to optimal focus and consequently impact performance.

Fatiguing effects from physical exertions can act as distractions in performance conditions by causing the shooter to focus on their own physiological state, which is indicative of an internal focus. However, physical exertions will not fatigue the fitter individual to the same degree as a less fit individual and may not be as much of a distraction to the fitter individual. This may allow the fitter person to maintain an external focus and continue to shoot well during physical exertions. The greater fatiguing effects on the less fit individual may distract them and prevent an external focus, cause an increase in reaction times, and prevent the individual from shooting as well.

Rose and Christina (1990) discussed the effects of distraction and external focus on precision pistol-shooting. It was found that elite and subelite shooters were more focused on the primary task (external focus) compared to the novice group of shooters. Elite and subelite shooters were reluctant to divide their attention during the aiming phase. If shooters were to shoot during a period of distraction, shooting performance would be compromised. The more skilled elite and subelite groups avoided shooting unless performance conditions allow them to sufficiently narrow their attention to obtain accurate shots.

Tremayne and Barry (2001) hypothesized that decreased heart rate may be used as an index of attention when major physical demands are not involved in the preparatory state being examined in highly skilled pistol shooters. This cardiac deceleration effect has not been apparent in archery and rifle studies where greater physical demands were involved but was observed in Tremayne and Barry's (2001) study involving minimal physical demands (holding the pistol). Tremayne and Barry (2001) noted that the study conducted by Konttinen and Lyytinen (1992) is an exception among the rifle studies and supports Tremayne and Barry's (2001) conclusion as a chain was used to support the rifle in Konttinen and Lyytinen's (1992) study, decreasing muscular demand for the shooter, and allowing a cognitive-related heart rate deceleration in the pre-test. Thus, Tremayne and Barry's findings can be generalized to highly skilled pistol and rifle shooters as long as the shooters are not participating in exercise or muscularly demanding activities.

According to Tremayne and Barry (2001), it would not be likely to see cognitive-related cardiac deceleration prior to shooting in the present study since muscularly fatiguing exercise will be involved. Participants' heart rates will be elevated due to

fatiguing exercise and will start to naturally recover after exercise has ceased prior to shooting. Decreases in heart rate due to recovery from exercise are different than decreases in heart rate due to increased external attentional focus. In this case, it is a reasonable assumption that the physiological state of the shooter may either mask or overcome the possible cardiac deceleration effects of attentional focus. Even so, Tremayne and Barry observed that heart rate (HR) deceleration was not related to respiration as heart rate deceleration occurred during a wide variety of respiratory patterns. This is interesting as, under normal healthy conditions, increased heart rate occurs with increased respiration and decreased heart rate occurs with decreased respiration. Tremayne and Barry found that this was not the case, that the shooter's external attentional focus was able to decrease heart rate despite various respiration rates. This finding supports the previous findings by Vickers and Williams (2007) and the Setchenov Phenomenon in that an external focus can aid in overcoming physiological states.

Arousal

In law enforcement, police officers are faced with inordinate risks and dangerous, stressful situations. During a situation requiring an officer to use lethal force, arousal levels will likely be elevated. It is important that the officer either maintains an optimal level of arousal or that the officer has the ability to still perform well at elevated arousal levels in order to allow greatest shooting performance and safety.

Duffy (1957) defined arousal as a “nondirective...intensity level of behavior.” When arousal levels become extremely elevated, unpleasant emotional reactions, referred to as “distress” or “anxiety”, may occur (Selye & Fortier, 1950) and performance may suffer.

Likewise, if arousal is too low, performance may suffer. Optimal arousal is a balanced state between underarousal and overarousal (Landers & Arent, 2006, p. 268). While there may be individual variations, sport-specific optimal arousal levels exist. For example, a lower level of arousal is optimal for golf whereas a much higher level of arousal is optimal for weight lifting (Landers & Arent, 2006, p. 271). Increased arousal can counteract fatigue and increase strength by facilitating motor unit recruitment (Powers & Howley, 2007, p. 411). Konttinen and Lyytinen (1992) found that moderate arousal levels yield superior shooting performances in competitive shooters, especially during the preparatory phase preceding trigger pull.

Using electroencephalography (EEG) to measure arousal, Konttinen and Lyytinen (1992) monitored six subjects (3 champion shooters and 3 inexperienced shooters) during two 300-shot sessions while shooting a rifle in the standing position. The arousal level was moderate, instead of high, during superior shooting performances. Konttinen and Lyytinen state that the need for arousal may be higher during the early stages of skill learning, which would explain why the novice group of shooters had higher arousal levels when compared to the champion shooters. Higher arousal allows for greater voluntary control over elements of performance that are not yet automatic for the novice (Konttinen and Lyytinen, 1992).

Tremayne and Barry (2001) measured skin conductance levels (SCL) to monitor arousal. Skin conductance levels are considered the gold standard in measuring arousal (Barry & Sokolov, 1993). Elite shooters had slightly lower SCL during their best shots. SCL (arousal) decreased prior to shooting and immediately returned to baseline levels after shooting. However, shooting performance was found to be independent of arousal

changes in elite shooters. This finding may be beneficial for police officers in stressful situations, as their arousal levels will not necessarily dictate their shooting performance. Tremayne and Barry (2001) also concluded that an earlier decrease in arousal levels prior to shooting may assist attentional focusing.

If the individual can deal effectively with a higher level of arousal, however, performance will not suffer. Mahoney (1979) emphasized that a higher level of arousal is not necessarily detrimental to performance as long as the athlete is able to manage it. Study results from Landers et al. (1980) support this point, finding that rifle and pistol shooters invariably increased their heart rate above resting levels when they fired, indicating an increase in arousal, and consistently performed well.

Similar results found by Meyerhoff and colleagues (2004) support this idea. Law enforcement trainees were put through a stressful, fast-paced, interactive scenario which tested the trainees' ability to survive a life-threatening situation. Instructors acted as role players, using simunitions, or simulated ammunition (commonly referred to as "paint balls"), in close range fire exchange. Heart rate, blood pressure, cortisol levels (stress hormone), shooting accuracy, and shooting judgment were among parameters measured. Results showed significant performance shortcomings under the highly stressful conditions, including 19% of trainees shooting the hostage and 97% of trainees failing to meet the criterion of 70% of their rounds hitting the suspect. Significant elevations in heart rate, blood pressure, and cortisol levels were observed during the scenario, indicative of increased arousal. Trainees who achieved passing scores demonstrated higher increases in heart rate responses than those who failed. These findings suggest

that higher arousal levels may be more beneficial to shooting performance, at least in a high-stress situation.

Oudejans (2008) conducted a study which concluded that reality-based practice under pressure (a stressful situation increasing arousal) helped in maintaining handgun shooting performance of police officers. Subjects were divided into two groups, a control group and an experimental group. Shooting performance of the experimental group, who had practiced with pressure, no longer deteriorated in front of a real opponent who was firing back with simunition (simulated ammunition) rounds during the post test, while shooting performance of the control group, who had practiced without additional pressure, still deteriorated in front of a real opponent. The findings from this study support the idea that increased arousal is not necessarily a detriment to shooting performance if the shooter is able to cope with the increased pressure. One way to help shooters to be able to cope with increased arousal and anxiety from stressful situations is to practice under stressful situations, especially those simulating real-life conditions such as an opponent who fires back. This will help the shooter “acclimatize” to the increased pressure and allow them to continue to perform well when stressful real-life situations occur, thus avoiding choking.

Vickers and Williams (2007) related their findings to the catastrophe model of performance by Hardy and associates which states that a high level of precompetitive cognitive arousal (CA) becomes a detriment to performance only when physical arousal becomes too high (Vickers & Williams, 2007, p. 383). Cognitive Arousal and d-CA (difference between Low Pressure and High Pressure CA conditions) were significantly higher in all athletes in the HP condition compared to the LP condition. However,

Vickers and Williams did not find that the combination of high levels of CA and high levels of physical arousal always led to catastrophe in performance, or choking, during HP conditions. Choking only occurred for the athletes who decreased their attentional focus on the target during the highest HP workloads. Athletes who increased their attentional focus avoided choking and shot accurately during the highest HP workloads. This shows that when physical arousal is at maximum, such as is the case during intense exercise, increased cognitive arousal combined with increased attentional focus on task-relevant external information results in a high level of performance.

As long as external focus is increased during maximum physical arousal, cognitive arousal does not cause choking in shooting performance. Training and increased attentional focus allow marksmen to overcome potentially debilitating effects of arousal and anxiety. It appears that a moderate level of arousal is best suited for optimal shooting performance except in highly stressful situations. A higher level of arousal may be beneficial in highly stressful situations, particularly if the shooter is trained to handle the higher level of arousal.

Cardiac Considerations

Exercise intensity and recovery rate can be assessed by measuring heart rate. Heart rate increases as a linear function of exercise intensity (Powers & Howley, 2007, p. 15b). Heart rate at any given submaximal work rate is an indicator of fitness, as aerobically trained individuals will have lower heart rates compared to untrained individuals (Powers & Howley, 2007, p. 181). Physical fitness is inversely related to recovery time from exercise, meaning, physically trained individuals will have a faster return to their resting heart rate than untrained individuals.

The effect of elevated heart rate on shooting accuracy was illustrated by Tharion, Hoyt, and Marlowe (1992) who studied the effects of exercise and high altitude (3,700 to 4,300 meters) on marksmanship. From a standing position, sixteen experienced marksman dry-fired a disabled, laser-based system rifle at targets positioned five meters away. Marksmanship was measured under five conditions: 1) at rest at sea level; 2) immediately after a 21-kilometer run/walk ascent from 1,800 m to 4,300 m elevation; 3) at rest during days 1 through 3 at altitude; 4) at rest during days 14 through 16 at altitude; and 5) immediately after a second ascent after 17 days at altitude. Tharion and colleagues (1992) found that exercise significantly reduced marksmanship accuracy. Exercise and acute high altitude exposure shared similar, but independent, detrimental effects on marksmanship. Both conditions caused fatigue by affecting oxygen uptake, consequently increasing respiration rate and heart rate. Tharion and colleagues (1992) suggest two possible strategies to reduce the adverse affects of exercise on marksmanship: 1) beta-blockers, and 2) biofeedback techniques.

Beta-blockers

Beta-blockers decrease heart rate by decreasing sympathetic innervation to the heart. Siitonen, Sonek, and Janne (1977) studied the effects of beta-blockers on physical performance in stressful situations, one such situation being pistol shooting competitions. Shooters reported feeling more relaxed, more focused, and a general sense of well-being after taking oxprenolol. When given a 40mg dose of oxprenolol 60 minutes prior to shooting, about two-thirds of shooters significantly improved their scores compared to shooting after taking a placebo. This improvement may be attributed to a reduced elevation in heart rates. The one-third who did not experience a scoring improvement

from the oxprenolol were more experienced shooters with lower heart rates before, during, and after shooting when compared to the larger, less experienced group of shooters. The less experienced shooters demonstrated more pronounced cardiovascular responses to the stressful competition, signified by their elevated heart rates during the shooting matches. These findings indicate that shooting accuracy is improved when heart rate is slowed, either naturally or by taking a beta-blocker, especially in stressful conditions where heart rates may be further elevated (Siitonen et al. 1977).

Biofeedback Techniques

Vickers and Williams (2007) stated that elite-level biathletes develop the ability to reduce their HR levels significantly during the preparatory stage of shooting. Biathletes completed four, two-minute, cycle ergometer workloads (55%, 70%, 85%, and 100% VO_2max) at 70 rpm, shooting after each workload. Heart rate monitors were continuously worn during the testing process. Data showed that HR dropped by as many as 20-30 bpm from completion of the exercise period to the end of the first block of five shots. Vickers and Williams (2007) also pointed out that shooting at 80% or less of a biathlete's maximum HR allows the biathlete to have greater control over their body movements and breathing, whereas shooting at 90% or more of maximum HR compromises shooting accuracy due to very rapid respiration rates.

Helin, Sihvonen, & Hanninen (1987) also concluded that experienced shooters are able to slow their heart rate prior to trigger pull. This was found to be true for both rifle and pistol shooters, as subjects in this study were comprised of both types of shooters. Under the simulated competition conditions in the study, champion level shooters had slower heart rates than beginning level shooters (Helin et al. 1987). By slowing down the

heart rate, by use of beta-blockers, biofeedback, or increased fitness, the shooter has an extended diastolic phase and has an increased advantage to shoot more accurately.

Cardiac Cycle

Helin et al. (1987) studied the timing of triggering in relation to the cardiac cycle during shooting. They found that champion shooters triggered during diastole while the inexperienced shooters triggered during diastole and systole, demonstrating random triggering. The small tremors produced by the heart contracting are not present during diastole and shots are consequently more accurate when fired during this stage of the cardiac cycle, according to Helin and colleagues. Furthermore, optimal timing of triggering appeared to be during late diastole when the heart had been relaxed for nearly the longest possible period of time. Of the beginners, those who triggered during diastole had better scores than those who triggered during systole. Experienced shooters seem to develop cardiac awareness and were able to consistently shoot during the short amount of time when the heart is at rest, ventricular diastole.

Mets, Konttinen, and Lyytinen (2007) also studied the timing of triggering in relation to the cardiac cycle during shooting but with differing results. Their results indicated that increased heart rate did not influence the relationship between trigger pull timing within the cardiac cycle and shooting performance, as there was not any optimal location within the cardiac cycle for triggering. No association was found between shooting performance and shot placement in the cardiac cycle, contrary to the findings of Helin et al. Mets and colleagues state that the timing of firing within the cardiac cycle does not determine superior shooting performance. However, Mets and colleagues did find that fewer shots were triggered during the middle of the cardiac cycle, indicating that shooters avoided

triggering during maximum heart muscle contractions and movement. Thus, Mets and colleagues recognized that the shot placement within a cardiac cycle “may play an important role in the skill acquisition process.”

Age and experience could explain the variation between the results of these two studies (Helin et al., 1987; Mets et al., 2007). Mets and colleagues studied junior-level air rifle shooters. Even though the subjects used in the study were considered elite rifle shooters, they were very young (13 to 20 years old; mean $\pm$ SD: 16.1 $\pm$ 2.1 years) with 2-10 years of shooting training (mean $\pm$ SD: 5.9 years, $\pm$ 2 years). In contrast, the champion rifle shooters in the Helin study aged from 20-53 years old and had 5-30 years of shooting training. Helin and colleagues suggest that it takes time to develop the reflexes necessary to shoot during the optimal cardiac phase (diastole) and that this may explain why many champion shooters are much older than beginners and as a result, have much more shooting experience. With experience, the shooters’ biofeedback of the heart beat becomes automatic, allowing the shooter to learn to trigger, even subconsciously, during the optimal time.

Fenici, Ruggieri, Brisinda, and Fenici (1999) studied the cardiovascular changes which take place during action pistol shooting, which differs from the precision shooting studied by Helin and colleagues (1987) and Mets and colleagues (2007). Action pistol shooting implies high stress by mimicking situations which are similar to real gunfights (Fenici et al. 1999). The shooter must run, jump, squat, reload, focus on targets, and determine optimal balance between speed and accuracy, all while coping with pistol recoil and loud explosions. Psychological and physiological factors are challenged in the performance and reactions of action pistol shooters.

Fenici and colleagues (1999) found that athletes in the same stressful situations and of equal fitness and training reacted in physiologically different ways. In one participant, increased heart rate was the prevailing effect, and in another participant, increased blood pressure was the prevailing effect to the stressful situation. Two of the six athletes studied experienced short runs of supraventricular arrhythmias, despite histories void of arrhythmia. Shooting performance can be compromised by stress-induced cardiac arrhythmias. When athletes' heart rates and blood pressures were extremely elevated, their performance was consequently impaired, causing further distress. It was concluded that psychological stress plays an important role in cardiovascular changes during action shooting, and that action shooting, and by extension combat situations or "fire fights", places more demand on the cardiovascular system than precision shooting (Fenici et al. 1999). Since action pistol shooting mimics high-pressure situations that law enforcement face, findings from this study may be applicable to law enforcement training.

Conclusion

Several factors have been examined in relation to shooting performance: fatigue; postural stability; automaticity, attention, arousal; and cardiac considerations. Shooting performance declines with fatigue from lower body and upper body exercises. Officers must be able to shoot quickly, even automatically, while maintaining accuracy and precision in fast-paced situations where time for aiming is limited. With continued training, shooting skills become automatic, requiring less cognitive effort and internal distraction. Superior shooters stay focused externally during shooting, especially the aiming phase, and are reluctant to divide their attention. A moderate level of arousal is

best for optimal shooting performance in non-stressful situations. However, a higher level of arousal may be beneficial in high-stress situations, particularly if the shooter has been trained to handle the higher levels of arousal. Elevated heart rate has been shown to negatively affect shooting performance especially in stressful situations where heart rates may be further elevated.

Of these factors, postural stability plays a major role in shooting performance, especially pistol shooting performance where both arm tremor and body tremor influence the shooter's postural stability. Effects from a fatiguing lower body exercise bout decreases postural stability and negatively affects shooting performance in shooters of all skill levels. Effective training helps to reduce fatigue from strenuous exercise. Increased fitness and fatigue tolerance would improve an individual's postural stability and thus improve shooting performance. However, reported effects of strenuous exercise on postural stability vary; some state effects to be moderate and short-lasting while others state effects to have larger impact. Therefore, the effect of body sway from strenuous exercise on shooting performance is unclear.

CHAPTER 3

METHODOLOGY

Study Design

Exercise-induced fatigue was the independent variable, achieved by interval cycling on a cycle ergometer. Three dependent variables were assessed: heart rate, serving as an indication of recovery from exercise-induced fatigue, and two elements of shooting performance, accuracy and precision.

Subject Characteristics

All participants were healthy, active police officers 40 years of age or younger, trained in fire arms safety and familiar with shooting a department approved semi-automatic service pistol, either a 9mm, .40 caliber, or .45 caliber (Table 1). All participating officers have passed yearly physicals given by their police department and had no history of heart disease, hypertension, or musculoskeletal disease or injury. The UNLV Institutional Review Board approved this study.

Table 1. Participant Demographic Information

Participant	Experience* (yrs)	Age (yrs)	Height (inches)	Weight (lbs)	BMI	VO ₂ (L·min ⁻¹)	Pre-exercise HR (bpm)
1	4	27	71	175	24.5	3.3	88
2	2	24	69	165	24.5	2.6	69
3	4	37	72	180	24.4	3.0	60
4	4	40	70	175	25.1	3.4	65
5	9	33	75	190	23.7	2.2	78
6	4	25	70	150	21.5	2.3	67
7	4	28	69	165	24.5	2.3	80
8	4	27	70	220	31.6	2.8	64
9	3	31	66	173	27.8	2.3	64
Means**	4 ± 1	30 ± 2	70 ± 1	177 ± 7	25.3 ± 1	2.7 ± 0.2	71 ± 3

Note: *Experience is measured by years on police department. **Means are ± SE.

Table 2. Participant Exercise Habits: Frequency, Type, Duration

Participant	Frequency (days/week)	Type of Exercise	Average Duration (min)
1	3-5	B	90
2	6	B	90
3	3	B	60
4	5-6	C	60-90
5	3	B	50
6	3	R	60-120
7	4	R	60
8	3	R	60
9	4	B	105

Note: C = cardiovascular training, R = resistance strength training, B = both

Instrumentation

Testing was conducted at an indoor shooting range with individually sectioned lanes. The exercise portion of the testing was conducted on a cycle ergometer. Cycle ergometry is a convenient, portable, and effective exercise modality. This form of exercise is easily performed in close proximity to the shooting lanes, allowing minimal resting time after completing the exercise bout and before commencing the shooting trials. Heart rate monitors (model Precision Trainer XT, Reebok, Deer Park, New York), including chest strap and watch, were worn by participants throughout the testing process. Participants used their own duty pistols, ear protection, and eye protection (safety glasses), and were responsible for their own pistol throughout the entire duration of the testing process. Bullets (full metal jacket/ball ammunition) and targets (human silhouette) were provided for all participants (Figure 1). Informed Consent forms were reviewed and signed by participants prior to testing.

Figure 1. Human silhouette target

Data Collection

Prior to participation, participants completed the PAR-Q (Physical Activity Readiness Questionnaire) and signed an informed consent form. The study was conducted at American Shooters, a local indoor shooting range.

Participants' shooting performance was tested prior to exercise (pre-exercise) and after exercise (post-exercise) on the same day. A cycle ergometer exercise test, being comprised of two parts, was administered after the pre-exercise test. Participants cycled at a cadence of 138 bpm (beats per minute) set by the metronome, which is equivalent to 70 rpm (revolutions per minute) on the cycle ergometer, for all workloads and intervals. The first part of the cycle ergometer test, lasting 3-4 minutes, allowed for a prediction of maximal oxygen uptake (VO_2max) from participants' heart rates and workload (600 kpm) and served as a warm-up. Heart rates were recorded every minute to determine when steady state was (consecutive heart rates within 5 beats per minute) was achieved. Participants' VO_2max was estimated from steady state heart rate using the Astrand nomogram (Astrand, 1960).

Immediately after completion of the first part of the cycling test, participants began the second part of the test: interval cycling. To induce fatigue, the participant cycled at a high intensity (900 kpm) for 60 seconds then rested for 30 seconds. During the rest period, participants continued to pedal without resistance at a rate of 70 rpm, or 138 bpm. The 60 second/30 second work-rest interval was repeated multiple times, for a total duration of 1-10 minutes. Heart rate was recorded at the end of each interval. Participants finished the exercise test when they reached 85% of their age predicted max heart rate or when they stopped voluntarily due to localized muscular fatigue. During the

final rest period of the exercise test, the participant moved quickly to the nearby shooting area, put on ear and eye protection, and prepared to fire for the first post-exercise trial within 15 seconds of completing interval cycling.

Both the pre-exercise and post-exercise shooting tests consisted of three shooting trials, each trial separated by a 15 second rest period. Heart rates were recorded directly prior to each trial. Each trial consisted of five rapid fire shots. The participant turned their back to the target during the rest period. Full magazine clips were available and ready for each trial. All targets were at the same distance, 10 yards. Each target was labeled prior to the trials, such as “pre-test, trial 1”, “pre-test, trial 2,” etc. A separate shooting lane was allotted for each of the three trials during pre- and post-tests. Targets were not brought in from the ten yard distance until after all three trials were completed. This increased safety and prevented participants from gaining feedback from previous trials. After all six trials were completed the targets were analyzed to determine shooting performance.

Shooting performance was comprised of two factors, shooting accuracy and shooting precision. Shooting accuracy was considered to be the average distance of each shot from the center of the target while shooting precision is the group shot diameter, or the diameter of the smallest circle that encompasses all five shots (Hoffman et al., 1992; Figure 2). Shooting precision was also considered to be the shot variability.

Figure 2. Target illustrating concepts of precision and accuracy

Heart rates were recorded at rest, immediately after each pre-test trial, each minute during exercise to determine when the participant has reached steady state and his target heart rate, immediately after exercise and immediately after each post-exercise trial. The time for the subject's peak heart rate to return to their resting heart rate was also noted but was not a reliable measurement as HR was affected by external variables.

Data Analysis Methods

A one-way repeated measures analysis of variance test was conducted on distance, another on diameter, and another on heart rate. Statistical significance was set at $p \leq .05$. Sidak's correction was used for pairwise comparisons. Pearson's correlation was used to evaluate the relationship between post-distance and post-HR, as well as post-diameter and post-HR.

CHAPTER 4

RESULTS

Heart rate increased significantly from pre-exercise to post-exercise and remained higher than pre-exercise values ($F_{3.105, 24.837} = 79.997$, $p < .001$, Figure 3). However, no significant differences were found in mean diameters (shot grouping) ($F_{2.246, 17.971} = .916$, $p = .428$) or distances from the target center (shot accuracy) ($F_{5, 40} = .935$, $p = .469$) between the pre-exercise trials and the post-exercise trials (Table 3).

Table 3. Heart rate, accuracy, and precision before and after exercise

	Pre-Exercise Shooting			Post-Exercise Shooting		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Heart Rate (bpm)	107 $\pm$ 6	105 $\pm$ 6	91 $\pm$ 6	173 $\pm$ 4	162 $\pm$ 4	153 $\pm$ 4
Distance (mm)	67 $\pm$ 11	77 $\pm$ 11	79 $\pm$ 14	78 $\pm$ 15	71 $\pm$ 8	57 $\pm$ 7
Diameter (mm)	110 $\pm$ 29	134 $\pm$ 29	128 $\pm$ 31	98 $\pm$ 13	101 $\pm$ 8	105 $\pm$ 22

Note: Heart rates were measured immediately after each shooting trial. Values are mean $\pm$ SE.

Neither exercise-induced fatigue nor increased post-exercise heart rate had an effect on shooting performance. Both accuracy and precision of shooting were not different between pre- and post-exercise trials. As participants recovered from exercise, accuracy (distance) tended to improve but this was not a statistically significant improvement (Figure 4). Precision (diameter) tended to improve after exercise as well, but again, this was not a statistically significant improvement (Figure 5). In the third post-exercise trial, shooting accuracy was negatively correlated with heart rate ($r = -.636$, $p = .033$, Figure 8). Shooting precision was also negatively correlated with heart rate in post-exercise trials 2 ($r = -.835$, $p = .003$, Figure 10) and 3 ($r = -.623$, $p = .037$, Figure 11).

Figure 3. Mean heart rates measured after each shooting trial

Figure 4. Mean accuracy for each shooting trial

Figure 5. Mean precision for each shooting trial

Figure 6. Correlation between distance and heart rate in post-exercise trial 1

Figure 7. Correlation between distance and heart rate in post-exercise trial 2

Figure 8. Correlation between distance and heart rate in post-exercise trial 3

Figure 9. Correlation between diameter and heart rate in post-exercise trial 1

Figure 10. Correlation between diameter and heart rate in post-exercise trial 2

Figure 11. Correlation between diameter and heart rate in post-exercise trial 3

CHAPTER 5

DISCUSSION AND CONCLUSION

The purpose of this study was to see if acute exercise-induced fatigue had an effect on shooting performance in police officers. Results show that neither acute exercise-induced fatigue nor increased heart rate has a significant effect on shooting performance and that shooting performance did not significantly vary between pre-exercise and post-exercise shooting. Thus, the first hypothesis stating that shooting accuracy and precision would decrease as a result of acute exercise-induced fatigue was rejected and the null hypothesis was retained. The second hypothesis stating that shooting performance will improve more quickly in fitter individuals who recover more quickly from exercise fatigue becomes a moot point as no significant difference was found in shooting performance in any subject between the controlled state and after exercise. Because no difference was found, differences in fitness levels of the subjects were not evaluated. Interestingly, there was a general trend for mean shooting accuracy to improve (shots were closer to the center of the target) during recovery from exercise when compared to pre-exercise values, but this was not statistically significant.

These results were surprising considering the background research on heart rate, tremors, and postural stability. After intense exercise, heart rate and stroke volume output are high, as well as adrenaline, which cause tremors that affect postural & weapon stability (Lakie, 2010). The task of shooting is comprised of two phases: targeting and aiming. Targeting is the initial larger arm movement, bringing the pistol up to an approximate position where the gun sights and target are roughly aligned. Aiming is a finer movement, homing-in and carefully aligning gaze, weapon sights, and target center

(Goonetilleke et al., 2009). Pistol shooting requires precision when aiming and can be affected by any movement, whether those movements are caused by postural instability of the lower body or minor tremors of the upper body due to muscular fatigue or rapid heart rate and increased breath rate, causing more rise and fall of the chest and by extension (literally), the arms and firearm (Lakie, 2010; Tang et al., 2008).

Elevated heart rate has been shown to negatively affect shooting performance (Siitonen et al., 1977; Vickers & Williams, 2007). Vickers and Williams (2007) have stated that elite-level biathletes are trained to reduce their HR levels significantly as they prepare to shoot, stating that “their goal is to shoot when their HR is no more than 80% of maximum because at that level they are able to control their breathing and body movements while the shots are being taken. If athletes’ HR exceeds 90% of their maximum capacity, however, then respiration rates become very rapid and the ability to shoot accurately is compromised” (Vickers and Williams, 2007, p. 383). Officers in the current study were asked to exercise to 85% of their estimated maximum heart rate or until voluntary termination of the exercise. All participating officers voluntarily exercised beyond the protocol requirement of 85% with eight of the nine officers’ heart rates exceeding 90%. This leads one to believe that their shooting performance would be compromised according to findings by Vickers and Williams (2007). However, this was not the case.

Lakie (2010) states that an elevated heart rate may actually be advantageous to shooting performance, at least in rifle shooting, as stroke volume decreases with an increased heart rate. A fast heart rate and low stroke volume works well because it produces smaller jerking movements compared to a slower heart rate and higher stroke

volume which produces greater jerking movements. A decreased stroke volume minimizes “pulsatile” effects on the rifle, and possibly pistol. “...Counterintuitively, rapid heart rate recovery following heavy exercise performance prior to shooting might be seen as disadvantageous,” (Lakie, 2010, p. 449). This is a possible explanation for the police officers’ shooting performances remaining consistent after intense lower body exercises and during elevated heart rates in the current study. This may also account for the correlations between heart rate, diameter, and distance in the present study. Correlations for individual scores revealed that as heart rate recovered (decreased), diameter and distance worsened (increased). Shooting performance, accuracy and precision, actually worsened as individual police officers’ heart rates recovered from exercise. This supports the findings by Lakie (2010).

The findings of this study may not have been quite as surprising if rifles were being used instead of pistols, as rifles offer greater shooting stability compared to pistols and thus, would not be as influenced by the fatiguing affects of exercise. Rifle shooting is only affected by body tremor, instead of the additive affects of both arm tremor and body tremor in pistol shooting (Goonetilleke et al., 2009). Pistols are held out in front of the body by one hand, or possibly two hands for added stability, while rifles are held against the upper body for support. Even with a double-handed grip, fully extended arms offer less stability than a rifle supported against the shooter’s body. Extended arms can move independently from the core of the body, yet can be affected by the body’s postural stability concurrently (Mononen et al., 2007). This indicates that postural stability is of even greater importance to shooting performance and consistency when shooting a pistol as opposed to a rifle, especially in the standing position. Despite these factors, officers

were able to overcome the effects of fatiguing lower body exercise and maintain pistol shooting performance.

Body sway has been shown to increase after strenuous physical exercise, especially lower body exercise at or beyond estimated anaerobic threshold (Nardone et al, 1997). Anaerobic threshold, the crossover point from aerobic to anaerobic metabolism, occurs around 50-60% of VO₂max in untrained individuals and around 65-80% in trained individuals (Gollnick, P., Bayly, W., Hodgson, D., 1986). Fatigue quickly occurs after reaching anaerobic threshold (Nardone, Taratola, Giordano, Schieppati, 1997), around 85% maximum heart rate. All participants in this study exercised with maximal effort to 85% maximum heart rate or beyond with voluntary fatigue. Thus, it can be assumed that all participants reached anaerobic threshold and were prone to experience increased body sway which would, theoretically, negatively affect shooting performance. However, shooting performance was not found to be negatively affected, demonstrating that even though officers were adequately fatigued, they were able to overcome the fatiguing effects of strenuous exercise and maintain postural stability.

Another possible contribution to maintaining shooting performance after exercise is physical fitness. Officers in this study may have a sufficient level of physical fitness and strength to maintain or control postural stability after fatiguing lower body exercise. Lower body exercise fatigue increases an individual's risk for loss of stability in the standing position which consequently negatively affects shooting performance (Hoffman, Gilson, Westenburg, & Spencer, 1992). Tang et al (2008) found that the ability to control postural stability greatly determined shooting performance. Effective physical training helps to reduce fatigue from strenuous exercise (Dicken and Doan, 2008). Reduced

fatigue would minimize postural instability, and thus, help to maintain shooting performance.

An additional point to take into consideration is the amount of time taken to aim. Goonetilleke et al. (2009) found that three seconds was a sufficient amount of time for novice shooters to aim and two seconds was enough time for expert shooters to aim. Officers in the current study were allowed six seconds to take five shots, though none of them took the entire amount of time allotted. It is a possibility, however, that the participants took longer to aim after exercise compared to before exercise. Taking a little bit more time to shoot, even seconds, may help to compensate for negative influences from fatiguing exercise that may causes decrements in shooting performance, helping marksmen maintain shooting performance after exercise. This could be a contributing factor to why there was not a decrement shown pre- to post- exercise as was expected.

Another possible explanation for shooting performance not changing from pre- to post-exercise is that the participating officers are skilled, well trained marksmen. Highly skilled and trained rapid-fire marksmen are consistent in form, movement, and accuracy (Walmsley & Williams, 1994). Well trained marksmen are able to stay focused and block out the negative effects of exercise. Negative effects of exercise, including fatigue (and consequently postural sway) and high heart rate (leading to tremors), have been shown to negatively impact shooting performance (Hoffman, Gilson, Westenburg, and Spencer, 1992; Evans, Scoville, Ito, and Mello, 2003; Niinimaa & McAvoy, 1983). However, when skilled shooters act quickly and intuitively, relying on developed skills and habits formed from effective training instead of consciously analyzing each aspect of shooting (such as aiming), skilled shooters are able to maintain shooting performance

(Kerick, Douglass, and Hatfield, 2004; Walmsley and Williams, 1994). The fact that shooting accuracy did not significantly vary between pre- and post-exercise during rapid fire shooting, supports the inference that the officers were well trained as their automatic shooting reactions were consistent despite effects from fatiguing exercise.(Goonetilleke et al., 2009; Lakie, 2010).

In fast-paced, rapid fire situations, like in this study, the shooter falls back on automatic responses and learned techniques. Lakie (2010) suggests that successful rapid-fire shooting after exercise is more a matter of preprogrammed responses rather than sensory control, minimizing the role of tremors in shooting performance and emphasizing the need for training. The type and quality of previous shooting, scenario training, and tactical training are important determining factors in these situations as there is often no time to think or aim in fast-paced, real-life situations. “The important fact for shooting of any form is that, if the time available for aiming is limited and is less than that for optimal aiming, it can be expected that the accuracy of aiming will be reduced,” (Goonetilleke et al., 2009, p. 501). This means that officers must be able to shoot quickly, even automatically, accurately and precisely. If the officer has been well trained with optimal and relatable techniques ingrained in his behavior, his automatic actions will reflect this training and successfully carry him through the fast-paced situation, helping him/her to respond appropriately in real-life situations. However, if the officer is not well trained or trained using techniques that are not directly applicable to the real-life situation, the officer’s automatic responses could cause an undesirable outcome during a stressful, real-life situation, such as shooting a hostage or failing to shoot a gunman/active shooter (Meyerhoff and colleagues, 2004). Continued training helps

shooting skills become automatic over time, requiring less cognitive effort and internal distraction (Kerick et al., 2004).

Learning how to control and appropriately adjust cognitive levels & mental arousal during high-pressure, stressful situations is also a determining factor in shooting performance and the situation's outcome. During stressful encounters, officers' cognitive control should be increased proportionally in order to overcome the challenging conditions (Vickers & Williams, 2007). While it appears that a moderate level of arousal is best suited for optimal shooting performance in non-stressful situations, a higher level of arousal may be beneficial in high-stress situations, particularly if the shooter has been trained to handle the higher level of arousal. When physical arousal is at maximum and sympathetic nervous system responses are heightened, such as is the case during intense exercise or foot pursuit of a suspect, increased cognitive arousal combined with increased external focus on task-relevant external information results in a high level of shooting performance by overcoming physiological states and blocking out negative effects and distractions from fatiguing exercise (or distractions period), leading to increased safety for the officer and those he/she is striving to protect (Kerick et al., 2004; Powers & Howley, 2007, p. 411; Rose & Christina, 1990; Tremayne & Barry, 2001; Vickers & Williams, 2007). Shooting while distracted compromises shooting performance, and consequently, safety. Superior shooters stay focused externally during shooting, especially the aiming phase, and are reluctant to divide their attention (Rose & Christina, 1990). Officers in the current study likely had appropriate cognitive control, including focusing externally on the task at hand and blocking out distractions, during both pre- and post-exercise shooting, allowing them maintain their level of shooting performance.

The importance of reality-based practice can not be stressed enough. Training under pressure, simulating real-life conditions & scenarios, improves shooting performance in police officers and better prepares officers for success in the field (Oudejans, 2008). Training scenarios and exercises incorporating higher levels of pressure and stress can help officers learn how to control and appropriately adjust arousal/cognitive levels and acclimatize an officer's shooting performance to high-pressure, stressful situations that they may encounter on duty. Reactions, both mental and physical, to stressful situations then become optimal and automatic. Qualifying with a firearm at a shooting range is much different than the shooting that takes place in the field. Reality-based training, including focus training, better prepares officers to deal with increased arousal levels and sympathetic nervous system responses such as elevated heart rate and adrenaline and consequently, body sway. In conclusion, the data from this study indicate that shooting accuracy and precision were not adversely affected by acute exercise-induced fatigue. These findings suggest that the trained automatic response overrides the potential negative effects of fatigue on shooting performance.

It's important to keep in mind the demographics of the sample police officer population in this study. All participants were males between the ages of 24 and 40, were physically active 3-6 days per week, had BMI's between 21.5 and 31.6, estimated VO₂ values between 2.2 and 3.4 L·min⁻¹, and 2-9 years of experience as police officers (with an average of 4 years on the department). Future research on how fatiguing exercise may impact shooting performance should be conducted on other police officer populations, such as female officers, older officers, and less fit officers, as well as implement other modes of lower body fatiguing exercises.

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APPENDIX 1

FORMS

Biomedical IRB – Expedited Review Approval Notice

NOTICE TO ALL RESEARCHERS:

Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE: July 7, 2009
TO: Dr. John Young, Kinesiology
FROM: Office for the Protection of Research Subjects
RE: Notification of IRB Action by Dr. John Mercer, Chair
Protocol Title: **The Effect of Acute Exercise Induced Fatigue on Pistol Shooting Accuracy in Police Officers**
Protocol #: 0905-3103M

This memorandum is notification that the project referenced above has been reviewed by the UNLV Biomedical Institutional Review Board (IRB) as indicated in regulatory statutes 45 CFR 46. The protocol has been reviewed and approved.

The protocol is approved for a period of one year from the date of IRB approval. The expiration date of this protocol is July 6, 2010. Work on the project may begin as soon as you receive written notification from the Office for the Protection of Research Subjects (OPRS).

PLEASE NOTE:

Attached to this approval notice is the **official Informed Consent/Assent (IC/IA) Form** for this study. The IC/IA contains an official approval stamp. Only copies of this official IC/IA form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through OPRS. No changes may be made to the existing protocol until modifications have been approved by the IRB.

Should the use of human subjects described in this protocol continue beyond July 6, 2010 it would be necessary to submit a **Continuing Review Request Form** 60 days before the expiration date.

If you have questions or require any assistance, please contact the Office for the Protection of Research Subjects at OPRSHumanSubjects@unlv.edu or call 895-2794.

Office for the Protection of Research Subjects
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047
(702) 895-2794 • FAX: (702) 895-0805

INFORMED CONSENT

Department of Kinesiology

TITLE OF STUDY: The effect of acute exercise induced fatigue on pistol shooting accuracy in police officers.

INVESTIGATOR(S): Dr. John Young (Primary Investigator), Melissa Brown (Student Investigator)

CONTACT PHONE NUMBER: Dr. John Young: 895-4626

Purpose of the Study

You are invited to participate in a research study. This study is designed to determine if there are differences in shooting accuracy before exercise (at rest) and after exercise (fatigued). This research has practical applications for all police officers. Findings from this study may encourage police departments to initiate and maintain physical fitness programs to aid in officer fitness and safety.

Participants

You are being asked to participate in the study because you are a healthy, active police officer of the State of Nevada under 40 years of age with no history of heart disease, hypertension, or musculoskeletal disease of injury. You must be a certified police officer familiar with fire arm safety, trained and experienced with fire arms, and licensed to carry a fire arm. Due to the intensity of the exercise, female subjects who are or who may become pregnant will also be excluded.

Procedures

This study will be conducted at a local indoor shooting range. You are asked to comply with all rules of the indoor shooting range. After completing the Physical Activity Readiness Questionnaire (PAR-Q), you will be asked to perform three shooting accuracy trials prior to exercise and three shooting accuracy trials after exercise. Each shooting trial will consist of five rapid fire shots, totaling 15 rapid fire shots prior to exercise and 15 rapid fire shots after exercise. You will use your own police department approved semi-automatic service pistol and will be responsible for your own pistol throughout the entire testing process of this study. The exercise portion of the study will be conducted on a stationary exercise bicycle and will include a 3-4 minute warm-up at a moderate resistance level (approximately a 600 kpm workload) followed by approximately 6 minutes of interval cycling at a higher resistance level (approximately 900 kpm workload). The interval cycling will consist of 60 seconds of pedaling at a high resistance followed by 30 seconds of resting without pedaling. This work/rest cycle will be repeated 3-4 times. The exercise portion of the study will stop when you reach 85% of your maximum heart rate or when you voluntarily decide to stop. You will wear a heart rate monitor throughout the entire testing process so heart rate can be monitored and recorded. You will also wear ear and eye protection during the shooting accuracy trials. After the shooting trials are completed for each officer, targets will be analyzed for shooting accuracy.

Participant Initials _____

TITLE OF STUDY: The effect of acute exercise induced fatigue on pistol shooting accuracy in police officers.

Benefits of Participation

Direct benefits to you as a participant in this study include a sense of shooting accuracy in two conditions (rested and after exercise), an estimation of your fitness level, and an opportunity to practice your professional skill of pistol shooting. As researchers, we hope to learn more about how police officer fitness may relate to shooting accuracy.

Risks of Participation

There are risks involved in all research studies. This study includes only minimum risks. During and upon immediate completion of the cycle exercise test, you may experience slight pain in your legs, dizziness, fatigue, and shortness of breath. The expected level of soreness will be typical of a hard exercise session.

Cost /Compensation

There *will not* be financial cost to you to participate in this study. Ammunition and targets will be provided for you. The study will take approximately one hour of your time on a single day. You *will not* be compensated for your time.

Contact Information

If you have any questions or concerns about the study, you may contact Melissa Brown at 702-202-6263 or Dr. John Young at 702-895-4626. For questions regarding the rights of research subjects, or any complaints or comments regarding the manner in which the study is being conducted, you may contact the **UNLV Office for the Protection of Research Subjects at 702-895-2794.**

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice. You are encouraged to ask questions about this study at the beginning or at any time during the research study.

Confidentiality

All information gathered in this study will be kept completely confidential. No reference will be made in oral or written materials that could link you to this study. All records will be stored in a locked facility in the Department of Kinesiology and Nutrition Sciences at UNLV for three years after completion of the study. After the storage time has expired, all information gathered will be destroyed.

Participant Consent:

I have read the above information and agree to participate in this study. I am a certified police officer in the state of Nevada and under 40 years of age. A copy of this form has been given to me.

Signature of Participant

Date

Participant Name (Please Print)

Participant Note: Please do not sign this document if the Approval Stamp is missing or is expired.

Participant Initials _____

Brenda Durosini, MPA, CIP, CIM -Director
Office for the Protection of Research Subjects
University of Nevada Las Vegas
4505 Maryland Parkway Box 451047
Las Vegas, NV 89154-1047

Subject: Letter of Authorization to Conduct Research at American Shooters.

Dear Ms. Durosini:

(This letter will serve as authorization for the University of Nevada, Las Vegas ("UNLV") researcher/research team, Dr. John Young and Melissa J. Brown, to conduct the research project entitled "The effect of acute exercise induced fatigue on pistol shooting accuracy in police officers" at American Shooters (the "Facility").

The Facility acknowledges that it has reviewed the protocol presented by the researcher, as well as the associated risks to the Facility. The Facility accepts the protocol and the associated risks to the Facility, and authorizes the research project to proceed. The research project may be implemented at the Facility upon approval from the UNLV Institutional Review Board.

If we have any concerns or require additional information, we will contact the researcher and/or the UNLV Office for the Protection of Research Subjects.

Sincerely,

Facility's Authorized Signatory

6/30/09
Date

BRENDA DUROSINI / DIRECTOR, BRENDA DUROSINI
Printed Name and Title of Authorized Signatory

DATA SHEET

"The effect of acute exercise-induced fatigue on pistol shooting accuracy in police officers"

Date _____

Name: _____

Age: _____ Resting HR: _____ Predicted MHR: _____ 85% MHR: _____ (target)

Wt: _____ lb _____ kg Height: _____ in _____ cm _____ m Caliber: _____

EXERCISE: Cycle Ergometer

Metronome: 138

RPM: 70

3-5 Minute warm-up while reaching steady state (SS), followed by 60 s work/30 s rest intervals for 4.5-6 minutes

Min	WU/WK/R	Work Load	HR	SS/85	Notes:
1	Warm Up	2kp/600kgm			SS: two consecutive HR's w/in 5 bpm between 110-150 bpm
2	Warm Up				*Circle both HR's
3	Warm Up				
4					Predicted VO2max: _____ liters/min
					*Multiply by correction factor if over 35 yrs:
5					* Divide by weight: _____ ml/kg/min
6	WORK	3kp/900kgm			Participant stops voluntarily or once they reach 85% MHR
	rest 30s	0kp/0kgm			*Circle Peak HR, start 2nd stop watch for HR Recovery Time
7	WORK				
	rest 30s				Keep an eye on the resistance!
8	WORK				
	rest 30s				
9	WORK				
	rest 30s				
10	WORK				
	rest 30s				
11	WORK				
	rest 30s				
12	WORK				Move quickly to shooting range (<15s)! Eye & ear protection!

SHOOTING: 5 rapid fire shots per 6 s trial; 15 s rest periods facing wall, moving to next lane, taking HR twice

Pre-Exercise	√	HR	Score
Trial 1			
Rest/HR			
Trial 2			
Rest/HR			
Trial 3			
Rest/HR			

Post-Exercise	√	HR	Score
Trial 1			
Rest/HR			
Trial 2			
Rest/HR			
Trial 3			
Finish/HR			

Recovery time for peak HR to return to resting HR: _____ mins Est. Fitness Level: _____

APPENDIX 2

DATA

Data Set

Subject	PreDist1	PreDist2	PreDist3	PreDiam1	PreDiam2	PreDiam3	PreHR1	PreHR2	PreHR3
1	68	37	47	85	57	85	116	120	112
2	113	101	59	103	82	70	132	119	105
3	50	90	88	67	78	61	72	103	89
4	57	92	92	97	196	121	99	95	85
5	52	90	75	86	199	176	116	100	99
6	60	41	51	53	80	87	108	71	72
7	54	63	44	95	95	96	122	132	118
8	21	46	78	60	102	104	110	117	74
9	126	134	179	340	320	356	88	90	66

Data Set Continued

Subject	PostDist1	PostDist2	PostDist3	PostDiam1	PostDiam2	PostDiam3	PostHR1	PostHR2	PostHR3
1	34	90	60	90	110	36	172	158	152
2	76	108	58	71	81	112	174	163	155
3	156	58	80	156	112	63	179	162	154
4	60	51	55	97	126	121	150	144	134
5	86	85	31	167	119	63	177	166	160
6	27	40	36	64	70	88	186	176	164
7	34	90	46	75	69	78	180	174	162
8	100	55	54	63	95	117	179	165	160
9	126	65	95	96	127	264	159	146	136

SHOOTING PERFORMANCE SCORES

SUBJECT: 1

mm	PRE1(5)	PRE2(5)	PRE3(5)	AVE PRE(5)	PRE1(4)	PRE2(4)	PRE3(4)	AVE PRE(4)
Diameter	160	137	117	138	85	57	85	75.67
1-shot Distances								
1	52	56	63		68	39	35	47.33
2	50	20	37					
3	74	30	71					
4	96	42	30					
5	56	80	49					
Dist. Ave.	65.6	45.6	50					
					68	37	46.75	

mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	159	119	92	123.33	90	110	36	78.67
1-shot Distances								
1	24	24	50		29	63	62	51.33
2	138	75	68					
3	32	86	74					
4	65	109	47					
5	14	90	15					
Dist. Ave.	54.6	76.8	50.8					
					33.75	90	59.75	

Comments:

SHOOTING PERFORMANCE SCORES

SUBJECT: 2

mm	PRE1(5)	PRE2(5)	PRE3(5)	AVE PRE(5)	PRE1(4)	PRE2(4)	PRE3(4)	AVE PRE(4)
Diameter	154	126	88	122.67	103	82	70	85
1-shot Distances								
1	106	91	64		117	102	56	91.67
2	163	110	71					
3	73	75	61					
4	110	89	51					
5	120	128	54					
Dist. Ave.	114.4	98.6	60.2		113	100.5	59.25	

mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	100	121	154	125	71	81	112	88
1-shot Distances								
1	141	92	33		79	112	65	85.33
2	99	112	63					
3	88	109	33					
4	57	120	103					
5	60	66	152					
Dist. Ave.	89	99.8	76.8		76	108.25	58	

Comments:

SHOOTING PERFORMANCE SCORES

SUBJECT: 3

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	82	128	85	98.33	67	78	61	68.67
1-shot Distances								
1	35	34	68		49	89	90	76
2	19	93	88					
3	73	91	82					
4	73	81	114					
5	45	96	125					
Dist. Ave.	49	79	95.4		50	90.25	88	

mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	246	172	115	177.67	156	112	63	110.33
1-shot Distances								
1	104	35	34		127	56	66	83
2	196	59	88					
3	52	103	144					
4	184	173	91					
5	190	35	89					
Dist. Ave.	145.2	59	89.2		155.5	58	75.5	

Comments: Excellent pre-exercise shoot. Post-exercise: shot performance decreased then recovered.

SHOOTING PERFORMANCE SCORES

SUBJECT: 4

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	165	246	222	211	97	196	121	138
1-shot Distances								
1	49	112	78		59	34	87	60
2	27	122	137					
3	60	189	103					
4	91	71	48					
5	98	65	74					
Dist. Ave.	65	111.8	88		56.75	92.5	91.5	

mm	POST1 (5)	POST2 (5)	POST3 (5)	AVE POST (5)	POST1 (4)	POST2 (4)	POST3 (4)	AVE POST (4)
Diameter	188	294	156	212.67	97	126	121	114.67
1-shot Distances								
1	115	273	129		55	11	37	34.33
2	90	48	44					
3	46	50	15					
4	42	37	76					
5	60	67	86					
Dist. Ave.	70.6	95	70		59.5	50.5	55.25	

Comments:

SHOOTING PERFORMANCE SCORES

SUBJECT: 5

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	145	222	202	189.67	86	199	176	153.67
1-shot Distances								56
1	57	19	78		29	99	40	
2	58	158	59					
3	57	87	11					
4	37	189	116					
5	79	64	113					
Dist. Ave.	57.6	103.4	75.4		52.25	89.75	74.75	

mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	184	190	115	163	167	119	63	116.33
1-shot Distances								64.33
1	162	88	28		90	86	17	
2	199	99	73					
3	92	28	20					
4	48	125	37					
5	42	103	37					
Dist. Ave.	108.6	88.6	39		86	85	30.5	

Comments:

SHOOTING PERFORMANCE SCORES

SUBJECT: 6

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	108	109	128	115	53	80	87	73.33
1-shot Distances								
1	44	2	26		4-shot Distance	59	41	28
2	66	36	49		1-shot Distances			
3	112	54	105		1	44	2	26
4	51	73	73		2	66	36	49
5	78	82	54		3	51	54	73
Dist. Ave.	70.2	49.4	61.4		4	78	73	54
					Dist. Ave.	59.75	41.25	50.5

mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	102	153	147	134	64	70	88	74
1-shot Distances								
1	26	28	80		4-shot Distance	5	36	23
2	26	39	24		1-shot Distances			
3	22	33	16		1	26	28	24
4	34	60	37		2	26	39	16
5	72	87	68		3	22	33	37
Dist. Ave.	36	49.4	45		4	34	60	68
					Dist. Ave.	27	40	36.25

Comments: Shot better post-exercise. PRE1 had 6 shots; worst shot thrown out (151).

SHOOTING PERFORMANCE SCORES

SUBJECT: 7

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	108	130	122	120	95	95	96	95.33
1-shot Distances					4-shot Distance	70	47	60.33
1	19	24	0		1-shot Distances			
2	42	65	20			24	0	
3	106	105	64			65	20	
4	102	56	90			105	64	
5	48	49	117			56	90	
Dist. Ave.	63.4	59.8	58.2		Dist. Ave.	62.5	43.5	

mm	POST1 (5)	POST2 (5)	POST3 (5)	AVE POST (5)	POST1 (4)	POST2 (4)	POST3 (4)	AVE POST (4)
Diameter	89	106	109	101.33	75	69	78	74
1-shot Distances					4-shot Distance	80	51	50.67
1	52	29	19		1-shot Distances			
2	42	82	80			82	19	
3	54	85	43			85	80	
4	15	106	40			106	43	
5	25	86	90			86	40	
Dist. Ave.	37.6	77.6	54.4		Dist. Ave.	89.75	45.5	

Comments: Shot better post-exercise.

SHOOTING PERFORMANCE SCORES

SUBJECT: 8

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	102	121	147	123.33	60	102	104	88.67
1-shot Distances								
1	59	28	74		4-shot Distance	27	24	42
2	5	39	110		1-shot Distances			
3	23	78	108		1	5	28	110
4	52	45	41		2	23	39	108
5	2	70	51		3	52	45	41
					4	2	70	51
Dist. Ave.	28.2	52	76.8		Dist. Ave.	20.5	45.5	77.5

mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	151	135	185	157	63	95	117	91.67
1-shot Distances								
1	23	62	74		4-shot Distance	107	54	64.67
2	88	37	19		1-shot Distances			
3	79	117	44		1	88	62	74
4	101	71	77		2	79	37	19
5	132	49	146		3	101	71	44
					4	132	49	77
Dist. Ave.	84.6	67.2	72		Dist. Ave.	100	54.75	53.5

Comments: Pre1 had six shots; worst shot was excluded (69).

SHOOTING PERFORMANCE SCORES

SUBJECT: 9

mm	PRE1 (5)	PRE2 (5)	PRE3 (5)	AVE PRE (5)	PRE1 (4)	PRE2 (4)	PRE3 (4)	AVE PRE (4)
Diameter	366	434	N/A	400	340	320	356	338.67
1-shot Distances								
1	63	115	43		4-shot Distance	57	135	71.33
2	201	195	96		1-shot Distances			
3	169	131	276		1	63	43	
4	119	236	302		2	169	96	
5	151	96	Missing		3	119	276	
Dist. Ave.	140.6	154.6	179.25		4	151	302	
					Dist. Ave.	125.5	179.25	
mm	POST1(5)	POST2(5)	POST3(5)	AVE POST(5)	POST1(4)	POST2(4)	POST3(4)	AVE POST(4)
Diameter	N/A	228	400	314	96	127	264	162.33
1-shot Distances								
1	75	52	83		4-shot Distance	48	35	67
2	145	76	122		1-shot Distances			
3	156	184	253		1	75	83	
4	128	89	37		2	145	122	
5	Missing	42	139		3	156	37	
Dist. Ave.	126	88.6	126.8		4	128	139	
					Dist. Ave.	64.75	95.25	

Comments: Cannot obtain accurate PRE3(5) and POST1(5) 5-shot diameters or distance averages due to missing shots.

Table 4. Heart rates

Participant	Age-predicted Max HR (bpm)	Highest Exercise HR (bpm)	Percentage (%) of Age-predicted Max HR
1	193	172	89
2	196	186	94
3	183	179	97
4	180	173	96
5	187	185	98
6	195	197	101
7	192	187	97
8	193	186	96
9	189	169	89
Means*	190 $\pm$ 2	182 $\pm$ 3	95 $\pm$ 1

Note: *Means are $\pm$ SE.

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Degrees:

Bachelor of Science, Kinesiology, 2007
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Thesis Title:

The effect of acute exercise-induced fatigue on pistol shooting performance in police officers

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