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Original Research

Effects of Heart Rate Biofeedback, Sleep, and Alertness on Marksmanship Accuracy during a Live-fire Stress Shoot

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ABSTRACT

International Journal of Exercise Science 14(6): 123-133, 2021. On the job, law enforcement may be required to utilize lethal force to maintain personal or public safety. Officers' attention to detail, decision-making, and marksmanship accuracy (MA) may be impaired by reduced sleep, increased heart rate (HR), and breathing rate (BR). HR biofeedback (emWave, EW) may help mitigate these impairments. This study sought to determine the impact EW had on MA, stress shoot time-to-completion (TTC), HR and BR versus placebo (PLA). Ten active-duty police officers volunteered for this study. Officers completed two live-fire stress shoots on a 25-m gun range (i.e., familiarization, followed by EW, or PLA trials). MA was assessed as "hit, no-hit." HR and BR were monitored before, immediately after, and 20 minutes post-trial. Sleep was monitored during the entirety of the study. Dependent *t*-tests were conducted for MA and TTC. A 2x3 repeated-measures ANOVA was conducted for HR, BR, before, during, and after each trial. There were no statistical differences (EW vs. PLA) for: HR (128 $\pm$ 23 vs. 136 $\pm$ 14; $p = 0.30$), BR (19 $\pm$ 2 vs. 21 $\pm$ 2; $p = 0.31$), TTC (108.4 $\pm$ 11.2s vs. 111.6 $\pm$ 20.2s; $p = 0.94$; $d = 0.21$). Alertness (83.2 $\pm$ 9.5 vs. 77.9 $\pm$ 15.5), was not statistically significant EW vs. PLA ($p = 0.32$; $d = 0.42$). MA (81.4 $\pm$ 10.2 vs. 85.9 $\pm$ 12.9%) was not statistically significant EW vs. PLA ($p = 0.95$; $d = 0.38$). Sleep (7.4 $\pm$ 2.9h vs. 5.4 $\pm$ 1.7h) was not statistically significant EW vs. PLA ($p = 0.13$; $d = 1.0$). EW usage did not affect the physiological and marksmanship performance of officers during a live-fire stress shoot based on HR, BR, TTC, and MA while considering sleep quantity.

KEY WORDS: Human performance, tactical, assessment, recovery

INTRODUCTION

On a daily basis, Law enforcement officers (LEOs) may encounter numerous unpredictable, high-risk, situations that may threaten personal and public safety (3, 27). During such high-stress events, LEOs are required to take quick and decisive action to maintain safety and neutralize any threats (44). For these reasons, it is essential that officers can process information from their environment rapidly and determine the appropriate level of force needed to resolve the situation.

Sleep disturbance (e.g. difficulty falling asleep, staying asleep, and daytime sleepiness) (20, 50) have been shown to impair performance across occupations such as aviation (5), healthcare (23), and military (28). Previous research has reported significant relationships between shift work and fatigue, on-duty fatal and non-fatal injuries (36, 40, 42, 45), insomnia (11, 40, 46), short sleep duration (13, 24, 34), day time sleepiness (10, 46) and overall poor sleep quality in police officers working night shifts (4, 5, 9, 11, 12, 14, 19, 22, 45, 47-49). LEOs may be at significant risk for sleep disturbances based on a variety of occupational factors, such as shift work, administrative responsibilities, post-traumatic stress (15). It has been found that non-restorative sleep may lead to both acute and chronic fatigue and exhaustion (1, 2, 21, 37). For LEOs these factors may lead to significant physical and cognitive impairments that put themselves, or others, in peril.

The negative impacts caused by long-term shift work have been shown to decrease response and memory performance (17). Also, acute physical fatigue can further increase stress and lower cognitive function and lead to poor judgment/decision making in law enforcement officers (14, 17, 29, 38), especially if it involves maximal, to near maximal, bouts of physical activity (sprinting, climbing, etc.) (32, 33)**.** During high physical and cognitive stress (especially when coupled with short sleep duration), there is a loss of dexterity of fine motor skills which may increase the time needed for target acquisition and reduce shooting accurately (15, 39, 41)**.** Infantrymen shooting in the prone position hit 25% fewer pop-up targets when sleep-deprived longer than 48h (16). These same infantrymen had a 10% increase in target acquisition time (after 90h of sleep deprivation) when those targets appeared at random locations on a firing range (16). While LEOs are most likely not going to be sleep-deprived for 90h, the impact of short sleep duration will most likely reduce the officers' ability to perform at their best considering LEOs have an accuracy rating of 90% or higher in static shooting tests, yet an average of 15-50% in real-life incidences (30).

One way to monitor the stresses caused by lack of sleep and difficult situations LEOs encounter is heart rate biofeedback; as it reflects the sympathetic and parasympathetic branches of the autonomic nervous system (26). One device that measures heart rate biofeedback is the emWave2 (EW) (a small handheld device) by measuring heart rate through a pulse in the thumb and the earlobe. This device is thought to synchronize both branches of the autonomic nervous system by having the user sync their inhale and exhale with rising and falling LEDs on the EW (25). With this device not requiring electrodes, it is thought that it is versatile to use in the field or in the home.

Therefore, the purposes of this study were to determine if there were significant differences in sleep, MA, and stress shoot time to completion (TTC) between the EW (Boulder Creek, CA) and placebo (PLA) trials. The authors hypothesized: 1) LEOs sleep would be less than the recommended ~7-8h of sleep per night, 2) Marksmanship accuracy (MA) would improve after using the EW versus the PLA, and 3) Stress shoot TTC would be faster after the EW versus PLA.

METHODS

Participants

Ten active-duty LEOs (eight males, two females; height (cm) 178.5 ± 8.3, total body mass (kg) (83.7 ± 17), skeletal muscle mass (kg) (37.2 ± 6.6), body fat (%) (21 ± 6.3), and age (y) (32.2 ± 9.4) who were free from injury and on the university's police department volunteered for this study. Based on a power analysis was using G*Power 3.1.9.4 (Universitat Kiel, Germany) it was determined that a minimum of ten participants were needed to achieve a power of 0.80 with an effect size of 0.5, if statistical significance were set at a priori at $p < 0.05$. Participants were informed, prior to completing this study, that their performance would not affect their professional standings within the police department. One participant dropped out due to personal reasons not associated with this study. In addition to this study being carried out per the ethical standards of the International Journal of Exercise Science (31), the Liberty University Institutional Review Board approved the study.

Protocol

The study utilized a single-blind treatment and PLA study design. The EW served as the treatment and two coconut flour capsules served as the PLA. The trials were conducted in a counter-balanced fashion with a familiarization trial being Trial 1.

All participants completed a live-fire stress shoot on a 25-m gun range that was similar to the one used during normal training by the Liberty University Police Department. This study included two counter-balanced stress shoots (EW and PLA) that followed the initial familiarization trial. For the familiarization trial, each participant chose a time and day that best fit their work schedule and that allowed them to be fasted for six to eight hours before reporting to Liberty University's Science Hall. Once they arrived, they were given an informed consent form to read and sign, a Physical Readiness Activity Questionnaire (Par-Q), and a medical history form to complete. After completing the paperwork and asking questions as necessary, each participant's height was measured using the SECA 216 mechanical measuring rod for children and adults (SECA, Chino, CA) and recorded. Total body mass, skeletal muscle mass, body fat percentage were collected using the InBody 770 Body Composition Analyzer (InBody, Cerritos, CA). After completing the study's forms and acquiring their body composition measured, LEOs transported themselves to the gun range where the range safety officer provided instructions for the group on each stage of the stress shoot; explaining the order, expectations, and safety protocol that would be adhered to for the stress shoot's entirety.

Both trials (EW and PLA) were conducted at the university's gun range at roughly the same time of day over a two-week period. Upon arriving to the gun range, each LEO was handed three magazines with an unknown number of rounds (unknown to the participant) for their service weapon. While at the range, participants completing the PLA trial were given a small bottle of water to consume two coconut flour-filled capsules. After obtaining their three magazines and personal protective equipment, the participants were escorted away from the range to Station One. This was a holding area when multiple participants arrived to the range at the same time.

The next participant in line to complete the stress shoot was escorted from Station One to Station Two.

At Station Two, the PLA participant would be seated quietly for ten minutes. The participant receiving the EW placed his or her thumb on the HR/pulse monitor at the bottom of the device once powered on, and the participant was instructed to match his or her breathing with the rising and lowering blue LED lights showing on the device. Participants were instructed to "inhale as the LED light raised and exhale as they lowered." The EW provided instantaneous feedback (by showing a green or red light) to inform the participant of how well his or her breathing pattern matched that of what the device produced. Participants maintained this breathing pattern for ten minutes. After the ten minutes, the participant was escorted to the starting line of the stress shoot.

Once at the starting line, the participant was briefed about what would be done during the shoot and then donned their ear and eye protection. Each participant was told, "The timer will start once the siren sounds from the patrol car. Then run up to the stairs, go up the stairs, get into the patrol car, buckle your seat belt, and place both hands on the steering wheel. You will get out of the vehicle when instructed and approach the first barricade pending instructions from the range safety officer (RSO). You will fire at the first target until your magazine is empty, reload your weapon, approach the target for a safety check along with the RSO, and once cleared you will proceed to the second barricade. You will repeat the same process at the last two barricade-target setups. Once the RSO declares that the range is clear and safe, your timer will stop and you will report to the deck for instructions." This statement remained consistent for each LEO, during each trial. Once the RSO signaled that the range was "cleared and ready," the research assistant signaled that the participant was "ready." Simultaneously as the patrol car siren sounded, "Prayer" (Disturbed, 2002) began playing (the song selection remained constant for each participant and for each trial), the participant began the 50-meter sprint to the stairs, the time of day was recorded, and the stress shoot timer was started by the research assistant. After climbing five stairs, the participant entered the patrol vehicle that had loud music playing, buckled the seat belt, and placed both hands on the steering wheel. The RSO loudly instructed the participant to get out of the car and to approach the first barricade 5-meters away. Upon reaching the barricade, the participant shot a target that was 19.2-meters (21-yards) away until the magazine, which contained five bullets, was empty. After realizing the magazine was empty, the participant reloaded his or her weapon. Once reloaded, the officer cautiously approached the target, to mimic approaching a situation in a way that would allow him or her to examine the surrounding environment and determine its safety. Once determined "safe" by the RSO, the participant approached the second barricade, positioned 19.2-meters (21-yards) away from the second target, and repeated the previously described process. Once completed, the same process was followed beginning at a third barricade positioned 13.7-meters (15-yards) away from the third target. Once the third target area was determined safe by the RSO, he raised his right fist, the timer stopped, the TTC was recorded, along with the time of day.

Immediately following the stress shoot, the participant was directed to a deck positioned at the end of the range and then taken to Station Three. After twenty minutes of recovery, the participant was escorted back to the gun range, and informed that the trial was complete. To document the performance of each participant, pictures were taken of each target immediately following their individual stress shoot. To evaluate MA, a point system connected to a "hit, no-hit" system was utilized. If a shot hit a target, the participant was awarded 5 points. If a shot missed a target, the participant was not awarded any points. As each officer was given five bullets in each magazine, there was an opportunity to obtain 75 points. The points obtained was then divided by 75, and multiplied by 100. The resulting number served as the level of marksmanship accuracy shown during a single trial. Figure 3 depicts how each officer engaged each of the steel target during the stress shoot.

Statistical Analysis
Microsoft Excel (Microsoft Corporation Redmond, Washington, USA) was used to calculate means and standard deviations for age, height, total body mass, body fat percentage, and skeletal muscle mass as well as the dependent *t*-tests on MA and TTC group means for EW and PLA trials. Statistics Package for Social Sciences (Version 25.0; IBM Corporation, New York, USA) was used to conduct a 2x3 (group by time) repeated-measures analysis of variances were used to analyze alertness for EW versus PLA at before, during, and after the stress shoot. Correlations were conducted between alertness and MA, alertness and TTC, sleep duration and MA, sleep duration and TTC. The alpha level was set at $p < 0.05$. Effect sizes (Cohen's d) for sleep, average alertness, TTC, and marksmanship were also calculated. Cohen's d was derived from the difference between the means divided by the pooled standard deviations (7). A d less than 0.2 was considered a trivial effect; 0.2 to 0.6 a small effect; 0.6 to 1.2 a moderate effect; 1.2 to 2.0 a large effect; 2.0 to 4.0 a very large effect; and 4.0 and above an extremely large effect (18).

RESULTS

Based on a power analysis using G*Power 3.1.9.4 (Universitat Kiel, Germany) a minimum of ten participants were needed to achieve a power of 0.80 with an effect size of 0.5 if statistical significance was set at priori at $p < 0.05$. Average sleep duration for the EW trial was 7.7 $\pm$ 2.9h and 5.4 $\pm$ 1.7h for the PLA trial was not statistically different ($p = 0.13$; $d = 1.0$). Average alertness scores for the EW trial was 83.2 $\pm$ 9.5; 77.9 $\pm$ 15.5 for the PLA trial and was not statistically different ($p = 0.32$). Means and standard deviations for MA and TTC can be found in Figures 1 and 2. There was a moderate positive correlation (0.32) between sleep and alertness for the EW trial and a large positive correlation (0.98) for the PLA trial. Multiple correlations were conducted among alertness, MA, and TTC that did not result in a moderate or large effect.

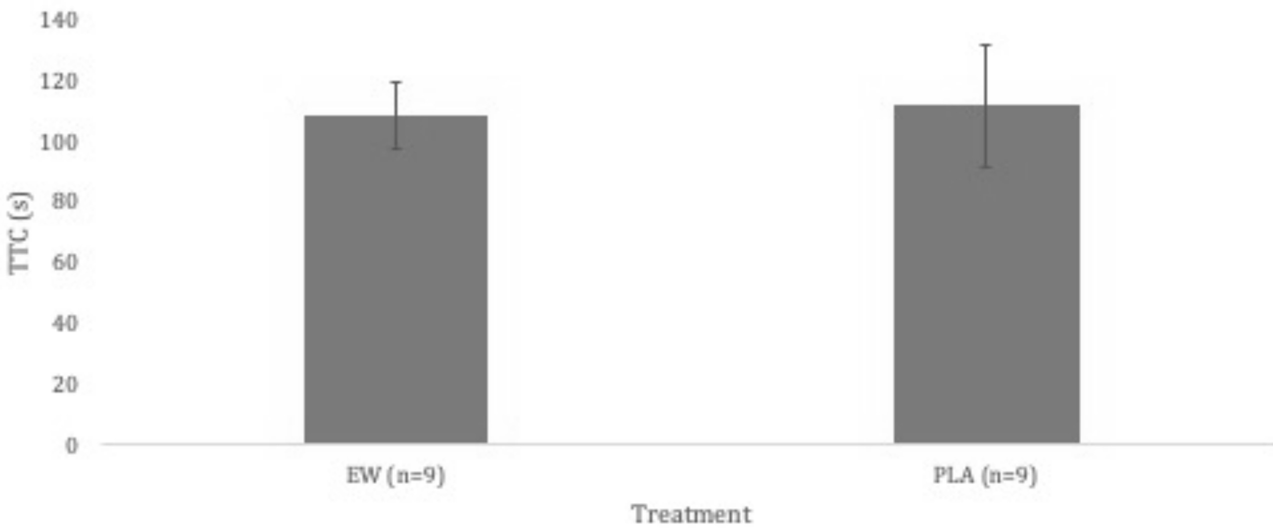

Figure 1. Time to Completion with error bars. EW did not cause significant improvement in TTC vs PLA. (EW: 108.4 $\pm$ 11.2s vs PLA: 111.6 $\pm$ 20.2s; p = 0.94; d = 0.21)

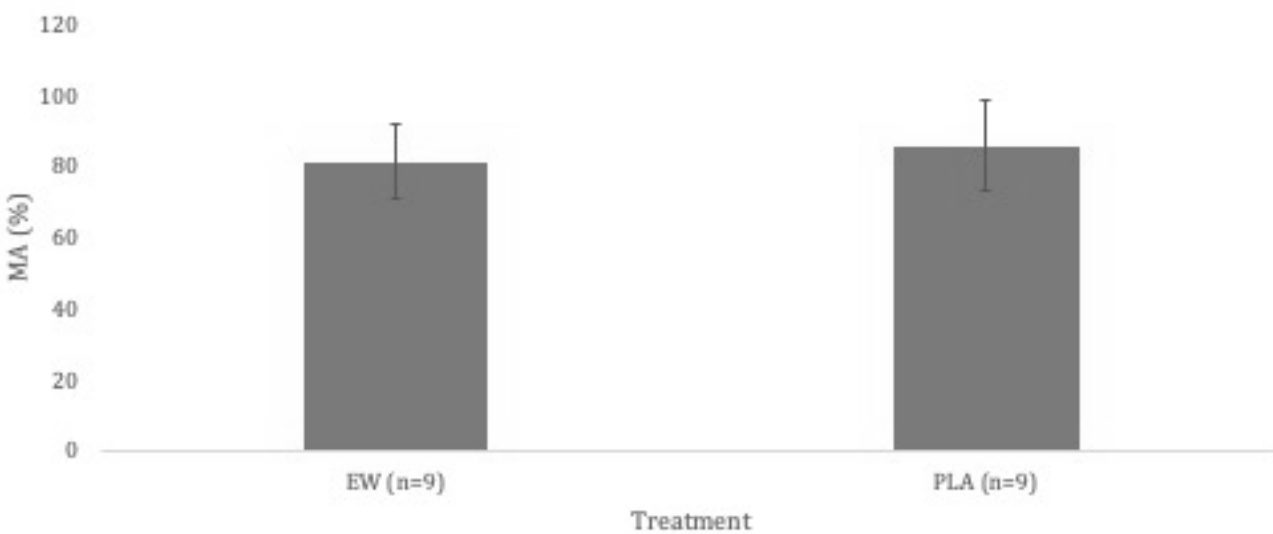

Figure 2. Marksmanship Accuracy with error bars. EW did not cause significant improvement in MA vs PLA. (EW: 81.4 $\pm$ 10.2% vs PLA: 85.9 $\pm$ 12.9%; p = 0.95; d = 0.38).

Figure 3. Depiction of an officer engaging a steel target from behind a barricade during the stress shoot.

DISCUSSION

This study sought to determine the effects of sleep duration, alertness, and EW use on MA and TTC during live-fire stress shoots. Although not statistically significant, the EW trial had a lower MA versus the PLA trial. The TTC was not statistically significant for the EW trial versus the PLA trial. Therefore, it could be speculated that this inverse relationship between MA and TTC may have been caused by the participants completing the stress shoot at a faster pace than they were comfortable during the EW trial, and/or because there was a larger variance in sleep duration between the trials.

The results of this study showed that the use of EW did not produce a significant reduction in TTC, or a significant improvement in MA in LEOs who were previously trained in trigger control. However, this does not mean the results would not have been changed in other training scenarios or with a larger sample size. For previous research indicates that controlled breathing caused an increase in MA; especially when coupled with trigger control (6, 8). These methods will help officers learn how to fire their service weapon after an inhale and before an exhale (6). Furthermore, trigger control will aid the person in not jerking or pulling the trigger, but rather squeezing it; this method coupled with the previously mentioned controlled breathing techniques may prove to be useful for regulating stress responses that can impact MA and TTC (6, 35). The results of those studies were the basis for the present study and additional research should be conducted to determine why there was a lack of agreement with regards to MA and TTC as well as why the EW did not improve marksmanship. But an initial hypothesis is because this study sought to utilize the minimum dose of the EW and have a stress shoot that would minimize cardiovascular and muscular fatigue while simulating an actual response while working as a LEO. Therefore, the duration of the stress shoot may have minimized the impact the EW could have on MA.

Regarding limitations, it is important to note that two participants (one during each trial) experienced issues with their weapon when attempting to reload at the second barricade. The slower times that resulted from these complications could have skewed the mean value for TTC after the use of each treatment. These two instances may have had an effect on the level of significance calculated for TTC after use of the EW versus PLA. In addition to this, it should be considered that other factors may have a greater impact on MA. Ammunition type, wind velocity, shooting position, and shooter experience could all have impacted MA (38). Due to LEO dropout and errors in technology, all data was not obtained for each LEO resulting in the study being under powered. With that said, there were several delimitations included in this study such as controlling for time of day, study protocol, and blinding the participants from the treatment they were receiving.

The results from this study could help improve a police department's current marksmanship training protocol. While safety is of the utmost importance, being trained to safely and accurately use lethal force is also important. With the occurrence of active shooters, it is important for LEOs to be trained on their department's standard operating procedures and then be able to train those proceeding during a live-fire stress shoot or a force-on-force stress shoot while wearing their duty uniform and gear.

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