Autonomic Response to Tactical Pistol Performance Measured by Heart Rate Variability

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Abstract

Thompson, AG, Swain, DP, Branch, JD, Spina, RJ, and Grieco, CR. Autonomic response to tactical pistol performance measured by heart rate variability. *J Strength Cond Res* 29(4): 926–933, 2015—This study evaluated changes in autonomic tone during a tactical pistol competition. At rest and during a match, heart rate variability (HRV) was examined in 28 healthy subjects. Heart rate variability time-domain variables (including interbeat interval [IBI]) and frequency-domain variables (low frequency [LF], high frequency [HF], total power [TP]) measured during shooting were subtracted from those measured during rest to produce Δs. The shooting task involved several, rapid tactical maneuvers. Raw time to completion and inaccurate shots (points down [PDs]) were recorded and combined to form a match score where lower values indicated superior shooting performance. Mean (±*SD*) raw time was 135.9 ± 34.1 seconds, PDs were 78 ± 34, and match score was 175.3 ± 39.8. Shooting decreased IBI (i.e., increased heart rate) and LF. ΔLF, ΔHF, and ΔTP were independent of ΔIBI. Raw time was significantly ($p \le 0.05$) correlated to shooting IBI (r = 0.404) and ΔIBI ($r = -0.426$). Points down were significantly correlated to ΔTP ($r = 0.416$) and ΔLF ($r = 0.376$). Match score was significantly correlated to ΔIBI ($r = -0.458$), ΔHF ($r = 0.467$), ΔLF ($r = 0.377$), and ΔTP ($r = 0.451$). In conclusion, individuals with a greater decrease in IBI (and thus heart rate) performed better by accomplishing the match faster. Individuals with less change in stress-related HRV measures (LF, HF, and TP) performed better through improved accuracy. Thus, HRV-derived sympathetic response is significantly related to shooting performance and should be used to assess marksmanship effectiveness under duress.

Key Words marksmanship, stress response, military, psychophysiology

Introduction

Specific responses while under duress can affect an individual's ability to perform mental and physical tasks (1,2,4–6,8,15,16,19,22). In the case of psychomotor tasks such as tactical shooting, autonomic response could potentially influence performance. For military operators, controlling this reflex could be the difference between life and death. A specific method for monitoring this stress response and autonomic tone, heart rate variability (HRV) analysis, has received increased attention in the scientific literature (1,6,7,8,11–13,15,17–19,22–25). Heart rate variability is the direct quantitative result of regulatory mechanisms within the autonomic nervous system (ANS) and can reflect internal changes from reacting to acute or chronic conditions and stimuli (1,11,13,18,20,25,27).

Neuroscience research has revealed that the sympathetic response can inhibit the prefrontal cortex (PFC), a structure responsible for higher-level executive functions (2,3,11,22,23). In combat, the PFC would not only help make strategic battlefield maneuver decisions but also assist with the fine motor coordination responsible for skillful marksmanship execution. Even mild, acute stress rapidly degrades cognitive performance, attention, and decision making. Decreases in parasympathetic drive (high-frequency [HF] HRV power) are often associated with amygdala activation and inhibition of the PFC (22,23). The resulting autonomic modulation and cognitive demands link perceived stress directly to motor performance through the medial visceromotor network (11), touting HF power as method of inferring neurocontrol. Thus, from a cognitive neuroscience standpoint, HRV is a noninvasive means of assessing subjective stress reactivity and its relationship to psychomotor performance.

In clinical studies, HRV has been linked to all-cause mortality (1,7,20,25). However, the bulk of these studies

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has focused primarily on subjects with diagnosed cardiopulmonary and metabolic diseases. If impaired HRV is related to inhibited physiological function, certain HRV profiles may be beneficial, especially during stressful events. Heart rate variability dynamics may even be an important predictor of psychomotor performance capabilities.

Among active duty men performing a mock-capture scenario in the U.S. Navy Survival Evasion Resistance Escape (SERE) School and among Special Forces divers in a Combat Diver Qualification Course (CDQC), those with an increased resting vagal tone performed significantly worse than those with lower resting vagal tone (15). However, HRV was assessed during classroom education, just before a stressor, and could potentially represent anticipation skewing the baseline. Another study found that sailors with a lower resting HRV (lower HF power) showed a significant improvement in reaction time and accuracy during a cognitive function test under threat of shock (8). In contrast, elite soldiers exhibited greater daily heart rate dipping, an indication of parasympathetic dominance (higher HF), than their nonelite counterparts and reported less perceived stress during the captivity portion of SERE School (21).

Very few studies have examined the relationship between marksmanship and HRV. During a shoot-house tactical room clearing exercise, Elkins et al. (6) found that untrained nonmilitary breach teams with a higher interteam HRV correlation performed significantly better at recognizing and shooting combatants vs. noncombatants. Saus et al. (19) demonstrated that police academy cadets who incurred less of a reduction in the HRV during a situation awareness shooting simulation scored higher on marksmanship and higher on identification of shoot vs. no-shoot conditions.

The previous studies indicate the importance of autonomic tone to military/tactical task performance and assist in validating HRV as a noninvasive method for assessing such tone. In this study, we sought to examine the relationship between this psychophysiological measure and marksmanship performance, a common functional test in the military and police community. Expanding the traditional strength and conditioning paradigm to include analysis of top-down neural control can provide more in-depth assessment and insight into systemic integration, function, and performance. As it pertains to psychological conditioning, identification of a robust, prompt, noninvasive stress marker related to cognitive and motor performance may prove valuable for future performance testing, training interventions, preselection criteria, and identifying dysfunctions in the military and first responder athlete. For this study, we hypothesized that individuals experiencing less sympathetic activation and vagal tone reduction would perform better during a shooting task.

Methods

Experimental Approach to the Problem

The independent variable was a tactical pistol course of fire (CoF) that is used to classify skill in the International Defensive Pistol Association (IDPA). Although it is not possible to reproduce the stress of combat in a testing environment, competitive pistol shooting requires individuals to perform at a rapid pace in a simulated tactical setting. Stress was experienced because of several factors. The event itself was a competition between shooters and a competition for each shooter against IDPA standards. Shooters were attempting to reach various levels of classification that indicate their individual proficiency. Before shooting, a range officer asked the shooter if he or she was ready, heightening anticipation. A buzzer then sounded to begin each string, which may have accentuated the arousal. The classifier involved several types of personal protective shooting events with single and multiple targets, testing several tactical skill components. The event consisted of 3 main stages, divided into a total of 14 separate "strings" of tasks, requiring 90 rounds to be fired. Short breaks, long enough to change magazines, holster the weapon, and position the shooter, occurred between strings and were not included in the timing of the event for match score calculation.

The dependent variables were measures of marksmanship and measures of autonomic response as determined by HRV. During each string, "raw time" for completion of each string was recorded. Shooting accuracy was judged by shot placements outside a central target area receiving "points down" (PDs). A total calculated match score was determined by adding PD/2 to the raw time in seconds; thus, lower values indicated better performance. This final IDPA match score was used as the primary measure of shooting performance. Raw time and PD were also used as separate measures of performance. Heart rate variability measurements were made and calculated according to standards set forth by the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (20). The average interbeat interval (IBI), or milliseconds between heart beats, the *SD* of the normal R-R intervals (SDNN), and root mean square of successive differences between adjacent normal R-R intervals (RMSSD) were the time-domain measures examined. The frequency-domain measures consisted of low-frequency (LF) power component, HF power, LF/HF ratio, and total power (TP).

Subjects

Subject selection was limited to adults, aged 18–60 years, free from pathological conditions, medications that affect cardiac function, and tobacco smoking. Additional exclusion criteria were a reported diagnosis of posttraumatic stress disorder, or pregnancy for females. Subjects were limited to members of IDPA and individuals who had been previously trained in firearms proficiency by law enforcement, any branch of the military, or a professional training organization. The university's Institutional Review Board approved the study. Subjects were recruited by a mass e-mail to IDPA members and in person at the scheduled classification matches. After passing a screening questionnaire, qualifying individuals were informed of the nature, purpose, and potential risks/benefits of the study. Those choosing to participate provided written informed consent. A total of 28 subjects (37 ± 11 years, 180 ± 7 cm, and 90.6 ± 16.9 kg) volunteered and completed the study. Although participants could be of either sex, only 1 female participated, owing to the low number of females in the sport. One additional subject was disqualified by the range officer during the shooting competition, and his data collection was not completed.

Procedures

In this study, all participants used semiautomatic pistols of 9 mm, 0.40 or 0.45 caliber (the primary type of weapon in such matches). The shooting task was completed indoors at the Norfolk County Rifle Range, Chesapeake, VA. With the exception of stage 1 string 5, the pistol was placed securely in a side holster and the hands were relaxed at the side in a casual manner. Once the shooter was positioned at the starting point, the shooter then indicated that he or she was ready to begin the string of fire by nodding or verbally responding. Within a second or two, a loud starting buzzer sounded and an automated electronic timer began. At the sound of the buzzer, the shooter drew his or her pistol and engaged the targets according to the CoF until the string was complete. During each string, the timer registered each shot and displayed the total time to the last shot fired.

The first stage occurred at a distance of 7 yd (6.4 m). String 1 involved drawing the handgun from a holster and engaging a first target (T1) with 2 shots to the body and 1 to the head. String 2 involved drawing and engaging a second target (T2) with 2 shots to the body and 1 to the head. String 3 involved drawing and engaging a third target (T3) with 2 shots to the body and 1 to the head. String 4 involved drawing and firing 2 shots at the head of each previously engaged target (T1-T3). During string 5, shooters started with the gun in their "weak hand" pointed down range at 45°; at the signal, they fired 1 shot at each target. During string 6, 2 magazines were loaded with only 3 rounds each. Shooters started with their backs to the targets. At signal, they turned, drew, and fired 1 shot at each target. They then reloaded from slide lock and fired 1 shot at each target. During the final string of the stage, subjects used their "strong hand" only to draw and fire 2 shots at each target.

During stage 2, all targets were placed 10 yd (9.1 m) from the subject. In string 1, shooters drew and advanced toward the 3 targets. They fired 2 shots at each while moving forward and before reaching a fault line 5 yd (4.6 m) from the targets. String 2 involved the shooters drawing at the 5-yd line and retreating from the targets. While on the move, they fired 2 shots at each target. During string 3, 2 magazines were loaded with 6 rounds each. Starting with their back to the targets, shooters turned, drew, and fired 2 shots at each target. They then performed a reload from slide lock and fired 2 more shots at each target.

In stage 3, 3 targets were placed 20 yd (18.3 m) away from a door-shaped vertical barricade. A 55-gallon (208 L) barrel was located 15 yd (13.7 m) from the targets. In string 1, the shooters drew and fired 2 shots at each target from 1 side of the vertical barricade. They then completed a tactical reload and fired 2 shots at each target from the other side of the barricade. A tactical reload consists of exchanging the partially loaded magazine in the firearm with a fresh magazine and storing the partially loaded magazine in a pocket or pouch. In string 2, the shooters drew and fired 2 shots at each target from 1 side of the barricade, performed a tactical reload, and advanced to the second position (15 yd from targets) behind the 55-gallon barrel. From there, the shooters kneeled and fired another 2 shots at each target. During string 3, from a standing position, the shooters drew, kneeled, and fired 2 shots at each target from either side of the barrel.

The IDPA scoring system is based on a combination of accuracy and speed of completion. The match score is calculated by adding one-half second of time to the shooters' raw time for each PD incurred on the target due to poor accuracy. Three seconds are added for procedural penalties like failure to maintain cover (at least 50% of the upper body and 100% of the lower body must be hidden from the target on stages that require cover) or failure to follow CoF guidelines or procedures. The official target (Figure 1) is an 18 × 30 in (45.7 × 76.2 cm) cardboard silhouette structure with a circular 8 in (20.3 cm) center of mass "A-Zone." Each target is marked with a number of "points down" for each shot location. Headshots and center of mass shots result in no PDs. The zone immediately outside the A-Zone is 1 PD. The zone outside that is 3 PDs. Failure to hit a target results in 5 PDs.

Within half an hour of their scheduled shoot time, subjects were prepared for HRV analysis by using an alcohol pad to clean and exfoliate the area from the xiphoid process to the anterior axillary line. After ensuring the skin was dry, an UltraTrace (MVAP Medical Supplies, Newbury Park, CA, USA) electrode was placed at the inferior aspect of the sternum and another was placed 4.25 in (10.8 cm) away, near the subject's left anterior axillary line. Subject preparation was completed a minimum of 20 minutes before competition. This was performed to help depreciate any effects of potential preparation-derived cognitive excitement or priming. To measure HRV, the Actiwave Cardio (CamNtech Ltd., Boerne, TX, USA), a single channel ECG waveform recorder, was worn. This system is an approved Class 2a medical device according to the Medical Device Directive 93/42/EEC and is also cleared by the United States Food and Drug Administration (510(k) K100266), which means its performance and validity have been independently analyzed. For each subject, a few minutes before stage 1 of the classifier, the Actiwave Cardio was set up by entering the subject's ID number, setting the frequency to 1,024 Hz and resolution to 10 bits. Once ready, the Actiwave Cardio was attached to the electrodes and remained on for the duration of the shooting classifier.

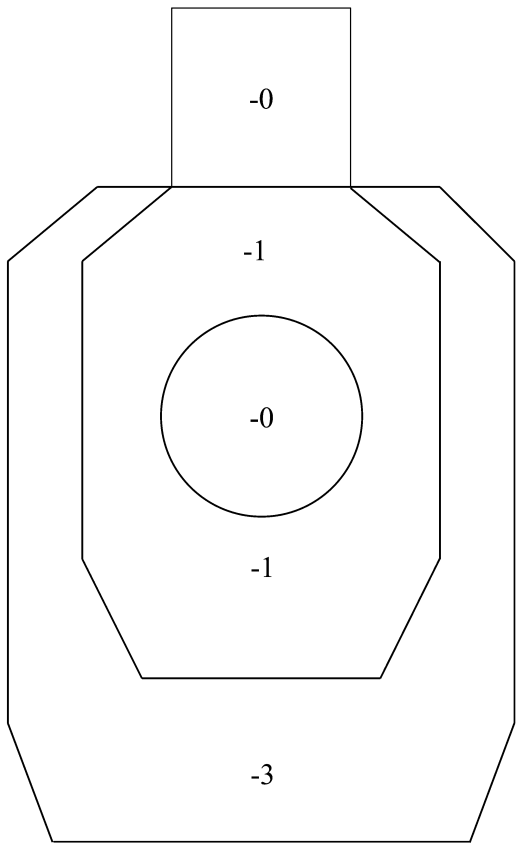

Figure 1. Diagram of shooting target showing scoring zones.

Table 1. Heart rate variability (mean ± *SD*).*

	Rest	Shooting
IBI†	0.926 ± 0.134	0.597 ± 0.087
SDNN	0.073 ± 0.042	0.071 ± 0.032
RMSSD	0.057 ± 0.047	0.046 ± 0.054
HF	360.0 ± 560.9	220.2 ± 438.9
LF‡	1,648.6 ± 1,988.2	616.6 ± 755.3
LF/HF	9.7 ± 9.9	6.3 ± 4.1
TP§	2,393.5 ± 2,836.7	1,232.8 ± 1,450.8

*IBI = interbeat interval; HF = high frequency; LF = low frequency; TP = total power.
†Significant difference between rest and shooting ($p \leq 0.05$, dependent *t*-test).
‡Significant difference between rest and shooting ($p \leq 0.05$, Wilcoxon signed rank test).
§Trend ($p < 0.10$, Wilcoxon signed rank test).

After completion of the IDPA classifier, subjects signed up for a day and time to collect resting HRV measurements. On that day, they reported to the university's Human Performance Laboratory. There, the subjects were prepared and fitted with the Actiwave in the same manner as during the shooting task. They were escorted to a quiet, dimmed room and asked to lie supine on a padded athletic training table. The subjects were instructed to perform metronomic breathing at a rate of 6 breaths per minute (4-second inhalation and 6-second exhalation). The initiation of the breathing cycle was timed with an audio recording of 2 different piano tones. A higher pitched tone indicated the start of the inhalation, whereas the lower pitched tone indicated the exhalation. Subjects were monitored for 2 cycles to ensure accuracy. The researcher then instructed the subjects to relax, close their eyes, and concentrate on the breathing rhythm. This was performed to minimize visual and cognitive distractions. The subject was then left alone and undisturbed in the room for 10 minutes. The first 5 minutes were considered an acclimation period and the last 5 minutes were isolated for analysis.

For the shooting task, ECG data were isolated from 5 seconds before inquisition of the shooter being ready to 5 seconds after the final shot was fired on each stage. Data collected during the 3 stages were used to determine an average data point for each HRV measure (LF, HF, etc.) over the course of each stage for each subject. Because data collection was continuous throughout any given stage, brief breaks between the individual strings of firing were part of the "shooting" data. During these breaks, which lasted only a few seconds each, subjects would reload their magazines and reset for the next string. It was assumed that the arousal experienced during the competition would not be appreciably diminished during these brief breaks. The HRV values from the 3 stages were averaged to determine a single data point for each subject who entered statistical analysis. As a post hoc analysis, the data points from each subject were recalculated using a time-weighted average from the 3 stages as opposed to a simple arithmetic average from the 3 stages. This had no effect on the results, and data from the original analysis are reported here.

The European Data Format (EDF+) file from each subject was analyzed with Actiwave Cardio analysis software version 3.0.8 (CamNtech Ltd, TX, USA). This software calculates time- and frequency-domain HRV variables in accordance with standards set forth by the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (20). Heart rate variability statistics of IBI, SDNN, RMSSD, HF, LF, LF/HF, and TP were computed. The change from rest to shooting (rest − shoot = Δ) was also calculated and analyzed.

Statistical Analyses

Data are presented as mean ± *SD* except where noted. Time-domain HRV measurements were normally distributed; however, frequency-domain HRV measures were not normally distributed and required nonparametric analysis. Paired sample statistics (T-Test for time-domain measures

TABLE 2. Shooting performance correlations.*

	Raw time		Points down		Match score	
	r	*p*	*r*	*p*	*r*	*p*
Resting LF	0.187	0.342	0.341	0.076	0.294	0.128
Resting HF	0.207	0.289	0.351	0.067	0.270	0.165
Resting TP	0.133	0.500	0.363	0.058	0.247	0.205
Shooting IBI	0.404	0.033	0.183	0.351	0.420	0.026
ΔIBI	−0.426	0.024	−0.212	0.279	−0.458	0.014
ΔLF	0.278	0.152	0.376	0.049	0.377	0.048
ΔHF	0.468	0.012	0.346	0.072	0.467	0.012
ΔTP	0.392	0.039	0.416	0.028	0.451	0.016

*LF = low frequency; HF = high frequency; TP = total power; IBI = interbeat interval.

and Wilcoxon signed rank test for frequency-domain measures) were used to determine if HRV variables differed between rest and shooting. All active, resting, and ΔHRV measures were analyzed individually for correlations to raw time, PDs, and the calculated final match score. Relationships between shooting performance and shooting IBI and ΔIBI were examined using Pearson's product-moment correlation, whereas relationships between shooting performance and frequency-domain variables were examined using Spearman's rank-order correlation. The alpha level for significance for all bivariate 2-tailed correlations was set at $p \leq 0.05$. To explain the variance in shooting performance, a stepwise linear regression was used.

RESULTS

Mean ($\pm SD$) raw time (135.9 ± 34.1 seconds) was combined with one-half of PDs (78 ± 4) to calculate match score (175.3 ± 39.8). As a result of the match, 4 subjects (14.3%) were classified as novice, 16 as marksman (57.1%), 6 as sharpshooter (21.4%), and 2 as expert (7.1%). Heart rate variability variables measured at rest and during shooting are reported in Table 1. Shooting IBI was significantly less than resting IBI ($p < 0.001$), reflecting an increase in heart rate during the shooting task. There was a significant decrease in LF from rest to shooting ($p = 0.017$), and there was a trend for a decrease in TP from rest to shooting ($p = 0.073$). No other HRV measures differed between rest and shooting.

Correlations between shooting performance and (1) HRV measures during rest, (2) HRV measures during shooting, (3) and the change in HRV measures from rest to shooting (Δ) are reported in Table 2. No resting HRV measure was significantly correlated to raw time. Resting LF, HF, and TP showed trends ($p < 0.10$) with inaccuracy (PDs). Shooting IBI exhibited a significant positive correlation to raw time and to match score. No other HRV measures during shooting correlated with performance, whereas several Δ measures (rest − shooting) did. ΔIBI was negatively correlated to raw time, whereas ΔHF and ΔTP exhibited positive correlations. ΔLF and ΔTP were positively correlated to inaccuracy and ΔHF displayed a trend. ΔIBI, ΔLF, ΔHF, and ΔTP were all significantly correlated to match score.

To explain the variance in shooting performance, a stepwise multiple regression analysis was used to determine what HRV measures best predicted the raw time. The results of the regression indicated that 2 HRV measures, ΔIBI and ΔRMSSD, explained 33.8% of the variance (adjusted $R^2 = 0.338$, $F_{2,25} = 7.88$, $p = 0.002$). Individually, ΔIBI significantly predicted the raw shooting time (standardized $\beta = -0.650$, $p = 0.001$), as did ΔRMSSD (standardized $\beta = 0.506$, $p = 0.008$). The same regression method was implemented to determine the best predictors for the match score. The resulting stepwise regression found that 34.6% of the adjusted variance in match score was explained by 2 variables, ΔIBI and ΔLF (adjusted $R^2 = 0.346$, $F_{2,25} = 8.192$, $p = 0.002$). Individually, ΔIBI (standardized $\beta = -0.582$, $p = 0.002$) and ΔLF (standardized $\beta = 0.447$, $p = 0.012$) significantly predicted the match score.

DISCUSSION

Interbeat interval and LF were the only HRV measurements to be significantly changed by the act of shooting. The reduction in LF power and IBI can be attributed to sympathetic activation that resulted from the mental stress and physical exertion of the shooting task. Total power exhibited a trend similar to IBI and LF, and perhaps with a larger subject population would prove to be significantly different and indicative of a generalized ANS response and allocation of functional resources. From rest to shooting, subjects who experienced greater ANS disturbance, as measured by greater changes in frequency-domain HRV measures, performed worse during the shooting classifier. This held true for raw time (ΔHF, ΔTP), inaccuracy (ΔLF, ΔTP), and calculated match scores (ΔLF, ΔHF, ΔTP). For all cases, less reduction was associated with better shooting performance. Greater disturbances to the resting HRV result in a loss of autonomic functional resources. These perturbations elicit a larger distribution of HRV fractional energy, causing a greater reduction in the frequency-domain measures. Pertaining to tactical shooting, minimal ANS alteration, as measured by reductions in HRV, is necessary to perform at a superior level.

ΔIBI inversely correlated with raw match time and the calculated match score. This indicated that those individuals who had less of a change in their IBI had higher scores, and thus did not shoot, as well as their counterparts who incurred a greater change in their heart rate. Similarly, the shooting IBI positively correlated with raw and calculated shooting scores. The 2 previous findings can be explained by examining the nature of the intervention. Better shooting performance is associated with a lower point value. This is achieved by being fast and accurate. Faster completion requires more biomechanical and physiological work, and therefore requires a greater cardiac output, thus explaining the association of higher shooting performance with an increased reduction in IBI (i.e., a greater increase in heart rate, given that IBI is the inverse of heart rate). Along the same line, those who completed the course slower, and had poorer scores, did not move as fast and thus did not incur as great of a change in IBI. The subjects who had lower IBI values (higher heart rates) and performed better during the shooting task also had less ANS sympathetic activation as measured by changes in frequency-domain HRV. Although the rate of SA node depolarization increased, their ANS functional resources (HRV) were less affected, and they were cognitively less stressed by the shooting task.

These findings argue for a strong psychophysiological influence in controlling perception and reaction to the stress response, regardless of impact on cardiac cycle rate. This conclusion is in concordance with Taylor et al. (21) who compared elite and nonelite military performance during SERE School. They found that, regardless of similar physiological cortisol responses, superior performance was associated with less perceived stress and a greater parasympathetic dominant heart rate. They too concluded that the performance differences were justified by the ability to selectively adapt to high-stress situations and potential ability to blunt the sympathetic response. The ΔIBI does not translate to a sense of psychological stress and thus a shift toward sympathetic dominance. This once again indicates the possible potential of high-performing shooters to attenuate the parasympathetic withdrawal and sympathetic excitation regardless of a reduction in IBI due to an increased cardiac output from physical work.

The resting time- and frequency-domain HRV measures did not prove to be significantly correlated to shooting performance, as measured by the raw and calculated match scores. However, resting LF, HF, and TP exhibited several strong trends toward significance with inaccuracy, as measured by the PDs scoring system. In a larger subject population, they would potentially prove to be statistically significant. Higher resting autonomic tone values provide a larger range for change to occur and perhaps a greater HRV range to be altered by a stress response. Therefore, those individuals with lower resting values have less HRV to be affected, incurred less of a sympathetic response from the task, and performed better. Along with the trends of higher resting frequency-domain HRV measures being related to inaccuracy, these findings are similar to those of Morgan et al. (15). They found that, in SERE School and the Navy's CDQC, a lower "resting" HF was associated with improved performance (15). However, Morgan took HRV measurements during classroom education before the intervention. The heightened cognitive activity may have been the cause of the association with low HRV. Similarly, Hansen et al. (8) also found that lower HRV was associated with better performance while under duress. The threat of shock caused their low HRV subjects to improve their accuracy and mean reaction time to 2 cognitive function tests. The working memory and action planning tests results were unaffected by the threat of shock in high HRV subject. Once again, this argues the presence of a HRV capacity-effect relationship. In both cases, subjects who had less of a maximum ceiling to be affected by the perception of stress performed better at tasks in which high HRV individuals may have experienced a larger change. In this study, the greatest decreases in HRV, from rest to active condition, have been demonstrated to be associated with inferior performance. This idea of a beneficial low HRV is contrary to the findings by Saus et al. (19). From testing 40 first-year students at the Norwegian Police University College, they found that higher resting HRV was associated with improved performance during a situational awareness shooting simulator (19). However, they were examining the effectiveness of a training protocol and grouped subjects based on this criterion.

Heart rate and HRV significantly affect shooting performance, but in different facets. Changes in HR, measured as IBI, are a result of increased physical activity. Greater ΔIBI is correlated to superior shooting performance because of the increased speed of task completion. An elevated cardiac output is required for controlling fine and gross motor coordination, ocular perception, cognitive analysis of biomechanical considerations, and other factors that alter shooting skill and performance. However, this change in IBI does not necessarily alter HRV, specifically frequency-domain measurements, and is therefore not an indicator of the stress response. Heart rate variability analysis during competitive shooting can be used to identify the stress response of competitors. Less reduction to the resting HRV profile is significantly correlated to superior shooting performance (accuracy and speed to completion) during a tactical pistol competition classifier.

When combined with previous literature, this study helps support the important role of autonomic tone in military/tactical task performance and further validates the use of

HRV as a noninvasive method for assessing such tone. In this study, the individuals who incurred smaller reductions in resting HRV performed better during a competitive pistol shooting classifier. In 2 previous studies (8,15), it was concluded that a lower resting HRV is associated with improved performance while under duress. Physiologically, those with greater parasympathetic dominance at rest (higher HRV) have much larger magnitudes of potential autonomic tone change to occur during a sympathetic response, and therefore performance can be affected to a greater extent. Conversely, an individual with a higher resting sympathetic tone has less of an initial maximum to diminish and incurs less of a change in autonomic tone when a stressed task is confronted. When normally operating at an elevated sympathetic level, the additional psychological stress exerts minimal influence. Some elite performing individuals may even display a shift to or enhanced increase in parasympathetic activation during a stressed psychomotor task, such as marksmanship, attributable to psychophysiological factors such as cognitive automation, superior executive function efficiency under duress, and other selective stress response mechanisms (4).

Practical Applications

The psychological aspects of tactical and sport performance can be among the most difficult to train, master, and assess. Stress significantly disrupts the behavior of many components essential to maintaining optimal function (2,3,11,20,22,23). Although there are many methods for assessing physiological function, few objective psychophysiological metrics are commonly implemented in testing and conditioning paradigms. The use of HRV, as an objective, robust, and noninvasive method for assessing autonomic response, may be beneficial to tactical operators, sport athletes, and their facilitators. In our study, changes in HRV, specifically minimal increases in sympathetic tone or maintenance of total autonomic power and parasympathetic tone, were significant markers of superior shooting performance. Because of the grand effects of sympathetic response on systemic function and control, we believe this HRV relationship may extend to most marksmanship applications. From a cognitive neuroscience position, the psychomotor task of shooting is similar to other tactical and sports movements, such as hand-to-hand combat, shooting a basketball, and putting a golf ball. This gives credence to the potential of using HRV as a significant marker in performance on other cognitive and psychomotor tasks. As such, tactical and athletic facilitators should consider using this method, potentially combined with subjective psychometric questionnaires, to completely characterize the psychophysiological profile, its response to stress, and predict field performance (9,10,27).

Assessing resting HRV measures and their change in response to a standardized task may aid in identifying the dichotomy between operators and athletes who have superior control over their stress response and those that need potential intervention. This could be used to track and index development or as criteria for selection and predicting performance (6,26). In healthy college-aged students, Thompson et al. (24) found resting HRV and maximal oxygen consumption to be independent of one another. This indicates that several potential special operations candidates may have similar maximum work capacities but varying resting HRV indices, and thus although they may be able to handle similar physical workloads, their stress responses could completely vary and condition for different event outcomes. The effect of an excessive sympathetic response is detrimental to cognitive and psychomotor tasks, such as shooting performance. Repetitive exposure to this constant strain can develop a stress inoculation effect, rendering less of a sympathetic response to similar stimuli. Assessment of an athlete's or operator's pre- and postintervention can assist in identifying just how effective and beneficial specific approaches are with respect to improving performance under duress (19). Heart rate variability can index conditioning of the autonomic response, and thus aid in the development of interventions by objectively quantifying their effectiveness at maintaining parasympathetic tone and total autonomic power.

Heart rate variability might also be used to examine team cohesion and environment (adaptive vs. maladaptive), 2 other aspects vital to military and sports performance (6,10,14,26). In 1 study, 4-man fire teams performed better with individuals that had similar HRV responses (6). Assessing the psychophysiological interactions and compliance among team members may aid in predicting performance to improve selection that benefits task requirements. A facilitator would look to pair those whose autonomic tones respond similarly to a given task and identify among which teams parasympathetic tone and autonomic power were most maintained under duress. Heart rate variability can be, and has been, used as a means of biofeedback (12,17). Informing operators or athletes of their autonomic profile might help provide kinesthetic mindful awareness and understanding of the connection between a specific psychological state and the associated physiological performance.

Combat and athletics create physically and mentally demanding conditions that have been shown to alter and condition the ANS (8,11,19,21). The results from this study advocate the implementation of HRV analysis in high-stress occupations where psychomotor performance is vital, such as the armed forces, police officers, firefighters, and professional athletics. Practically, HRV can serve as a quantitative measure of the sympathetic response, or lack thereof, and because of its association with cognitive control should thus be incorporated in most facets of training and testing. Future studies should also expand assessments to include other relative and validated psychophysiological measures, such as mindfulness, mental toughness, anxiety, cognitive workload, flow state, and personality type. Such studies should aim to increase external validity with the targeted application. This study was conducted based on the availability of subjects, equipment, and testing facility. The CoF was already being routinely conducting at a local range and HRV could easily be tested in volunteer subjects.

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