



## Exploring Field-Expedient Readiness Monitoring in a Tactical Athlete: Relationships Among HRV, Resting Heart Rate, Grip Strength, and Sleep

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### ABSTRACT

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**Background:** Tactical athletes may require practical readiness-monitoring methods when direct heart rate variability (HRV) assessment is unavailable or operationally impractical. This retrospective observational exploratory pilot study examined daily relationships among autonomic, cardiovascular, sleep, and neuromuscular measures and explored whether grip strength or resting heart rate (RHR) warrant further investigation as field-expedient adjuncts to HRV.

**Materials and methods:** One adult male tactical athlete completed 22 consecutive days of monitoring. HRV, RHR, sleep duration, and proprietary Sleep Score were obtained using a Garmin fenix 8 smartwatch, while dominant-hand isometric grip strength was measured using digital dynamometry. Relationships were evaluated using Pearson correlations, Spearman sensitivity analyses, and Benjamini-Hochberg false discovery rate correction.

**Results:** Grip strength demonstrated a strong positive association with HRV ( $r = .674$ ;  $p = .690$ ), while RHR demonstrated strong inverse associations with HRV ( $r = -.655$ ;  $p = -.629$ ) and grip strength ( $r = -.711$ ;  $p = -.754$ ). Sleep Score demonstrated a strong positive association with HRV ( $r = .624$ ;  $p = .682$ ). Its association with grip strength was moderate and nonsignificant using Pearson correlation ( $r = .404$ ) but significant using Spearman sensitivity analysis ( $p = .531$ ). Sleep duration demonstrated negligible relationships with HRV, RHR, and grip strength.

**Conclusion:** These preliminary within-participant findings support further investigation of RHR and grip strength as complementary field-expedient measures when HRV monitoring is unavailable. Larger studies incorporating independent performance and readiness criteria are required before substitution or readiness-monitoring validity can be established.

### KEYWORDS:

Physical Readiness, Exercise Physiology, Military, First Responder, Physical Training

### INTRODUCTION

Tactical athletes, such as military, law enforcement, fire, and emergency medicine personnel, operate in environments characterized by overlapping physical, psychological, occupational, and sleep-related demands that may affect their capacity to perform required tasks. Unlike conventional sport, in which training and competition can often be planned around structured recovery periods, military and other tactical personnel may be required to maintain

physical and cognitive readiness despite irregular schedules, sleep restriction, sustained workload, and other operational stressors. Research conducted in military populations has demonstrated that sleep, fatigue, and recovery can fluctuate substantially during demanding training and operational conditions, while sleep-related characteristics have also been associated with physical readiness and performance (1,2). One study reportedly found an average sleep duration of approximately 6.3 hours across a 12-week iteration of basic military training and that combined sleep measures better explained perceived stress, recovery, and fatigue than individual measures alone (1). Similarly, another study found that sleep-related characteristics, including daytime sleepiness, contributed to physical-performance differences during simulated military operational stress (2). These findings support a broader view of readiness as a

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multidimensional and dynamic state rather than a single physiological characteristic. Viewing readiness through this lens while considering the operational challenges faced by tactical athletes aids in understanding their respective training readiness in the physical readiness domain.

Heart rate variability has been utilized as a noninvasive physiological measure of autonomic recovery and readiness to inform subsequent training decisions. HRV represents variation in the intervals between successive heartbeats and provides information regarding autonomic cardiac modulation (3,4,5). This application extends to tactical populations, where HRV has been investigated in relation to occupational performance, physical fitness, physiological stress, training, and recovery (6). HRV-guided approaches emphasize repeated measurements interpreted relative to an athlete's individual baseline, allowing acute changes in autonomic recovery to contribute to decisions regarding training intensity and load (3,6,7). Acute recovery has been distinguished from longer-term training adaptation, supporting frequent HRV monitoring and longitudinal trends for load management, performance readiness, and recovery strategies (8). However, HRV responses do not uniformly correspond with all dimensions of physical performance or recovery, and findings across athletic populations support its interpretation as one component of a broader readiness assessment rather than a definitive standalone measure (9-13).

Resting heart rate (RHR) provides an additional cardiovascular measure that may complement HRV in monitoring physiological status. RHR and HRV are both influenced by autonomic regulation but may provide different temporal information, with HRV demonstrating greater sensitivity to acute autonomic changes and RHR potentially reflecting slower changes associated with cardiovascular fitness, cumulative stress, and recovery (14). Both measures have consequently been incorporated into athlete-monitoring and commercial readiness frameworks, particularly when collected under standardized conditions and interpreted longitudinally relative to the individual (13,14). Considered together, HRV and RHR therefore provide readily obtainable, complementary cardiovascular measures that may contribute to a multidimensional assessment of training readiness and recovery rather than functioning as independent determinants of readiness.

The utility of physiological monitoring for strength and conditioning professionals, however, is dependent upon the feasibility of obtaining these measures repeatedly in applied environments. Traditional electrocardiography provides criterion measurement of cardiac activity but requires equipment, expertise, and controlled conditions that limit its practicality for routine field-based monitoring (8). Mobile and wearable technologies provide an increasingly practical alternative by enabling repeated collection of cardiovascular measures with minimal disruption to training.

Mobile devices were found to be appropriate for resting HRV monitoring when used under suitable conditions and emphasized that their practical value extends beyond isolated measurements to frequent assessment of intra-individual physiological trends (8). Similarly, one research group identified HRV as a noninvasive and readily repeatable measure applicable to strength and conditioning settings (7), while other researchers described wearable and mobile technologies as practical tools for longitudinal recovery management and training-load adjustment (3).

Wearable accessibility does not eliminate the need for standardized measurement or appropriate interpretation. Device accuracy varies according to sensor technology, acquisition conditions, and manufacturer methodology (14,15), with photoplethysmography-based measures particularly susceptible to reduced accuracy during and immediately following exercise (8). Accordingly, wearable-derived HRV and RHR are most appropriately utilized for standardized, repeated within-individual monitoring rather than interpreted as interchangeable with clinical electrocardiography or as isolated diagnostic measurements. This approach prioritizes longitudinal changes relative to an athlete's own physiological state, which is an application of factors that emphasized intra-individual trends over comparisons with other athletes (8). While HRV and RHR provide practical cardiovascular indicators of recovery and readiness, their autonomic origins may not fully represent neuromuscular recovery or physical performance capacity. This limitation supports consideration of an additional field-expedient measure capable of assessing a different physiological domain, such as isometric grip strength.

Isometric handgrip strength represents a potential field-expedient adjunct to cardiovascular measures because it can be rapidly assessed using portable equipment while providing information related to physical function. Relative handgrip strength was associated with favorable cardiovascular-health biomarkers (16), while autonomic reactivity differences were identified when compared to recovery based upon relative grip strength (17). Similarly, relationships were demonstrated between handgrip strength, lean mass, vertical-jump performance, and aerobic fitness when normalized to body mass (18). More direct relationships between grip strength and autonomic function have also been observed, with positive relationships identified between HRV and muscle strength (5) and associations reported between grip strength and multiple HRV indices (19). However, these findings were derived primarily from civilian and clinical populations, limiting their direct application to tactical athletes. Within a military population, it was found that only a weak relationship between grip strength and upper-body power among U.S. Marines, further supporting the consideration of grip strength as a complementary measure rather than an independent representation of physical readiness (20).

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Sleep provides an additional consideration because variation in sleep and recovery may influence both physiological and physical readiness measures. One research group demonstrated that within-person deviations from habitual sleep duration were associated with next-day mood, motivation, and sleepiness, supporting individualized interpretation of sleep behavior (21). Relationships between sleep and grip strength have also been observed across multiple populations, including associations with sleep duration (22,23) and subjective sleep quality (24). Additionally, research demonstrated changes in grip strength following a short-term recovery intervention, further supporting the potential influence of recovery state on neuromuscular performance (25). Collectively, these findings support the inclusion of sleep as contextual information when examining physiological and neuromuscular measures of readiness and recovery.

Despite growing support for multidimensional athlete monitoring, relationships among HRV, RHR, sleep, and grip strength remain incompletely characterized within tactical athletes, particularly through repeated within-person assessment. Existing research has examined these measures across tactical personnel, competitive athletes, healthy civilians, and clinical populations, but has provided limited evidence regarding their combined longitudinal behavior within an individual tactical athlete. Accordingly, the purpose of this exploratory pilot study was to examine daily within-participant relationships among wearable-derived HRV, RHR, sleep duration, proprietary Sleep Score, and dominant-hand isometric grip strength across 22 consecutive days. Particular emphasis was placed on whether grip strength and raw daily RHR demonstrated consistent associations with HRV sufficient to warrant further investigation as field-expedient adjuncts, rather than replacements, for physiological readiness and recovery monitoring.

### RESEARCH QUESTIONS & HYPOTHESIS STRUCTURE

This investigation was guided by the following research questions (RQs) and associated hypotheses (Hs) and null hypotheses (H0s); each Hypotheses and Null Hypotheses were tested at the  $\alpha = .05$  threshold.

**RQ1:** To what extent are daily HRV and resting heart rate associated with average isometric grip strength in a tactical athlete?

**H1a:** Daily HRV is significantly associated with average isometric grip strength.

**H01a:** Daily HRV is not significantly associated with average isometric grip strength.

**H1b:** Daily resting heart rate is significantly associated with average isometric grip strength.

**H01b:** Daily resting heart rate is not significantly associated with average isometric grip strength.

**RQ2:** To what extent are daily sleep duration and wearable-derived Sleep Score associated with HRV, resting heart rate, and average isometric grip strength?

**H2a:** Sleep Score is significantly associated with HRV.

**H02a:** Sleep Score is not significantly associated with HRV.

**H2b:** Sleep Score is significantly associated with resting heart rate.

**H02b:** Sleep Score is not significantly associated with resting heart rate.

**H2c:** Sleep Score is significantly associated with average isometric grip strength.

**H02c:** Sleep Score is not significantly associated with average isometric grip strength.

**H2d:** Sleep duration is significantly associated with HRV.

**H02d:** Sleep duration is not significantly associated with HRV.

**H2e:** Sleep duration is significantly associated with resting heart rate.

**H02e:** Sleep duration is not significantly associated with resting heart rate.

**H2f:** Sleep duration is significantly associated with average isometric grip strength.

**H02f:** Sleep duration is not significantly associated with average isometric grip strength.

### HYPOTHESES

The below listed hypotheses were tested at the  $\alpha = .05$  threshold.

1. There is a statistically significant association between physiological recovery metrics (HRV and resting heart rate) and average isometric grip strength.
2. Sleep duration and sleep quality are significantly associated with one or more physiological or neuromuscular readiness measures.

### NULL HYPOTHESES

The below listed hypotheses were tested at the  $\alpha = .05$  threshold.

1. There is no statistically significant association between physiological recovery metrics (HRV and resting heart rate) and average isometric grip strength.
2. Sleep duration and sleep quality are not significantly associated with HRV, resting heart rate, or average isometric grip strength.

MATERIALS AND METHODS

Study Design

This pilot study employed a quantitative, ex post facto, repeated-measures observational design to examine preliminary associations between wearable-device reported HRV, Sleep Hours, RHR, and sleep quality; as well as dynamometer reported average Isometric Grip Strength of a tactical athlete over 22-days. In this non-experimental design, no manipulation of independent variables or random assignments to control or intervention groups occurred. Instead, the design assessed naturally occurring day-to-day variation in the aforementioned metrics over 22-days using secondary data analysis of voluntarily provided participant data. The intent of the ex post facto study was to explore preliminary associations among readily obtained indicators of training readiness without attempting to establish causal inference or predictive relationships. This pilot study’s findings were intended to evaluate feasibility of incorporating field-expedient measures into routine monitoring of tactical populations. This study involved retrospective collection of data from a single adult male tactical athlete. The dataset consisted of daily measures of sleep and training readiness metrics using commercially available, minimal-risk monitoring devices and standard field-based assessment procedures. Because the study analyzed pre-existing data, involving no intervention or interaction with the participant, and did not include sensitive personal information, it met the criteria for exempt human subjects research. All study data were stored securely and managed in accordance with data security standards.

Participant and Selection Criteria

This pilot study utilized retrospective data from a single adult male tactical athlete ( $N = 1$ ) who was also the author and investigator of the present study. Accordingly, the investigation represents a retrospective single-participant self-study of physiological, sleep, and neuromuscular monitoring data originally collected during routine personal readiness monitoring. The decision to analyze these data for research purposes was made retrospectively following the monitoring period; therefore, data collection was not initiated or prospectively modified to produce predetermined research outcomes.

The dataset was selected for analysis based on the availability of complete daily measurements across 22 consecutive days, including wearable-derived physiological and sleep metrics, as well as daily isometric grip strength

measurements. The participant was healthy enough to perform maximal voluntary grip strength testing and routine physical training throughout the observation period. For the purpose of this study, a tactical athlete was defined as an individual employed in a military occupational role requiring routine participation in occupational physical training and maintenance of mission-related physical readiness.

Eligibility of the retrospective dataset required: (a) an adult participant at least 18 years of age; (b) complete daily recordings of wearable-derived HRV, RHR, sleep duration, and Sleep Score; (c) completion of daily isometric grip-strength assessments using the same hand dynamometer throughout the monitoring period. Exclusion criteria included incomplete daily monitoring records, missing wearable-derived physiological or sleep data, inability to complete grip strength assessments, or the presence of any condition that substantially interfered with routine data collection during the observation period. Because this investigation involved retrospective analysis of pre-existing observational data from a single participant, no recruitment procedures, interventions, or experimental manipulation were conducted. Due to the participant and investigator being the same individual, the potential for measurement and investigator-participant bias inherent to a self-study design was considered during the interpretation of the findings.

Participant Dataset Characteristics

The study consisted of retrospective analysis of repeated observations from a single adult male tactical athlete ( $N = 1$ ), who was also the investigator. The participant was 42 years old at the time of data collection and had completed 24 years of military service in tactical occupational roles. pre-existing sleep, physiological, and neuromuscular readiness data were analyzed retrospectively across 22 consecutive observation days. Routine physical training was performed on 12 of the 22 days of observation.

Prior to the observation period, the wearable device had established an individualized HRV baseline range of 27-65 ms based on the participant’s longitudinal measurements. This device-derived range was retained as contextual information and was not treated as a clinical threshold or used to classify autonomic state. For the purposes of this study, a tactical athlete was defined as an individual serving in a military occupational role that required the maintenance of physical readiness and the performance of physically demanding occupational tasks. Table 1 provides full Participant characteristics.

Table 1: Participant Characteristics

| Age | Mil Svc | Sex  | Height | Weight   | BMI                     | Training/Observation Days |
|-----|---------|------|--------|----------|-------------------------|---------------------------|
| 42y | 24y     | Male | 175 cm | 93.89 kg | 30.67 kg/m <sup>2</sup> | 12/22                     |

The analyzed dataset consisted of 22 consecutive days of observations. Daily measures included wearable-device-reported heart rate variability (HRV), resting heart

rate (RHR), sleep duration, and sleep quality, as well as average isometric grip strength measured using a hand dynamometer. Each observation day represented a repeated

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measurement from the same participant rather than an independent participant-level observation. Table 2 provides preliminary descriptive results for these data.

**Table 2: Descriptive Results**

| Variable       | <i>n</i> | Mean      | SD   | Median | Range     |
|----------------|----------|-----------|------|--------|-----------|
| Sleep Score    | 22       | 73.7      | 16.9 | 77.5   | 31-93     |
| Sleep Duration | 22       | 408.5 min | 79.5 | 408.0  | 175-578   |
| Night HRV      | 22       | 39.9 ms   | 11.3 | 39.5   | 18-61     |
| RHR            | 22       | 56.2 bpm  | 3.5  | 57.0   | 50-61     |
| Grip Strength  | 22       | 39.0 kg   | 3.3  | 38.9   | 31.8-45.2 |

Because the study involved a single participant, demographic percentages and between-participant descriptive comparisons were not applicable. Participant characteristics were reported to provide context for interpreting the within-participant findings. Repeated daily observations represent measurements from the same individual and should not be interpreted as independent participant-level observations. The single-participant self-study design substantially limits external validity; therefore, the findings should be interpreted as exploratory, within-person findings and should not be generalized to the broader tactical-athlete populations.

### *Instrumentation and Measures*

The study examined five daily measures obtained from two data sources: a commercially available wearable device and a handgrip dynamometer. Wearable-derived measures included heart rate variability (HRV), resting heart rate (RHR), sleep duration, and sleep quality. Average isometric grip strength was measured using a handgrip dynamometer.

Wearable-derived data were obtained using a Garmin fēnix® 8 smartwatch (Garmin Ltd., Olathe, KS, USA) worn continuously by the participant throughout the 22-day observation period and for a period prior to data collection to establish an individualized HRV baseline. The device recorded HRV, RHR, sleep duration, and a proprietary sleep-quality metric during routine daily use. Daily values were extracted from the Garmin Connect™ application and recorded once per observation day for analysis. Isometric grip strength was measured using a Hichor Blue 108E digital handgrip dynamometer. Grip-strength values were reported in kilograms. The participant sat upright with the back supported, feet flat on the floor, the shoulder relaxed in a neutral position, the elbow flexed to 90°, and the forearm and wrist maintained in a neutral position. The tested arm was unsupported throughout each measurement.

Wearable-derived data were obtained using the participant's Garmin Connect application after the application completed its post sleep cycle sync with the wearable media. heart rate variability was reported as an average of sleep HRV in milliseconds and represented root mean square of successive differences (RMSSD). Resting

heart rate was reported in beats per minute and reflected the participant's device-calculated resting cardiovascular rate. Sleep duration was reported as the total number of hours and minutes classified by the wearable device as sleep during each monitoring period and the sleep quality metric was represented by Garmin's Sleep Score (0–100), a proprietary composite metric incorporating sleep duration, sleep stages, movement, and physiological indicators measured during sleep. Because the complete algorithm was not publicly available, the sleep-quality metric was treated as a device-derived composite measure rather than a direct clinical assessment of sleep quality. Wearable data were retrospectively extracted from Garmin Connect application and entered into the study dataset. Values were recorded once per observation day using the device-generated daily summary. No modifications were made to the wearable-generated values before analysis.

The participant completed three maximal voluntary isometric contractions with his dominant hand during each testing session. Each contraction was maintained for approximately 3-5 seconds, with 30 seconds of rest provided between trials. The daily average isometric grip-strength value was calculated by averaging trials from the dominant hand. Measurements were obtained within approximately 30 minutes of waking each day and, when possible, before strenuous physical activity to reduce variability associated with acute exertion. The same dynamometer and measurement procedures were used throughout the observation period. Device calibration status was verified through standardized pretesting check, when applicable.

The wearable device and handgrip dynamometer provided practical, minimally invasive methods for obtaining repeated daily measures under field conditions. However, wearable-derived HRV, RHR, sleep duration, and sleep-quality estimates were not equivalent to laboratory electrocardiography or polysomnography. The sleep-quality metric was also dependent on a proprietary algorithm and therefore could not be independently reproduced from the available raw data. Similarly, grip-strength measurements may have been influenced by participant effort, testing position, time of day, recent physical activity, hand dominance, and familiarization with the testing procedure.

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Standardized collection procedures were used, when possible, to reduce these sources of measurement variability.

### Statistical Analysis

Descriptive statistics were calculated for all study variables, including the mean, standard deviation (SD), median, minimum, maximum, and range. Continuous variables included wearable-derived heart rate variability (HRV), resting heart rate (RHR), sleep duration, Garmin proprietary Sleep Score, and average dominant-hand isometric grip strength. Time-series plots and scatterplots were visually inspected to identify potential outliers, temporal trends, and gross violations of normality.

Pearson product-moment correlation coefficients ( $r$ ) were calculated to examine linear associations among HRV, RHR, sleep duration, Garmin Sleep Score, and average isometric grip strength. Because of the repeated-measures pilot design, relatively small number of daily observations ( $n = 22$ ), and the possibility of non-normal distributions or influential observations, Spearman rank-order correlations ( $\rho$ ) were also calculated as a nonparametric sensitivity analysis to evaluate the consistency of observed relationships. Correlation strength was interpreted using heuristic guidelines, where coefficients of 0.00–0.19 were considered very weak, 0.20–0.39 weak, 0.40–0.59 moderate, 0.60–0.79 strong, and 0.80–1.00 very strong associations (26).

To account for multiple comparisons, the Benjamini-Hochberg false discovery rate (BH-FDR) procedure was applied separately to the eight Pearson tests and the eight Spearman sensitivity tests corresponding to RQ1 and RQ2. Statistical significance for these comparisons was evaluated using BH-FDR-adjusted  $p$ -values at  $\alpha = .05$ . Due to the pilot investigation being exploratory in nature and consisting of repeated observations obtained from a single participant, emphasis was placed on the magnitude, direction, and consistency of observed associations rather than statistical significance alone. Consequently, correlation

coefficients, adjusted  $p$ -values, and the magnitude and consistency of observed associations were considered collectively when evaluating relationships among readiness measures. Statistical analyses were performed using Microsoft Excel (Microsoft 365). Descriptive Statistics as well as both Pearson and Spearman correlation analysis were independently replicated using JASP (version 0.98.1) to verify the magnitude, direction, and statistical significance of the observed associations.

### RESULTS

Complete data were available across all 22 observation days for HRV, RHR, Sleep Score, sleep duration, and average dominant-hand isometric grip strength. Descriptive characteristics for the observed variables are presented in Table 2. Pearson product-moment correlations were used to examine the magnitude and direction of linear relationships among the daily physiological, sleep, and neuromuscular measures, with Spearman rank-order correlations used as a sensitivity analysis. The primary correlation findings and corresponding significance values are presented in Table 3. Scatterplots were additionally used to visually present the relationships among HRV, RHR, and grip strength across the 22 daily observations (Figures 1–3).

Daily HRV demonstrated a strong positive association with average isometric grip strength ( $r = .674$ , unadjusted  $p < .001$ , BH-FDR-adjusted  $p = .002$ ), while daily RHR demonstrated a strong inverse association with grip strength ( $r = -.711$ , unadjusted  $p < .001$ , BH-FDR-adjusted  $p = .002$ ). Spearman sensitivity analyses showed corresponding associations between HRV and grip strength ( $\rho = .690$ , unadjusted  $p < .001$ , BH-FDR-adjusted  $p = .001$ ) and between RHR and grip strength ( $\rho = -.754$ , unadjusted  $p < .001$ , BH-FDR-adjusted  $p < .001$ ). The distributions of the daily observations and corresponding linear relationships between HRV and grip strength and RHR and grip strength are presented in Figures 1 and 2, respectively.

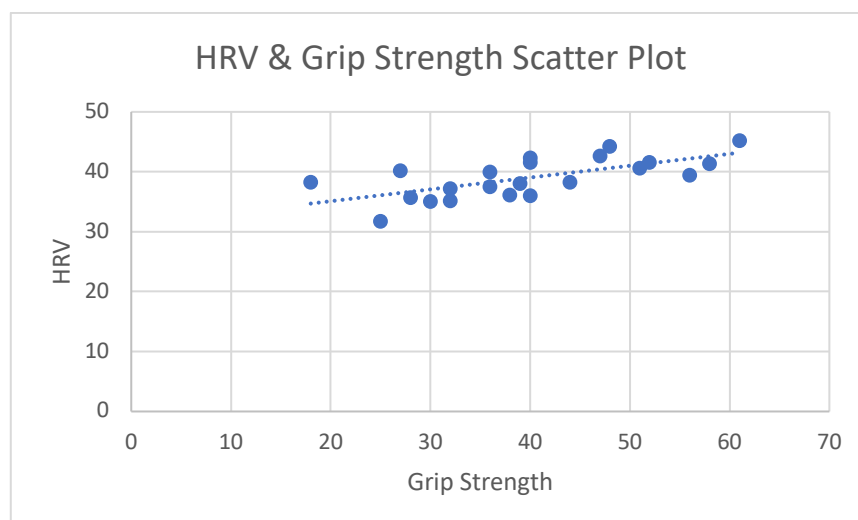
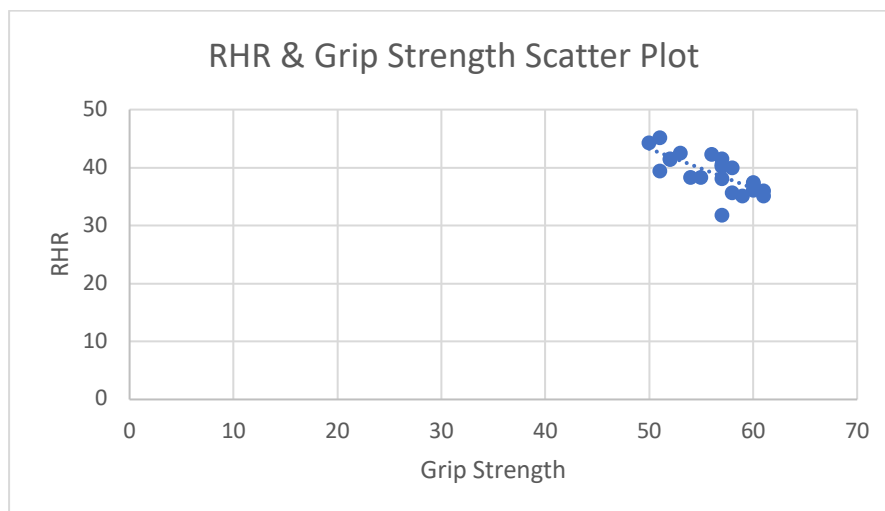


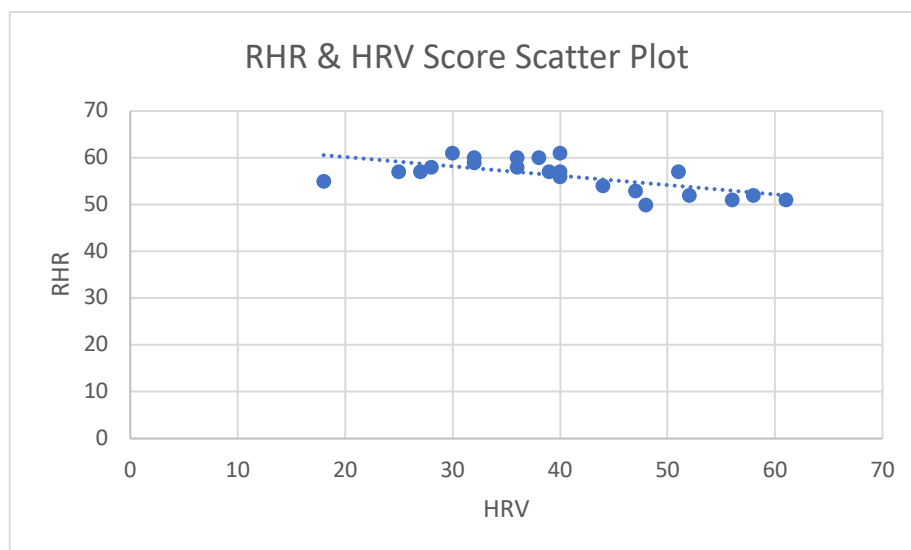
Figure 1. Relationship Between Daily HRV and Average Isometric Grip Strength



**Figure 2. Relationship Between Daily RHR and Average Isometric Grip Strength**

An additional exploratory comparison, outside the eight primary relationships specified under RQ1 and RQ2, identified a strong inverse association between daily HRV and RHR using Pearson ( $r = -.655$ , unadjusted  $p < .001$ ) and

Spearman ( $\rho = -.629$ , unadjusted  $p < .01$ ) correlations. This comparison was not included in the primary BH-FDR correction families. The relationship between HRV and RHR across the 22 daily observations is presented in Figure 3.



**Figure 3. Relationship Between Daily RHR and Daily HRV**

Sleep Score demonstrated a strong positive association with HRV,  $r = .624$ ,  $p = .002$ , which remained statistically significant following FDR correction. Sleep Score demonstrated a moderate positive association with grip strength,  $r = .404$ ,  $p = .062$ , and a weak inverse association with RHR,  $r = -.296$ ,  $p = .182$ ; neither relationship reached statistical significance using Pearson analysis. Spearman sensitivity analysis also demonstrated a strong positive association between Sleep Score and HRV,  $\rho = .682$ . The association between Sleep Score and grip strength was moderate,  $\rho = .531$ ,  $p = .011$ , and remained statistically

significant following FDR correction. The inverse association between Sleep Score and RHR was moderate using Spearman analysis,  $\rho = -.456$ ,  $p = .033$ , but did not remain statistically significant following FDR correction.

Sleep duration demonstrated very weak associations with HRV, RHR, and grip strength using both Pearson and Spearman correlations, with none of the relationships reaching statistical significance. Complete Pearson and Spearman correlation coefficients, unadjusted p-values, and Benjamini-Hochberg FDR-adjusted p-values for the primary comparisons are presented in Table 3.

**Table 3: Association Among Daily Physiological, Sleep, and Neuromuscular Measures.**

| Relationship          | Pearson <i>r</i> | <i>p</i> | BH-FDR <i>p</i> | Spearman $\rho$ | <i>p</i> | BH-FDR <i>p</i> |
|-----------------------|------------------|----------|-----------------|-----------------|----------|-----------------|
| HRV x Grip            | .674             | < .001   | .002            | .690            | < .001   | .001            |
| RHR x Grip            | -.711            | < .001   | .002            | -.754           | < .001   | < .001          |
| Sleep Score x HRV     | .624             | .002     | .005            | .682            | < .001   | .001            |
| Sleep Score x RHR     | -.296            | .182     | .290            | -.456           | .033     | .053            |
| Sleep Score x Grip    | .404             | .062     | .124            | .531            | .011     | .022            |
| Sleep Duration x HRV  | .059             | .794     | .794            | .103            | .648     | .741            |
| Sleep Duration x RHR  | .083             | .713     | .794            | .116            | .607     | .741            |
| Sleep Duration x Grip | -.124            | .582     | .777            | -.047           | .835     | .835            |

**Note.** HRV = heart rate variability; RHR = resting heart rate; Grip = average dominant-hand isometric grip strength; BH-FDR = Benjamini-Hochberg false discovery rate. Each correlation included 22 daily observations from one participant ( $N = 1$ ;  $n = 22$  observation days). Unadjusted *p*-values are two-sided. BH-FDR-adjusted *p*-values were calculated separately across the eight Pearson tests and the eight Spearman tests shown.

## DISCUSSION

The purpose of this exploratory pilot study was to examine within-participant relationships among wearable-derived HRV, RHR, sleep measures, and isometric grip strength across 22 consecutive days in a tactical athlete. The primary findings demonstrated significant relationships between both cardiovascular measures and grip strength, with higher HRV associated with greater grip strength and higher RHR associated with lower grip strength. Sleep Score was also positively associated with HRV, while sleep duration demonstrated no significant association with HRV, RHR, or grip strength. The Spearman sensitivity analysis generally demonstrated similar direction and magnitude to the Pearson findings, although a significant relationship between Sleep Score and grip strength was identified only through the Spearman analysis. These findings should be interpreted as preliminary within-participant associations and not as evidence of causal or predictive relationships.

### *Research Question 1: Associations of RHR and HRV with Grip Strength*

Research Question 1 (RQ1) examined the extent to which daily HRV and RHR were associated with average isometric grip strength. HRV demonstrated a strong positive association with grip strength ( $r = .674$ ,  $p < .001$ ), which remained statistically significant following FDR correction. The Spearman sensitivity analysis demonstrated a similarly strong positive association ( $\rho = .690$ ). Accordingly, H01a was rejected, indicating a statistically significant association between daily HRV and average isometric grip strength within the observed participant.

RHR demonstrated a strong inverse association with average isometric grip strength ( $r = -.711$ ,  $p < .001$ ), which also remained statistically significant following FDR correction. The corresponding Spearman coefficient demonstrated a similarly strong inverse association ( $\rho = -.754$ ). H01b was therefore rejected. Together, the findings addressing RQ1 demonstrated that both cardiovascular measures were significantly associated with grip strength

during the 22-day observation period, with greater grip strength corresponding with higher HRV and lower RHR.

These findings are consistent with portions of the existing literature examining relationships between autonomic function and muscular strength; where greater muscle strength was associated with reduced autonomic reactivity, while a positive relationship between HRV and muscle strength has also been observed (5,17). This further aligns with reported associations between grip strength and multiple HRV indices (19). Although these studies differed from the present investigation in population and methodology, their findings provide context for the positive relationship observed between daily HRV and grip strength. Though it is worth reiterating that it has also been reported that only a weak relationship between grip strength and upper-body power among U.S. Marines (20), demonstrating that relationships involving grip strength may vary according to the physiological or performance variable against which it is compared.

An additional analysis demonstrated a strong inverse association between HRV and RHR ( $r = -.655$ ), with a similarly strong inverse relationship identified through Spearman analysis ( $\rho = -.629$ ). Although the HRV-RHR relationship was not itself a hypothesis specified under RQ1, it provides additional context for the two cardiovascular measures examined in the research question. Across the observation period, higher HRV was associated with lower RHR, while both higher HRV and lower RHR were each associated with greater grip strength. The observed pattern is consistent with the conceptual relationship between HRV and RHR described in previous athlete-monitoring literature, in which both measures are influenced by autonomic cardiovascular regulation but provide distinct physiological measurements (13,14).

### *Research Question 2: Associations of Sleep Score and Duration with RHR, HRV, and Grip Strength*

Research Question 2 (RQ2) examined the extent to which daily sleep duration and wearable-derived Sleep Score were associated with HRV, RHR, and average isometric grip

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strength. The findings differed between the two sleep measures and across the three physiological and neuromuscular variables. Sleep Score demonstrated a strong positive association with HRV ( $r = .624$ ,  $p = .002$ ), which remained statistically significant following FDR correction. The Spearman sensitivity analysis also demonstrated a strong positive association ( $\rho = .682$ ). Accordingly, H02a was rejected, indicating a statistically significant association between wearable-derived Sleep Score and HRV within the participant.

In contrast, Sleep Score demonstrated a weak inverse Pearson association with RHR ( $r = -.296$ ,  $p = .182$ ), which was not statistically significant. Although the Spearman analysis produced a moderate inverse association ( $\rho = -.456$ ,  $p = .033$ ), this relationship did not remain statistically significant following FDR correction. H02b was therefore not rejected. The relationship between Sleep Score and grip strength differed between the primary and sensitivity analyses. Pearson analysis demonstrated a moderate positive association ( $r = .404$ ,  $p = .062$ ) that was not statistically significant before or after FDR correction. Therefore, H02c was not rejected based upon the primary analysis. However, the Spearman sensitivity analysis demonstrated a moderate positive association ( $\rho = .531$ ,  $p = .011$ ) that remained statistically significant following FDR correction. The difference between the Pearson and Spearman findings indicates that evidence for the Sleep Score-grip strength relationship was dependent upon the analytical approach and should therefore be distinguished from relationships that were statistically significant across both analyses.

Sleep duration did not demonstrate statistically significant relationships with any of the three physiological or neuromuscular measures. Associations with HRV ( $r = .059$ ), RHR ( $r = .083$ ), and grip strength ( $r = -.124$ ) were all very weak, with similarly weak relationships observed through Spearman sensitivity analysis. H02d, H02e, and H02f were therefore not rejected. Within the observed participant, sleep duration alone was not significantly associated with HRV, RHR, or average isometric grip strength during the 22-day observation period.

The differing findings for Sleep Score and sleep duration provide context for previous research examining sleep and readiness-related measures; in which it was demonstrated that within-person deviations in sleep duration were associated with next-day mood, motivation, and sleepiness (21), while other researchers found relationships between sleep duration and grip strength in other populations (22,23). The absence of corresponding sleep-duration relationships in the present participant therefore differs from portions of the existing literature. However, differences in population, observation period, and outcome measures limit direct comparison. The stronger relationships observed for Sleep Score than sleep duration are also consistent with research indicating that sleep-related physiological status

may not be represented by duration alone, as combined sleep measures better explained perceived stress, recovery, and fatigue during military training than individual sleep measures (1).

## CONCLUSION

The present exploratory pilot study examined within-participant relationships among HRV, RHR, wearable-derived sleep measures, and isometric grip strength across 22 consecutive days in a tactical athlete. The findings demonstrated strong associations between greater grip strength and both higher HRV and lower RHR, with these relationships remaining statistically significant across Pearson and Spearman analyses and following correction for multiple comparisons. Sleep Score was also strongly associated with HRV, while sleep duration demonstrated very weak and nonsignificant relationships with HRV, RHR, and grip strength. Collectively, these findings demonstrate that the measured physiological and neuromuscular variables covaried across daily observations, although the strength and consistency of these relationships differed among measures.

The relationships between HRV, RHR, and grip strength are particularly relevant to the potential development of multimodal monitoring approaches for tactical athletes. HRV provides information regarding autonomic modulation but requires appropriate measurement capability and is most informative when interpreted longitudinally against an established individual baseline. RHR is readily obtainable from many contemporary wearable devices, while isometric grip strength can be collected independently of wearable technology using portable dynamometry. Within the present participant, both RHR and grip strength demonstrated strong relationships with HRV and with one another in physiologically consistent directions, with higher HRV and lower RHR corresponding with greater grip strength. These findings suggest that HRV, RHR, and grip strength may provide complementary information when incorporated into individualized longitudinal monitoring rather than relying upon a single daily metric.

The observed relationship between HRV and grip strength also raises the possibility that grip strength may have utility when HRV measurement is unavailable or when an individualized HRV baseline has not been established. The present findings do not demonstrate that grip strength is interchangeable with HRV or that one measure can validly predict the other. However, the strong within-participant association between the measures supports further investigation of grip strength as a field-expedient neuromuscular measure when HRV cannot be obtained. Similarly, RHR may provide useful cardiovascular information when HRV is unavailable, particularly because RHR can be obtained by a broader range of wearable devices and can be interpreted longitudinally. Future research should determine whether changes in RHR or grip strength can

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reliably identify physiological states otherwise characterized through HRV and whether combining these measures provides greater information than any individual metric alone.

The sleep findings further suggest that the selection of monitoring variables may be as important as the number of variables collected. Wearable-derived Sleep Score demonstrated a strong relationship with HRV, whereas sleep duration alone demonstrated negligible relationships with HRV, RHR, and grip strength. Sleep Score may therefore contribute additional information within a multimodal monitoring approach, but its interpretation requires caution because it is a proprietary composite derived from multiple sleep and physiological inputs. Its association with HRV cannot be assumed to represent an independent physiological signal, particularly if HRV or related cardiovascular information contributes to the underlying scoring algorithm. Based upon the present findings, sleep duration alone demonstrated comparatively little relationship with the physiological and neuromuscular measures examined during the observation period.

For tactical athletes, the potential value of these findings lies in the feasibility of collecting multiple measures with relatively little disruption to daily activity. A wearable capable of measuring HRV and RHR, combined with a brief standardized grip-strength assessment, could provide cardiovascular, autonomic, and neuromuscular information across repeated observations. When HRV is unavailable, RHR and grip strength represent candidate measures for further investigation as components of a reduced monitoring approach. Such monitoring should remain individualized and longitudinal, as the present study does not establish population-level thresholds at which any of these measures indicate readiness or impaired readiness. Furthermore, the study did not directly measure occupational performance, training performance, fatigue, or a validated criterion measure of readiness. Consequently, the observed associations should not be interpreted as demonstrating that HRV, RHR, grip strength, or Sleep Score independently measure tactical-athlete readiness.

### *Limitations and Future Research*

Several limitations constrain interpretation and external validity of the present findings. The study included a single tactical athlete observed across 22 consecutive days, substantially limiting generalizability to other tactical athletes or occupational populations. Repeated observations increased the number of within-participant measurements but did not represent 22 independent participants. Individual characteristics, training history, occupational demands, habitual sleep, and physiological responses may therefore have influenced the observed relationships. The observational and retrospective design further prevents causal inference, and the study cannot determine whether changes in autonomic status caused changes in grip strength, whether

both responded to another underlying factor, or whether the observed relationships would persist under experimentally controlled conditions.

The participant was also the study author and investigator, introducing potential measurement, selection, and interpretive bias. Grip-strength measurements were self-administered and may have been influenced by participant effort or expectations. Although wearable-derived measures were generated automatically, dataset selection and interpretation were performed by the investigator-participant without independent oversight. Replication of statistical calculations using a second software package can assess computational consistency but does not eliminate these sources of bias. Accordingly, the findings should be interpreted as exploratory and hypothesis-generating.

Future research should evaluate these relationships prospectively in larger and more diverse tactical-athlete populations, including military, law-enforcement, firefighting, and other occupational groups where appropriate. Longer observation periods would allow evaluation of whether relationships among HRV, RHR, grip strength, and sleep measures remain stable across changes in training load, operational stress, recovery, and sleep opportunity. Prospective studies should also incorporate criterion or independently validated measures of physical performance, fatigue, recovery, and occupational readiness to determine whether the physiological relationships observed in the present study correspond with meaningful changes in performance.

The present findings therefore provide preliminary within-participant evidence that HRV, RHR, and isometric grip strength demonstrate related daily variation in a tactical athlete, while wearable-derived Sleep Score demonstrated a relationship primarily with HRV and sleep duration demonstrated little relationship with the measured physiological or neuromuscular variables. These findings do not establish a validated measure of tactical-athlete readiness, but they provide an empirical basis for further investigation of individualized, multimodal monitoring strategies and, specifically, whether readily obtainable RHR and grip-strength measurements can supplement or provide useful information when HRV monitoring is unavailable.

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