Heart Rate Variability Metrics from Commercial Devices Predicts Strength and Cardiovascular Performance in a Military Cohort

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Abstract: Heart rate variability (HRV) has become popular for assessing improvements in physical fitness, performance, and recovery. The purpose of this study was to assess the ability of HRV metrics to predict strength and cardiovascular performance in a military cohort using data obtained from commercial off-the-shelf (COTS) wearables. (1) Methods: Twenty-four active-duty military personnel (17 males; 7 females), ranging from age 23 to 41 (32.70 ± 4.65), were equipped with a Whoop Strap 3.0, a Garmin Fenix 5, and an Omegawave during a 12-week exercise intervention study. For this experiment researchers focused solely on HRV metrics obtained on scheduled "Gameday" competitions that occurred periodically during the intervention and contained a battery for strength, power, and cardiovascular performance tests. (2) Statistical Analysis: HRV metrics fitted with linear mixed models and applied to a composite strength variable derived following interrogation of performance tests with principal component analysis (PCA). Akaike's information criterion (AIC) was also used to compare cardiovascular and strength metrics. (3) Results: Results indicated that standard deviation of NN intervals (SDNN)] obtained from Omegawave was the best overall predictor of performance (AIC > 5.00). (4) Conclusion: Our analyses demonstrated that traditional metrics obtained with the Omegawave were the best performance predictors. HRV measured by Omegawave immediately prior to Gameday assessment was inversely related with strength performance, suggesting that a lower HRV was associated with higher performance (p = 0.002). These findings demonstrate the potential influence of timing and raw values utilized on HRV interpretation to predict strength and cardiovascular performance.

Keywords: Heart Rate Variability, Performance, Strength Training

1. Introduction

Heart rate variability (HRV), i.e., the variability in time between successive heartbeats, is related to dimensions of health and fitness [1, 2]. For instance, higher HRV is associated with lower mortality rate and improved physical fitness [1]. In elite athletes, high HRV has been linked to improved performance in aerobic tasks and lower perceptions of physical effort [3]. HRV has also been found to be an effective indicator of key fitness and performance elements among tactical personnel, and thus, a valuable tool for tracking health and performance in the tactical environment [4].

In recent years, wearable device companies have attempted to capitalize on these research findings by incorporating HRV metrics into commercial fitness trackers. To make it easier for

users to interpret complex HRV statistics, many of these wearable device companies have developed proprietary variables with simple sounding names, but whose underlying components and computations are likely based on combinations of HRV metrics.

However, it is difficult to know which variables are more important for each of their unique end-user metrics. Some of the HRV metrics that are traditionally collected as performance indicators include: the standard deviation of NN intervals (SDNN), the root mean square of the successive differences between adjacent NNs (RMSSD), and the ratio of low-frequency to high-frequency power from spectral analysis of NN intervals (LF/HF) [5].

NN interval: Time (normalized between two detected heartbeat detections [5]. Standard deviation of NN intervals (SDNN) is measured in milliseconds and affected by the sympathetic and parasympathetic nervous systems [5]. SDNN is more accurate when it is calculated over a longer period (24 hours) as opposed to a short period of time [5]. Root mean square of successive RR interval differences (RMSSD) is the variance in HR from beat-to-beat and is more influenced by the parasympathetic nervous system (PNS) compared to SDNN [5]. Low frequency (LF) power, the power on the low-frequency band (0.04-0.15 Hz), is hypothesized to represent sympathetic tone. High frequency (HF) power, the power on the high-frequency band (0.15-0.4 Hz), is suggested to be indicative of parasympathetic or vagal tone [5]. Therefore, the LF to HF ratio (LF/HF), the ratio between low and high frequency power on the HRV spectrum, may estimates the amount of activity between the PNS and SNS under controlled conditions (e.g. a high LF/HF may indicate dominance of sympathetic tone, while low LF/HF ratio may be indicative of parasympathetic dominance [5].

The purpose of the current study was to collect a range of HRV metrics using several off-the-shelf devices (i.e., Garmin Fenix 5, Whoop band, and Omegawave; see Figure 1) from individuals engaged in a 12-week long structured exercise training protocol in order to determine which devices' metrics might best predict physical performance during a Gameday competition (Table 3). A secondary objective was to analyze whether participants exhibited improvements in strength and cardiovascular fitness by utilizing the prescribed training program.

In some cases, the traditional HRV metrics described above are available from the commercial off-the-self (COTS) devices examined in the current study. In most cases, traditional metrics are available as supplements to proprietary (and likely derivate) metrics developed by the manufacturer (Table 1). For example, specific measures of interest from Garmin are all day stress and HRV stress. All day stress is a proprietary algorithm that incorporates an individual's sleep, daily stress, and physical stress [6]. Both the Garmin Fenix 5 and Whoop devices measure continuous variables throughout the day that are used to derive daily summaries. The Whoop tracks an individual's sleep, recovery, and strain based on variables such as resting heart rate (RHR), respiratory rate, HRV, and sleep [7]. The proprietary variable of interest from

Whoop for this study is recovery score. The Omegawave differs from the other devices and includes three omega sensors and three electrocardiogram (ECG) sensors. The omega sensors measure direct current (DC) potential--the ultraslow brain wave activity (e.g. resting cortical activity) while the ECG sensors capture data from the cardiac and metabolic systems [8]. Unlike the Garmin Fenix 5 and the Whoop Strap, the Omegawave is a chest strap that is not worn all day but can nevertheless be easily equipped to collect HRV data, i.e., just prior to exercise.

Figure 1. *Garmin Fenix 5, Whoop Band, and Omegawave.*

Table 1. *Device Variables.*

Garmin Variables	Whoop Variables	Omegawave Variables
Garmin All Day Stress	Whoop Recovery Score	Omegawave HRV
		Omegawave RMSSD
Garmin HRV Stress	Whoop HRV	Omegawave SDNN
	Whoop RMSSD	Omegawave LF/HF Ratio

*Note: Photos derived from: "runnerclick.com"; "performanceexperiences.com"; "omegwave.com".

2. Methods

2.1. Participants

Twenty-four (17 males; 7 females) finished all data collection requirements for this investigation, with ages ranging from 23 to 41 years old (M = 32.70, SD = 4.65). Participants included a convenience sample of healthy, active-duty military adults, who were recruited at Wright Patterson Air Force Base, OH. Participants were required to meet the following inclusion criteria to participate in this study: a) active-duty military and b) between 18 and 45 years of age. Exclusion criteria for this study included: participants who were unable/unwilling to commit to participating in this study for 14 consecutive weeks, potential candidates who were currently on a medical or pregnancy profile, currently breastfeeding, taking prescribed blood pressure medication, or undergoing hormone therapy. Individuals were also excluded if they were unwilling to discontinue herbal dietary supplements, performance supplements, or other substances which contain ingredients that could affect cardiovascular response during exercise (e.g., blood pressure medication). Finally, participants were excluded if they had a history of abdominal hernia surgery, were currently suffering from a musculoskeletal injury, or had a cardiovascular/respiratory disease as these conditions would likely limit their capacity to routinely engage in strenuous exercise. Demographic data collected from each of the participants included self-reported gender, age, height, weight, body fat percentage, and VO_{2max} (see Table 2).

Table 2. *Mean Demographics (standard deviation in parentheses).*

Age (years)	32.70 (4.65)
Height (in)	68.52 (2.90)
Weight (lb)	183.25 (31.21)
Body Fat (%)	27.79 (7.42)
VO_{2max} (mL/kg/min)	49.22 (12.21)

2.2. Procedures

This study represented a repeated measures design employing a 12-week supervised exercise training protocol. The training protocol was prescribed and monitored by a certified strength and conditioning specialist (CSCS), with each session lasting 45-60 minutes. Training specifics can be reviewed in Appendix I. Subjects were instructed to wear the wearable devices daily throughout a 12-week supervised exercise training study and included the Whoop Strap (Whoop Ltd, Boston, MA), Garmin Fenix 5 Smartwatch (Garmin Ltd, Olathe, KS), and the Omegawave chest strap and sensor (Omegawave Ltd, Espoo, Finland). Participants wore the Fenix 5 and the Whoop devices continuously (all day) for the 12-week duration of the study, unless the device was removed to re-charge the device (Garmin only). Omegawave was worn for a four-minute data capture immediately before each exercise session.

For the larger exercise intervention study, participants engaged in scheduled exercise five days per week (excluding holidays). For this report experimenters focused solely on examination of three "Gameday" sessions that occurred during a Tuesday or Thursday during weeks 4, 8, and 12. For these sessions participants took part in a competition designed to assess physical performance (note: these sessions replaced regular training for that day). The Gameday consisted of assessments of physical power (e.g., standing long jump), strength/endurance (e.g., max reps bench press), and cardiovascular fitness (e.g., 2000-meter row time; see Table 3. The Omegawave returns a wide range of HRV metrics, including proprietary derivatives (e.g., Parasympathetic balance) and standard metrics, such SDNN, RMSSD, and LF/HF power ratio. The metrics obtained from the Whoop Strap included their proprietary "Recovery Score" and the more traditional RMSSD. Both Whoop metrics were derived during sleep, which is the normal use case for this device. From the Fenix 5 we obtained two metrics: an "HRV Stress" metric obtained immediately prior to the exercise session and the "All-Day Stress" metric, which aggregates HRV data over a 24-hour period.

Table 3. *Gameday Tests.*

Test	Assessment
Standing Long Jump	Lower Body Power
Hand Grip Dynamometer	Upper Body Strength
Lower Body Dynamometer	Lower Body Strength/Endurance
Hex Bar Deadlift	Whole body Strength/Endurance
Bench Press	Upper Body Strength/Endurance
Modified Pull-Ups	Upper Body Strength/Endurance
2,000-meter Row	Cardiovascular Fitness

2.2.1. Statistical Analysis

To examine effects of HRV on performance, linear mixed models were fitted to row time and a composite strength performance metric. The composite strength performance metric was error variance empirically derived by conducting principal component analysis (PCA) on strength metrics for Gameday. Examination of the eigenvalues of the PCA showed that the first component accounted for 66% of the variance and had an eigenvalue of 3.32 while the second largest component had an eigenvalue equal to 0.59. Loadings on the first principal component for the variables were all positive and ranged from .77 (modified pull-ups) to .83 (lower body dynamometer and hex bar deadlift). Scores from projecting the data from the first principal component were thus used as a single composite variable that captured strength and endurance. Duration for the 2000-meter row was used as an indicator of cardiovascular fitness in separate models. The factors and covariates included in the initial analyses predicting rowing and strength performance were training week, training week^2 (to capture any quadratic trend over time), gender, age, and all possible interaction of these variables. These variables were also included as random effects. The best fitting model was chosen using likelihood ratio tests of nested models. These models were then used to test the ability of HRV metrics to predict cardiovascular and strength performance, which were compared using Akaike's information criterion (AIC) using the following formula (1),

$$\Delta_i(AIC) = AIC_i - min(AIC) \qquad (1)$$

In this way, the relative performance of the models was compared: Values of $\Delta_i(AIC)$ less than 2 can be considered to provide a fit that is approximately as good as the best model, models with $\Delta_i(AIC)$ values above 6 are usually deemed inferior, and models with $\Delta_i(AIC)$ values above 10 are considered implausible [10]. All prior mentioned HRV metrics were entered as predictors in two separate analyses, first in their original form and second after centering the observations on each participant's average value, which was done to remove person-specific variance and allow models to evaluate the predictive power of fluctuations around individually meaningful data points (i.e., each individual's own mean values).

2.2.2. Abbreviations (SciencePG-Level 3)

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

3. Results

3.1. Row Time Performance

Results from the linear mixed model analyses determined that gender and training week were significant predictors of row time performance (see Table 4). Specifically, row time was significantly lower (better) for men compared to women

(*p* = 0.030). Row time also improved over time for all participants (*p* = 0.003). Results from the AIC analyses of the HRV metrics showed that participant centered SDNN from the Omegawave was the best predictor of performance, although uncentered SDNN was a somewhat poorer predictor of performance (difference in AIC = 1.37). Meanwhile, Whoop RMSSD from the previous night was a relatively weaker predictor of performance in comparison to Omegawave values (difference in AIC = 3.22).

Evaluation of the coefficients from these models showed that HRV taken immediately before Gameday physical performance tasks yielded a negative relationship with row time performance (higher Omegawave SDNN predicted higher row time, *p* = 0.016), but that HRV recorded the night before Gameday competition was positively related to performance (high Whoop RMSSD predicted faster row time, *p* = 0.039).

Table 4. Results from linear mixed model predicting corrected row time duration.

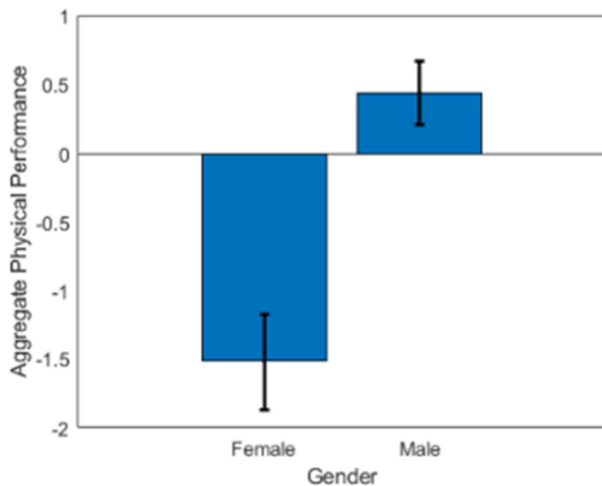| Predictors	Estimates	CI	p
(Intercept)	-1.42	-1.76 – -1.08	<0.001
Training Week [1st degree]	1.78	1.28 – 2.27	<0.001
Training Week [2nd degree]	0.56	0.18 – 0.94	0.011
GenderMale [1]	1.96	1.56 – 2.36	<0.001
Random Effects			
σ^2	0.03		
$\tau_{00\ Subject}$	0.19		
$\tau_{11\ Week\|Subject}$	0		
$\rho_{01\ Subject}$	0.13		
ICC	0.88		
$N_{Subject}$	24		
Observations	52		
Marginal R^2 / Conditional R^2	0.801 / 0.977		

Figure 2. Aggregate physical performance from projections through first principal component of performance variables as a function of gender.

Figure 3. Aggregate physical performance from projection through first principal component of performance variables as a function of training week.

Table 5. Results from Linear Mixed Model Predicting Physical Performance.

Predictors	Estimates	CI	p
(Intercept)	-1.42	-1.76 – -1.08	<0.001
Training Week [1st degree]	1.78	1.28 – 2.27	<0.001
Training Week [2nd degree]	0.56	0.18 – 0.94	0.011
GenderMale [1]	1.96	1.56 – 2.36	<0.001
Random Effects			
σ^2	0.03		
$\tau_{00\ Subject}$	0.19		
$\tau_{11\ Week\|Subject}$	0		
$\rho_{01\ Subject}$	0.13		
ICC	0.88		
$N_{Subject}$	24		
Observations	52		
Marginal R^2 / Conditional R^2	0.801 / 0.977		

3.2. Aggregate Performance

Results from the linear mixed model analyses showed that gender, training week (first degree), and training week (second degree) were significant predictors of strength performance (see Table 5). Specifically, strength performance was higher for men compared to women ($p < 0.001$) (Figure 2). Strength performance improved over time ($p < 0.001$) and showed a positive quadratic trend ($p = 0.010$) (Figure 3).

Results from the AIC analyses of the HRV metrics (Appendix II) showed that participant-centered LF/HF from the Omegawave was the best overall predictor of strength performance. Participant-centered prior all-day stress (Fenix 5) and uncentered LF/HF (Omegawave) were also significant predictors of strength performance, with nearly indistinguishable differences between these two devices, $\Delta_i(AIC) = 0.49$ and 0.73, respectively. Evaluation of the coefficients from these models showed that HRV immediately prior to Gameday assessment yielded an inverse relationship with strength performance (lower LF/HF predicted better strength performance, $p = 0.003$). Increased HRV captured the day prior to Gameday testing was associated with worse performance. However, Omegawave taken just prior to exercise, indicated that a lower HRV was associated with higher performance ($p = 0.002$).

4. Discussion

As expected, performance improved with training, indicating that the training intervention was effective. Though males showed higher overall levels of performance, the rate of improvement was the same for both males and females. With respect to HRV metrics, our findings showed that while HRV values predict performance, it does not always occur as practitioners and coaches might traditionally expect. Typically, if an individual has a higher HRV they will exhibit higher performance [3]. However, while higher resting HRV measured the night before was predictive of better performance in a rowing task, (regardless of which of the three commercial devices was used), lower HRV in measurements taken immediately before performing (as recorded by Omegawave) were predictive of better performance in both rowing and various strength tasks. It is possible that participants who were most anticipating Gameday had increased sympathetic nervous system activation immediately prior (i.e., the upcoming challenge aroused a "fight-or-flight" response) [9], which likely inspired a positive readiness state. Time-sensitive investigations utilizing norepinephrine spill-over and resting sympathetic nerve activity could allow for an in-depth exploration of both time aspect and basal sympathetic tone.

4.1. Training Weeks and Gender Predict Strength and Cardiovascular Performance

All participants exhibited an improvement in performance with time. The results indicate that training week was a significant predictor of strength performance ($p = <0.05$). Interestingly, there was a greater increase in strength from week 8 to 12 compared to week 4 to 8. These findings are consistent with the pattern of development in training in which the adaptations that occur early on (up to 8 weeks) are neural adaptations, and those after that are typically associated with muscular adaptations [10, 11]. Even though we did not measure changes in muscle volume, it is possible the participants in this study may have demonstrated their greatest improvements in strength as a result of true muscular adaptations (e.g., hypertrophy) since a greater increase occurred from week 8 to 12 [12].

Results from the linear mixed model predicting corrected row time duration indicate that the training week had a statistically significant effect ($p = 0.003$) on row time duration. This was to be expected because as training increased, participants experienced improvements in physical performance, leading to improvements in row time. Another predictor of row time was gender ($p = 0.030$) indicating that males typically had faster row times. Again, this was expected, due to the male participants experiencing a greater increase in performance measures, and increased quantity of lean muscle mass when compared to females. The high ICC (0.98) indicated that gains in training consistently resulted in performance improvements.

Male participants consistently demonstrated significantly ($p < 0.001$) better strength and cardiovascular physical performance compared to the female participants in the present study. Gender-related factors such as muscle fiber characteristics and overall body size may contribute to this finding, as well as our subjects not being selected at random [10, 13]. A subgroup of participants in this study may have had less previous training experience in this setting and may have achieved greater improvements as an indicator of neurological adaptations and task learning in addition to true strength gains over a 12-week period. Unfortunately, prior training experience was not evaluated for the participants in the current study.

4.2. Differences Between Commercial Device HRV Variables to Predict Gameday Performance

While Omegawave was the best performance predictor overall ($\Delta_i(AIC) = 0.00$), the other devices did have notable results. Participant centered prior all-day stress collected from the Fenix 5 ($\Delta_i(AIC) = 0.49$) and uncentered LF/HF from the Omegawave ($\Delta_i(AIC) = 0.73$) elicited almost identical results. Therefore, these results suggest that these two variables from separate devices could be used interchangeably and produce similar results. High Whoop RMSSD from the day before was a moderate predictor of performance, as high Whoop RMSSD scores indicated a faster row time for Gameday ($p = 0.039$). This finding was anticipated since a higher RMSSD is indicative of improved fitness level and therefore related to better performance [16]. Prior night Whoop scores (RMSSD), while predictive of row scores ($\Delta_i(AIC) = 3.22$), were not as strong of a predictor as SDNN from the Omegawave ($\Delta_i(AIC) = 0.00$). Overall, raw values from the devices tended to yield

better performance predictors versus proprietary values.

4.3. Time of Day Measurement of HRV and Performance Predictions

A significant negative relationship between HRV, as captured from Omegawave just prior to exercise, and physical performance was observed on Gameday assessments (p =0.002), such that a lower HRV was associated with higher performance. This result was in contrast to our expectations. Previous literature [14] and statements by the companies who produce the devices included in this study suggest that a higher HRV indicates the body is rested, ready, and capable of performing its best [3]. This was not consistently the case in our cohort, but could indicate the influence of effect intense workouts during the week on a subject's parasympathetic activity [15]. It could also be indicative of the participant's anticipatory responses immediately prior to Gameday [16].

4.4. Possible Catecholamine Effects on HRV

Increased epinephrine release in anticipation of performing exercise could initiate an individual's "fight or flight" response, leading to an increase in HR and a decrease in HRV [15]. However, this is a typical response. At the onset of exercise, vagal activity decreases as a result of central command and resetting of the arterial baroreflex [17]. Typically, before sport performance it is better to have an individual aroused and ready for competition as opposed to being lethargic. It has been previously found that a moderate level of arousal often yields peak performance [18]. Additionally, it has been suggested that an adaptation from a training stimulus that is composed of moderate intensity aerobic work can cause a gradual increase in HRV trend [19].

Additionally, if participants are frequently exposed to high intensity training that is unfamiliar or stressful, it could cause a larger disruption of homeostasis and cause an increase in their HRV trend [19]. A previous study that had similar results to those of the current study, identified that healthy male professional tennis players experienced improvements in VO_{2max} and speed-strength over a 30-day period, however, at the end of the training program their participants also demonstrated a significant decrease in RMSSD [10]. A relatively high VO_{2max} in our cohort suggests that we tested a sample of relatively fit individuals, which may correspond to these high-performing tennis players.

4.5. Limitations

There were some limitations identified in this study. The first limitation is that the participants in this study were young, healthy active-duty military members and therefore, study results may not be directly applicable to the general population or elite athletes. Another limitation to this study was the small sample size due to challenges with recruitment in a military population. Another potential limitation is due to not capturing the difference in chronobiology, which may impact HRV values. Finally, there was a high dropout rate (35%) in our sample, which further led to a small sample size. This underscores the challenges of recruiting and training participants in military populations and should be considered in future studies.

5. Conclusions

Our analyses showed that metrics obtained with the Omegawave were the best predictors of performance overall, but both Garmin and Whoop metrics provide additional benefit by providing continuous minimally intrusive background observations that can complement more intrusive, and time-consuming measures taken immediately before performing. Overall, this study found that raw values from the devices were better predictors of performance when compared to the proprietary variables. In conclusion, it appears reasonable to suggest that practitioners and coaches consider utilizing Omegawave in addition to reviewing an individual's HRV metrics from the previous day to obtain a more complete understanding of potential performance.

Appendix

Appendix I: Prescribed Training Plan for Participants

Table 6. Prescribed Training Plan for Participants.

Week 1			
"V" Toe Touch	Quadruped w/Leg Lift	Side Plank	Goblet Squat
1-Leg SLDL	RDL – Trap Bar	Slow Cycle	Heel Touch
3-Part Touch the Sky	RKC Plank	Spiderman Stretch	Inchworm
Ant Lat Bounding	Release Push-Up	Squat – Dumbbell (Goblet)	Incline Bench Press – Dumbbell
Anti-Rotation Press – Feet Staggered (TRX)	Reverse Lunge – Alternating	Squat Jump - Continuous	Kneeling Plank Reach w/Rotation
	Reverse Lunge – Dumbbell	Squat Jump – Countermovement to Stabilize	
Band Face Pull	Romanian Deadlift (Dowell)		Lateral Bound to Stabilize
Band Pull Apart	Romanian Deadlift - 1 Leg 1 Arm Landmine (Contra)	Squat Jump – Non-Countermovement to Stabilize	Lateral Lunge Crawl
Bench Press – Barbell			Lateral Skier
Bent Over Row	Romanian Deadlift – Dumbbell	Supported Single Leg RDL	Line Hops
Butt-to-Ground Chest-to-Bar Pull-Up	Rower	TRX Inverted Row	Ls (TRX)
Fire Hydrant	Tornado	TRX Pull-Up Row	Overhead Press – 1 Arm – ½
Glute Bridge	Upper Back Foam Roll Extension	TRX Push-Up	Kneeling Landmine
Plate Squeeze Chest Activation	YTW Shoulders	TRX Squat	Plank w/Shoulder Tap

Week 2

15% Incline Treadmill	RDL – Trap Bar	Heel Touch	Side Plank
Band Face Pull	RKC Plank	Inchworm	Side Plank Dips
Band Overhead Tricep Extension	Release Push-Up	Kneeling Plank Reach w/Rotation	Slow Cycle
Band Pull Apart	Reverse Lunge – Alternating	Lateral Bound to Stabilize	Spiderman Stretch
Bench Press – Barbell	Reverse Lunge – Dumbbell	Lateral Lunge Crawl	Squat Jump – Continuous
Bent Over Row	Quadruped w/Leg Lift	Lateral Skier	Squat Jump –
Bicep Curls – Standing Dumbbell	Romanian Deadlift (Dowel)	Lateral Squat – DB (Goblet)	Countermovement to Stabilize
Butt-to-Ground Chest-to-Bar Pull-Up	Romanian Deadlift – 1 Leg 1 Arm Landmine (Contra)	Leg Curl (TRX) / TRX Band Double Hamstring Curl	Squat Jump – Non-Countermovement to Stabilize
Dying Bug	Romanian Deadlift – Barbell	Line Hops	TRX 3 Point Skiers
Fire Hydrant – Warmup	Romanian Deadlift – Dumbbell	Overhead Press – 1 Arm – ½ Kneeling Landmine	TRX Pull-Up Row
Glute Bridge	Rower	Overhead Press – Seated Dumbbell	Tall-Kneeling Band Paloff Press
Goblet Squat	Sandbag Push Press	Plate Squeeze Chest Activation	
Upper Back Foam Roll Extension	YTW Shoulders		

Week 3

15% Incline Treadmill	Quadruped – w/Leg Lift	Sandbag Full Squat & Press	Kneeling Plank w/Rotation
Band Face Pull	RDL – Trap Bar	Side Plank Dips	Lateral Lunge Crawl
Band Pull Apart	RKC Plank	Slow Cycle	Lateral Skier
Belly Plate Breath	Reverse Lunge – Alternating	Spiderman Stretch	Line Hops
Bench Press – Barbell	Reverse Lunge – Dumbbell	Squat – Dumbbell (Goblet)	Overhead Press – 1 Arm – ½
Bent Over Row	Romanian Deadlift (Dowel)	Squat Jump – Continuous	Kneeling Landmine
Bicep Curls – Standing Dumbbell	Romanian Deadlift – 1 Leg 1 Arm Landmine (Contra)	Squat Jump – Countermovement to Stabilize	Plank – w/Shoulder Tap
Broad Jumps	Romanian Deadlift – Dumbbell	TRX Pull-Up Row	Plate Squeeze Chest Activation
Butt-to-Ground Chest-to-Bar Pull-Up	Rower	Tall-Kneeling Band Paloff Press	Push-Up
Dying Bug	YTW Shoulders	Trap Bar DL Low-Handle	Inchworm
Fire Hydrant	Upper Back Foam Roll Extension	Tricep Extension (TRX)	Knee In and Out
Get Out of Bed			

Week 4

Anti-Rotation Press – Feet Staggered (TRX)	RKC Plank	Fire Hydrant	Squat Jump - Continuous
Band Dislocates	Romanian Deadlift	Inch Worm	Squat Jump - Countermovement to Stabilize
Band Face Pull	Romanian Deadlift - 1 Leg 1 Arm Landmine (Contra)	Incline Bench Press – Dumbbell	Trap Bar DL Low-Handle
Band Pull Apart	Romanian Deadlift (Dowel)	Inverted Row	Triceps Extension (TRX)
Belly Plate Breath	Row - Assisted Stance 1 Arm (TRX)	Knee In and Out	TRX 1-Leg Squat
Bench Press – Barbell	Side Plank Dips	Lateral Lunge Crawl	TRX 3 Point Skiers
Bent Over Row	Slow Cycle	Lateral Skier	TRX Bicep Curl
Bicep Curls – Standing Dumbbell	Spiderman Reach Through	Lateral Squat – DB (Goblet)	TRX Pull-up Row
Broad Jumps	RDL – Trap Bar	Ls (TRX)	TRX Push-Up
Chin-Up	Release Push-Up	Overhead Press – 1 Arm – ½ Kneeling Landmine	Tuck Jumps - Continuous
Plate Squeeze Chest Activation	Spiderman Stretch	Overhead Squat (Band)	Upper back Foam Roll Extension
Quadruped – w/Leg Lift		Plank	YTW Shoulders

Week 5

1 Arm Landmine Press	Ls (TRX)	Inchworm	Squat Jump - Continuous
1 Leg RDL (DB)	Overhead Squat - Hands Clasped (Bodyweight)	Knee In and Out	Squat Jump - Non-Countermovement to Stabilize
Band Face Pull	Overhead Squat (Band)	Landmine Floor to Side Press	Trap Bar DL Low-Handle
Bench Press - Barbell	Plank Reach with Rotation	Lateral Bound to Stabilize	TRX Band Single Arm Press with Rotation
Bent Over Row - Hand and Knee on Bench 1 Arm Dumbbell	Plate Squeeze Chest Activation	Lateral Lunge - In Place Dumbbell alternating (goblet)	TRX Inverted Row
Broad Jumps	RDL - Trap Bar	Lateral Lunge Crawl Lateral Lunge	TRX Pull
Bulgarian Split Squat	Release Push-Up	Lateral Shuffle - Cutting	TRX Pull-up Row
Dying Bug Hold	Reverse Lunge Overhead Stretch	Lateral Skier	TRX Push-Up
Fire Hydrant - Warmup	RKC Plank	Line Hops	Upper back Foam Roll Extension
Forearm Alternating Side Plank	Row - Assisted Stance 1 Arm (TRX)	Linear Hop - Countermovement to Stabilize Over Hurdle	YTW Shoulders
Glute Bridge	Scissor Jumps	Spiderman Stretch	Spiderman Reach Through
Hanging Leg Raise	Single Leg Squat - Hands in TRX	Split Squat- Back Foot Elevated BB	Slow Cycle
Hurdle Hop - Lateral to Medial CM			

Week 6

1 Arm Landmine Press	MB Windshield Wiper	Goblet Squat	Squat Jump - Non-Countermovement to Stabilize
1 Leg RDL (DB)	Overhead Squat (Band)	Hanging Leg Raise	

Week 6			
Band Face Pull	Plank - with 1 Arm Row	Inchworm	Trap Bar DL Low-Handle
Bench Press - Barbell	Dumbbell alternating	Jumping Lunge	Triceps Extension (TRX)
Bent Over Row - Hand and Knee on Bench 1 Arm Dumbbell	Plank Reach Through with Drag	Knee In and Out	TRX Band Single Arm Press with Rotation
Biceps Curls - Standing Dumbbell	Plate Squeeze Chest Activation	Landmine Floor to Side Press	TRX Bicep Curl
Broad Jumps	Pull Up	Lateral Lunge - In Place Dumbbell alternating (goblet)	TRX Pull-up Row
Bulgarian Split Squat	Push Up - Feet in TRX	Lateral Lunge Crawl Lateral Lunge	Upper back Foam Roll Extension
Chin Up	RDL - Trap Bar	Lateral Shuffle - Cutting	V-Up
Chin-up - Eccentric	Release Push-Up	Lateral Skier	YTW Shoulders
DB Swing	Reverse Lunge Overhead Stretch	Lawnboy Sled Push & Pull	Single Leg Squat - Hands in TRX
Dying Bug Hold	RKC Plank	Leg Curl (Stability Ball)	Spiderman Reach Through
Fire Hydrant - Warmup	Romanian Deadlift - 1 Leg 1 Arm Landmine (Contra)	Scissor Jumps	Spiderman Stretch
Forearm Alternating Side Plank	Row - Assisted Stance 1 Arm (TRX)	Side V-Up	Squat Jump – Continuous
Front Plank Alternating Arm Raise		Glute Bridge	Russian Twist
			Rower

Week 7			
1 Arm Landmine Press		Knee In and Out	Sled Low Push
Band Face Pull	Mod Pro Agility Suicide Shuffle	Landmine Floor to Side Press	Spiderman Reach Through
Bench Press - Barbell	Overhead Squat - Hands Clasped (Bodyweight)	Lateral Lunge - In Place Dumbbell alternating (goblet)	Spiderman Stretch
Bent Over Row - Hand and Knee on Bench 1 Arm Dumbbell	Overhead Squat (Band)	Lateral Lunge Crawl Lateral Lunge	Squat Jump - Continuous
Biceps Curls - Standing Dumbbell	Plank - with 1 Arm Row	Lateral Shuffle - Cutting	Trap Bar DL Low-Handle
Broad Jumps	Dumbbell alternating	Lateral Skier	TRX Pull-up Row
Bulgarian Split Squat	Plank Reach Through with Drag	Leg Curl (Stability Ball)	Tuck Jumps - Continuous
Chin Up	Plank Reach with Rotation	Line Hops	Upper back Foam Roll Extension
DB Swing	Pull Up	Ls (TRX)	V-Up
Fire Hydrant - Warmup	RDL - Trap Bar	Goblet Squat	YTW Shoulders
Forearm Alternating Side Plank	Release Push-Up	Hanging Leg Raise	Scissor Jumps
Romanian Deadlift - 1 Leg 1 Arm Landmine (Contra)	Retro Lunge Kick Back	Hollow Hold	Side Plank Dips
Rower	Reverse Lunge Overhead Stretch	Inchworm	Side V-Up
	RKC Plank		Jumping Lunge

Week 8			
1 Arm Landmine Press	Overhead Squat (Band)	Knee In and Out	Swing - 2 Arm Kettlebell
Band Face Pull	Plank - with 1 Arm Row	Landmine Floor to Side Press	Trap Bar DL Low-Handle
Bench Press - Barbell	Dumbbell alternating	Lateral Lunge - In Place Dumbbell alternating (goblet)	Tricep Extension - overhead High split Cable (rope)
Bent Over Row - Hand and Knee on Bench 1 Arm Dumbbell	Plank Reach Through with Drag	Lateral Lunge Crawl Lateral Lunge	Triceps Extension (TRX)
Biceps Curls - Standing Dumbbell	Pull Up	Lateral Skier	TRX Inverted Row
Broad Jumps	Push Up to Row (two rows per rep)	Line Hops	TRX Pull-up Row
Bulgarian Split Squat	RDL - Trap Bar	Linear Hop - Countermovement to Stabilize Over Hurdle	Tuck Jumps - Continuous
Chin Up	Release Push-Up	Mountain Climber	Upper back Foam Roll Extension
DB Swing	Retro Lunge Kick Back	Overhead Press - Standing Dumbbell	V-Up
Dying Bug Hold	Reverse Lunge Overhead Stretch	Goblet Squat	YTW Shoulders
Fire Hydrant - Warmup	RKC Plank	Hanging Leg Raise	Spiderman Stretch
Force Treadmill Sprint	Romanian Deadlift - 1 Leg 1 Arm Landmine (Contra)	Inchworm	Split Squat Jump - Alternating Continuous
Side V-Up	Scissor Jumps		Jumping Lunge
Spiderman Reach Through			
Side Plank Dips			

Week 9			
1 Leg RDL (DB)	Overhead Squat (Band)	Dying Bug Hold	Split Squat- Back Foot Elevated BB
15% Incline Treadmill	Plank - with 1 Arm Row	Farmer's Walk - 1 Arm KB	Squat - Dumbbell (goblet)
Band Dislocates	Dumbbell alternating	Fire Hydrant - Warmup	Squat Jump - Continuous
Band Face Pull	Plank Reach Through with Drag	Get Out of Bed	Trap Bar Hamstring Deadlift
Bench Press - Dumbbell	Release Push-Up	Glute Bridge	Trap Bar Squat
Bent Over Row - Hand and Knee on Bench 1 Arm Dumbbell	Reverse Crunches	Glute Bridge - Marching	TRX Inverted Row
Broad Jumps	Reverse Lunge - Dumbbell	Glute Bridge - Shoulders on Bench	Upper back Foam Roll Extension
Bulgarian Split Squat	Reverse Lunge Overhead Stretch	Hollow Hold	V-Up
Chin Up	RKC Plank	Inchworm	Spiderman Reach Through
DB Swing	Romanian Deadlift - 1 Leg 1 Arm Landmine (Contra)	Incline Bench Press - Dumbbell	Spiderman Stretch
Side Plank Dips		Inverted Row	
		Scissor Jumps	

Week 10

1 Leg RDL (DB)	Reverse Lunge - Dumbbell	Inchworm	Trap Bar Hamstring Deadlift
15% Incline Treadmill	Reverse Lunge Overhead	Incline Bench Press - Dumbbell	Trap Bar Squat
Band Dislocates	Stretch	Inverted Row	TRX 1-Leg Squat
Band Face Pull	RKC Plank	Jumping Lunge	TRX 3 Point Skiers
Bench Press - Barbell	Romanian Deadlift - 1 Leg 1	Leg Curl - 1 Leg (Foot in TRX)	TRX Inverted Row
Bench Press - Dumbbell	Arm Landmine (Contra)	Leg Curl - Alternating (TRX)	TRX Pull-up Row
Bent Over Row - Hand and Knee on Bench 1	Row (TRX) / TRX Band	Ls (TRX)	TRX Push-Up
Arm Dumbbell	Double Lat Row	Overhead Squat (Band)	TRX Squat
Bulgarian Split Squat	Rower	Plank - with 1 Arm Row	Ts (TRX)
Chin Up	Scissor Jumps	Dumbbell alternating	Tuck Jumps - Continuous
Dying Bug Hold	Spiderman Reach Through	Release Push-Up	Hanging Slow Cycle
Fire Hydrant - Warmup	Spiderman Stretch	Upper back Foam Roll Extension	Reverse Crunches
Glute Bridge - Marching	Split Squat- Back Foot	V-Up	Squat Jump -
	Elevated BB	Squat Jump - Continuous	Non-Countermovement to Stabilize

Week 11

1 Leg RDL (DB)		Broad Jumps	Overhead Squat (Band)
15% Incline Treadmill	Incline Bench Press - Dumbbell	Chin Up	Plank Reach Through with
Band Dislocates	Inverted Row	DB Swing	Drag
Band Face Pull	Leg Curl (Stability Ball)	Dying Bug Hold	Release Push-Up
Bench Press - Barbell	Leg Curl (TRX) / TRX Band Double	Fire Hydrant - Warmup	Reverse Lunge Overhead
Bent Over Row - Hand and Knee on Bench 1 Arm	Hamstring Curl	Glute Bridge - Shoulders	Stretch
Dumbbell	Spiderman Stretch	on Bench	Scissor Jumps
Upper back Foam Roll Extension	Squat - Dumbbell (goblet)	Hanging Slow Cycle	Spiderman Reach Through
V-Up	Squat Jump - Continuous	Hollow Hold	Inchworm

Week 12

15% Incline Treadmill	15% Incline Treadmill	15% Incline Treadmill	15% Incline Treadmill

Appendix II: AIC Variables for Statistical Analysis

Table 7. *AIC Variables for Statistical Analysis.*

Index	Variable	AIC	dAIC (thisAIC-min (allAIC))
1	0 Null	52.40514988	6.148701561
2	Garmin_HRVStress	53.97551227	7.719063945
3	PriorAllDayStres	48.31823914	2.061790817
4	Garmin_AllDayStress	53.15817471	6.901726389
5	Whoop_RecoveryScore	53.44642644	7.189978121
6	Whoop_HRVRMSSD	53.65235406	7.395905733
7	OW_Readiness	54.12502683	7.868578511
8	OW_SDNN	54.22754438	7.971096059
9	OW_RMSSD	53.03078154	6.774333217
10	OW_LF_HF	46.98900229	0.732553966
11	Garmin_HRVStress (centered)	54.40123846	8.144790133
12	PriorAllDayStress (centered)	46.74388249	0.487434169
13	Garmin_AllDayStress (centered)	51.84055713	5.584108809
14	Whoop_RecoveryScore (centered)	53.30767168	7.051223352
15	Whoop_HRVRMSSD (centered)	52.45876627	6.202317951
16	OW_Readinesss (centered)	53.65176762	7.395319301
17	OW_SDNN (centered)	53.28382209	7.027373765
18	OW_RMSSD (centered)	49.7175459	3.461097578
19	W_LF_HF_hrvCols (centered)	46.25644832	0
20	WellnessScale_Total	52.89856394	6.642115613
21	PhysicalFatigue	53.53953916	7.283090838
22	Recovery	51.83228159	5.575833271
23	WellnessScale (centered)	50.2460722	3.989623876

Note* "(centered)" indicates the variable was centered around each individual participant's mean values.

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