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The Effectiveness of Utilizing HRV Indices as a Predictor of ACFT Performance Outcomes

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ABSTRACT

Background:

The Army Combat Fitness Test (ACFT) is a performance assessment used by the U.S. Army to assess a cadet's strength, endurance, and agility with a series of six events to ensure that cadets are combat ready. Heart rate variability (HRV) is an instrument that measures cardiac autonomic modulation and has been incorporated to predict the performance of athletes in daily training and competition since acute bouts of exercise alter HRV variables.

Purpose:

To assess the applicability of using HRV to predict ACFT score performance outcomes in cadets.

Methods:

Fifty army cadets ($n = 36$ male; $n = 14$ female; age $= 20.60 \pm 3.61$ years; height $= 173.34 \pm 10.39$ cm; body mass $= 76.33 \pm 14.68$ kg; body fat percentage $= 17.58 \pm 5.26\%$) completed the ACFT and reported for HRV assessment. HRV assessment had the participant lay supine for 5 minutes, and traditional time and frequency domain variables were assessed. A Pearson's correlation and multiple linear regressions were run.

Results:

HRV time and frequency domains were not significantly correlated in linear regression models except the stress index (SI) and the 2-mile run (2MR). The standing power throw and sprint drag carry were significantly correlated with traditional HRV variables.

Conclusions:

HRV was not a predictor of ACFT performance for individual events or overall ACFT. The SI presented predictive properties only for 2MR, with no other significant correlations between HRV variables with standing power throw and sprint drag carry. The SI ability to predict 2MR performance outcome via HRV is a promising tool to assess army cadet performance and recovery.

INTRODUCTION

The Army Combat Fitness Test (ACFT) is a physical assessment test implemented by the U.S. Army to ensure that soldiers are physically capable and ready for combat.[1] More specifically, the ACFT was developed to better assess the cadet's strength, endurance, and agility, which are attributes needed during combat situations.[1] As of 2022, the ACFT officially became the physical fitness test of record for all army-associated personnel.[1,2] The ACFT utilizes six events to assess the combat readiness of cadets. The events include a three-repetition maximum trap-bar deadlift (3DL), standing power throw (SPT), hand release pushups (HRPU), a sprint drag carry (SDC), a leg tuck (LT) or a plank (PLK), and a 2-mile run (2MR). The 3DL, SPT, and HRPU measure the strength and power of cadets, whereas the LT and PLK assess the muscular endurance of the cadets.[1] The 2MR assesses the aerobic endurance ability, and the SDC assesses the speed and power of the cadets.[1,3] These performance tests provide the U.S. military leadership a more comprehensive understanding of the physical capacities of cadets to assist them in determining combat readiness.[4]

Heart rate variability (HRV) is a noninvasive method of observing the actions of the autonomic nervous system through the heart, more precisely the branches of the parasympathetic and sympathetic nervous systems.[5] Currently, HRV is used to measure and predict the performance of athletes and individuals during day-to-day training and competition.[6] HRV has been used as the predominant noninvasive metric to quantify autonomic nervous system recovery after aerobic exercise and performance tests and is also used to predict performance outcomes.[7] An added benefit of assessing HRV is to provide an additional metric for exercise specialists and certified Army Fitness Trainers over aerobic and strength assessments of participants or cadets.[8–10]

Certain HRV metrics are used to assess cardiopulmonary health and to predict cardiac complications during

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exercise.[11–14] More recently, HRV metrics are now being implemented as metrics related to performance.[6,10,15] Time domain variables such as the standard deviation (SD) of NN intervals (SDNN) and the root mean square of successive RR interval differences (RMSSD) are used to monitor the performance and recovery of athletes.[5,16,17] Frequency domain variables, such as high-frequency (HF) power (HF) and low frequency (LF) to HF ratio (LF/HF), are used to assess the recovery and performance of strength and power athletes.[18,19] The stress index (SI), which measures the amount of stress placed on the heart, has recently been implemented to observe recovery and predict performance outcomes.[20] In a previous study, aerobically trained individuals with higher cardiorespiratory fitness (VO_2 max) had a lower SI and quicker recovery time relative to individuals with lower VO_2 max.[20] An overall higher HRV appears to be a better predictor of a higher aerobic performance since it demonstrates a better self-regulatory capability when presented with external stresses such as exercise.[5,10] Similar results have been observed in athletes that participate in resistance training. Therefore, trainers have been utilizing HRV more consistently to monitor vascular health and outcomes.[18]

The combination of HRV with the ACFT could potentially give test exercise specialists and coaches a more insightful look at a cadet's physical capabilities, more specifically their cardiac performance and strength/power performance, and allow for better judgments as to whether or not they are combat ready.[2,17,21] Utilizing HRV variables, such as SI, time domain variables, and frequency domain variables, could help predict overall ACFT scores, aerobic performance, and strength/power performance.[16,18,20] To our knowledge, the first-time HRV that is being utilized in a military setting as a way to assess performance. Therefore, the purpose of this study is to assess the applicability of using HRV to predict ACFT score performance outcomes in army cadets, and thus, the hypothesis of this study is that HRV metrics are indicative of ACFT performance.

METHODS

Study Design

This cross-sectional descriptive study observed the relationship between ACFT performance and HRV variables. All participating cadets took the ACFT with their local army cohort, and the assessments were conducted in accordance with army procedures and guidelines.[1] ACFT results, for each cadet, were provided to researchers following the completion of the assessments. Cadets and active duty soldiers reported to the lab for HRV data collection within a week of completing the ACFT. Participant demographics are presented in Table I.

TABLE I. Participant Demographics

	ACFT cadets ($n = 50$)
Male:Female (n)	36:14
Age (years)	20.60 ± 3.61
Height (cm)	173.34 ± 10.39
Body mass (kg)	76.33 ± 14.68
TBF (%)	17.58 ± 5.26

Abbreviation: TBF, total body fat percentage.

ACFT

The ACFT consists of six events (see Supplementary Table SI) that occur in the following order: (1) 3DL, (2) SPT (10-lb ball), (3) 2-min max rep HRPU, (4) 300 m SDC, (5) max rep LT or max hold PLK, and (6) 2MR. Regarding the LT and PLK, cadets and active duty soldiers had an option to select which one was used for the standardized grading. The ACFT is scored out of a maximum 600 points, and each event is scored out of a possible 100 points. For a cadet to pass the ACFT, they must score a minimum of 60 points per event or, in total, a minimum of 360 points. One week after completing the ACFT, cadets and active duty soldiers visited the lab once to complete their HRV assessment. The participants were asked to refrain from exercising 24 hours before their lab visit. ACFT was completed to U.S. standards and was conducted by U.S. officials. A more detailed and thorough explanation of ACFT data can be found in one of our previous publications.[22]

Subjects

Sixty participants were recruited, and 10 participants were excluded from the study because of the lack of HRV data or failure to complete or pass ACFT. Participants were recruited from the U.S. Reserve Officers' Training Corps student population of Baylor University and Central Texas but was not limited to cadets. The study was open to local military personnel, which included active duty, reserve, and national guard. Although a few active duty military members were included for this study, the majority of the subjects were cadets. The inclusion criteria for participation are as follows: (1) completed an ACFT within 6 weeks, (2) at least 18 years of age, (3) not pregnant, and (4) free of any known chronic diseases that could affect the performance. This study was approved by the Baylor University Institutional Review Board and was performed in accordance with the ethical standards of the Declaration of Helsinki. All participants were informed of the experimental procedures and associated risks before participating in the study and provided written informed consent.

Baseline demographics

HRV Protocol and assessment. HRV was recorded using an elastic electrode Polar belt (H7™, Polar Wearlink®, Lake Success, NY), placed on the distal third of the sternum. Participants completed the ACFT and had up to a week to complete HRV data collection in the lab. Participants were asked to arrive to the lab after an overnight fast and lie supine for 5 minutes in a climate-controlled room (22–23 °C). During this time, participants were asked to relax and

TABLE II. ACFT Result Demographics

Variables	ACFT cadets ($n = 50$)
3DL (lbs.)	257.70 ± 73.59
SPT (m)	8.43 ± 2.46
HRPU (reps)	41.66 ± 12.48
SDC (seconds)	118.17 ± 32.06
LT (reps)	11.27 ± 6.69
PLK (seconds)	136.89 ± 27.82
2MR (seconds)	932.86 ± 196.50

Abbreviations: lbs., pounds; reps, repetitions.

refrain from speaking or moving. HRV time and frequency domains were collected during this 5-minute resting period. SI was also measured and calculated by using the CardioMood equation n(SI = [Amplitude of Mode%]/[2*Mode* (RRmax – RRmin)].[20] All HRV indices are presented in Supplementary Table SII.

Statistics. Means and SDs were determined for all ACFT and HRV variables. Normality was assessed via the Shapiro–Wilk test, and visual inspection of histograms and P-P plots and independence of residuals was determined by the Durbin–Watson statistic. Associations between HRV variables and ACFT were reported as Pearson's correlation coefficients (r). Multiple linear regression analysis was used to test the relationship between total and individual ACFT scores and HRV frequency (total power [TP], HF, LF, and very low frequency [VLF]), time domains (RMSSD and SDNN), and the SI. The significance was set a priori at $P < .05$. Data were analyzed with SPSS version 27 (IBM SPSS, Chicago, IL) and SAS software version 9.4 (SAS, Cary, NC, USA).

RESULTS

Cadet Demographics

Participant demographic data are presented as means ± SDs in Table II. The participants' ACFT scores, both overall and individual event scores and event metric values, were compared to HRV time domain variables and frequency domain variables to determine correlation confidents of each ACFT event and traditional HRV variables (see Table III). Traditional HRV variables include TP, HF, LF, VLF, RMSSD, and SDNN, which were selected for their predictive purposes for both performance and clinical outcomes.

Linear Regressions

A linear regression was run to determine the predictive relationship of HRV variables to ACFT event metrics and total score. The SI was the only predictor of ACFT and was a predictor of 2MR, which demonstrated a significant linear relationship ($F = 16.93$, $P = .0002$), with a lower SI being indicative of a quicker 2MR time. No other HRV variables resulted in a linear relationship with the ACFT.

Correlations

The correlations between the overall ACFT event scores and traditional HRV variables are presented in Table III. SPT and SDC events were significantly correlated ($P < .05$) with TP, HF, LF, VLF, RMSSD, and SDNN HRV. The correlation between the raw metric value of the ACFT events and traditional HRV variables can be seen in Table IV. The raw metric value of SDC was significantly correlated with TP, HF, LF, VLF, and RMSSD, whereas SPT only had a significant correlation with VLF. The 2MR had significant correlations with the time domain variables of RMSSD and SDNN. None of the other events demonstrated a significant correlation with the HRV variables in either the event score or the raw metric value scenario.

DISCUSSION

The focus of this study was to determine if HRV variables were indicative of determining ACFT performance outcomes in army cadets and active duty soldiers. Significant correlations were observed in SPT and SDC event scores when compared to traditional HRV variables. When comparing ACFT event scores to HRV variables, there were only correlations observed in SPT and SDC with traditional HRV variables, whereas the 2MR was only correlated with the SI. Finally, the 2MR was correlated with RMSSD and SDNN. In the regression model, the SI was the only variable able to predict 2MR performance, suggesting that the SI has predictive capabilities regarding 2MR performance.

Certain types of exercise have demonstrated a specific reliance to either time domain HRV variables or frequency domain variables. Resistance exercise appears to have a correlation with frequency domain variables in either a recovery aspect or a performance aspect.[11,13,18] Previous research by Chen et al.[18] observed a lower HF metric, which demonstrated a decrease in resistance exercise performance because of lower parasympathetic power, which is reflected by a lower HF.[18] Additionally, LF has been correlated with sympathetic power, which can demonstrate strength performance based on how well sympathetic power is reflected.[18] Since SPT and SDC are considered predominately anaerobic exercises, implying these events are assessing resistance training performance. However, because of the lengths of these assessments, it is possible that they may be assessing aerobic exercise. Moreover, the results from our study indicated that there were correlations of SPT and SDC event scores with frequency domain HRV variables (TP, HF, LF, and VLF). This could be explained by the fact that frequency domain variables have been linked to resistance performance and recovery.[6,13] These baseline HRV frequency domain measurements may be indicative of a better SPT and SDC performance; however, it can be used to assess recovery in-between events to ensure that each participant is adequately recovered from their previous event. Our results also demonstrated that SPT and SDC event scores were correlated with time domain variables (RMSSD and SDNN). This correlation seems abnormal

TABLE III. ACFT Event Score Correlation with HRV Variables

Event	TP	HF	LF	VLF	RMSSD	SDNN
3DL	–0.19246	–0.18664	–0.18557	–0.20908	–0.18127	–0.1691
SPT	–0.53121*	–0.52604*	–0.49844*	–0.55152*	–0.46412*	–0.43675*
HRPU	–0.15053	–0.14799	–0.14587	–0.15665	–0.12412	–0.11817
SDC	–0.48324*	–0.47926*	–0.44525*	–0.50797*	–0.41252*	–0.37735*
PLK	–0.14361	–0.14329	–0.1517	–0.13685	–0.15371	–0.16816
LT	0.05716	0.08473	0.01763	–0.02579	–0.03379	–0.00606
2MR	–0.15249	–0.14809	–0.14908	–0.16177	–0.12453	–0.12171

*Significant correlation ($P \leq .05$).

TABLE IV. ACFT Event Result Correlation with HRV Variables

Event	TP	HF	LF	VLF	RMSSD	SDNN
3DL	–0.20276	–0.19719	–0.19314	–0.22067	–0.18011	–0.16809
SPT	–0.2785	–0.27406	–0.26699	–0.2882*	–0.26307	–0.24794
HRPU	–0.14884	–0.1464	–0.14082	–0.15796	–0.11743	–0.11108
SDC	0.37108*	0.36683*	0.33373*	0.40204*	0.30547*	0.27475
PLK	–0.10187	–0.10149	–0.10826	–0.09692	–0.10232	–0.11588
LT	0.05849	0.08614	0.01925	–0.02534	–0.03224	–0.00552
2MR	0.25519	0.24764	0.27021	0.2502	0.28246*	0.29774*

*Significant correlation ($P \leq .05$).

since many studies have not demonstrated a relationship or correlation between resistance performance and time domain HRV variables.[12,13] However, our findings suggest that there may be a relationship between SPT and SDC alongside time domain HRV variables. This could indicate that these events may not be fully anaerobic or cadets and active duty soldiers with better HRV recovered and performed better. Considering that SDC is an event that combines four different types of exercises (sprint, sled drag, lateral shuffle, and farmer carry) and covers a distance of 250 m, it suggests that it would take longer to complete than anaerobic energy pathways that could sustain energy output.[1] This event typically does take longer than a minute to complete, meaning that aerobic energy pathways would begin to be utilized for energy and heart rate would stay elevated for a prolonged amount of time.

Sprint training has also been proven to improve the overall cardiac autonomic modulation, which could also help explain the correlation in the time domain variables.[1,14] Although the correlations between SDC and SPT event scores were uniform and correlated with all the traditional HRV variables, the raw event measurements demonstrated similar but somewhat different results. First, SPT was only correlated with VLF, which represents the sympathetic nervous system activity.[5] This finding further emphasizes that SPT is primarily a resistance performance event, and it has been noted that LF HRV is primarily altered after an acute bout of resistance training by a reduction of LF after a bout of exercise.[18,23] If cadets and active duty soldiers had higher VLF, it could indicate that those individuals have the ability to recover quicker, which may potentially influence performance outcomes.[15] SDC event measurements were correlated with TP, HF, LF, VLF, and RMSSD, which strengthens the likelihood that this event is not entirely an anaerobic resistance performance event. Currently, RMSSD is primarily utilized to assess the performance of aerobic-based exercises and cardiorespiratory fitness.[5,16,24] It is possible that RMSSD could be an indicator that more rest may be needed following this event and HRV variables. Furthermore, both time and frequency domain may well be used to assess the performance and recovery of SDC.[24] Additionally, both time domain variables, RMSSD and SDNN, were correlated with the 2MR event measurement, which was to be expected. However, for the event score and HRV variables, we are unsure why no correlation was found between the two.

In our regression model, the only significant linear relationship was observed between SI and the 2MR. This model demonstrated that a lower baseline SI is linearly related to a lower 2MR time. This can be attributed primarily to a lower SI having a correlation with higher VO_2 max.[20] A higher maximal VO_2 would indicate that cadets and active duty soldiers are more aerobically fit and have a lower 2MR time compared to the cadets and active duty soldiers who have a lower maximal VO_2, or for the purpose of this study, a lower baseline SI would be indicative of a lower 2MR time. Since the ACFT is a combination of six events that occur consecutively, recovery between each event can have an effect on the cadet's performance.[10,21,23,25] As demonstrated by multiple studies, HRV can be used as a tool to evaluate recovery and is noted by the fact that individuals with lower baseline SI levels appear to recover more efficiently than those with higher SI levels.[18,20] In this case, cadets and active duty soldiers with lower baseline SI levels would be able to recover quicker in-between event sessions and have higher performance outcomes.

LIMITATIONS

This study, although novel, did have certain limitations. First, we relied on U.S. platoons to conduct the ACFT and adequately report their results. The United States has set up very rigorous guidelines to conduct the ACFT properly and can only be conducted by certified higher ranking official.[1] This allows for the ACFT to be standardized but cannot control biases that different practitioners may have. Yet these implicit biases would have had minimal impact to our results because of the standardization of the AFCT.[1,4] It is also important to note that we could not control aspects such as dietary intake, hydration status, or sleep for the ACFT. Moreover, it was also assumed that all participants were fasted and had abstained from exercise for at least 24 hours before their lab visit. This limitation would have caused the cadets and active duty soldiers to have slightly elevated SI levels but nothing extremely different from their baseline values, and any SI value that was extremely high would have been deemed an outlier.[20] Additionally, we understand that, with the number of correlations that were run, the possibility of a type 1 error occurring could increase.

CONCLUSION

In conclusion, HRV was not a total predictor of ACFT performance in army cadets and active duty soldiers. The SI provided predictive capabilities specifically for the 2MR, which demonstrated that a lower SI would indicate a better 2MR performance than cadets and active duty soldiers who had higher SI at baseline. The SDC and SPT events were correlated with traditional HRV variables, meaning that there was no linear relationship between the events and the HRV variables. However, there could be other relationships not assessed within HRV and the ACFT, such as a recovery aspect or an assessment relationship. Although HRV has been used for decades, the practical implications regarding the exercise performance are still being explored, and further examination is needed to better understand the mechanisms of HRV and performance. Future research is warranted for the reporting of the SI and a more focused investigation into the reliability of SI with performance. More specifically, further research focused on utilizing HRV in real-world setting and with the results yielded from this study can provide researchers with the necessary HRV variables to assess.

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SUPPLEMENTARY MATERIAL

Supplementary material is available at *Military Medicine* online.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY STATEMENT

The raw data sets can be provided to readers upon request from the corresponding author.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

University Institutional Review Board for research with human subjects (Project No. AY2018-1169) grant approval was obtained before the start of data collection. The research study and protocol adhere to the ethical guidelines outlined in the 1975 Declaration of Helsinki.

CONSENT FOR PUBLICATION

All authors have read and agreed to the published version of the manuscript.

AUTHORS' CONTRIBUTIONS

J.S.F., J.L.H., and R.E.T. assisted with the study conception and design; J.S.F., R.E.T., T.J.C.-L., and J.L.H. assisted with the acquisition of subjects and/or data; J.S.F., K.A.R., J.L.H., R.E.T., and T.J.C.-L. assisted with the analysis and interpretation of data; and J.S.F., R.E.T., T.J.C.-L., J.L.H., K.A.R., and L.K.F. assisted with the preparation of manuscript.

CLINICAL TRIAL REGISTRATION

Not applicable.

INSTITUTIONAL REVIEW BOARD (HUMAN SUBJECTS)

This study was approved by the Baylor University Institutional Review Board (Project ID: 1,675,892-3) and was performed in accordance with the ethical standards of the Declaration of Helsinki.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC)

Not applicable.

INSTITUTIONAL CLEARANCE

Institutional clearance approved.

REFERENCES

1. Army Publishing Directorate: Holistic health and fitness testing. Available at https://armypubs.army.mil./ProductMaps/PubForm/Details.aspx?PUB_ID=1020966; accessed March 17, 2022.
2. Orr RM, Lockie R, Milligan G, Lim C, Dawes J: Use of physical fitness assessments in tactical populations. Strength Cond J 2022; 44(2): 106–13. 10.1519/SSC.0000000000000656.
3. Pihlainen K, Santtila M, Häkkinen K, Kyröläinen H: Associations of physical fitness and body composition characteristics with simulated military task performance. J Strength Cond Res 2018; 32(4): 1089–98. 10.1519/JSC.0000000000001921.
4. Barringer ND, McKinnon CJ, O'Brien NC, Kardouni JR: Relationship of strength and conditioning metrics to success on the army ranger physical assessment test. J Strength Cond Res 2019; 33(4): 958–64. 10.1519/JSC.0000000000003044.
5. Shaffer F, Ginsberg JP: An overview of heart rate variability metrics and norms. Front Public Health 2017; 5: 258. 10.3389/fpubh.2017.00258.
6. Makivić B, Nikić Djordjević M, Willis MS: Heart rate variability (HRV) as a tool for diagnostic and monitoring performance in sport and physical activities. J Exerc Physiol Online 2013; 16(3): 103–31.

7. Urzeala C, Bota A, Serbanoiu S, Mezei M, Dutheil F, Courteix D: Heart rate variability as a possible predictor of sport performance in junior rhythmic gymnastics. Isokinet Exerc Sci 2020; 28(2): 171–9. 10.3233/IES-192222.
8. Lewis GF, Hourani L, Tueller S, et al: Relaxation training assisted by heart rate variability biofeedback: implication for a military predeployment stress inoculation protocol. Psychophysiology 2015; 52(9): 1167–74. 10.1111/psyp.12455.
9. Holmes CJ, Winchester LJ, MacDonald HV, Fedewa MV, Wind SA, Esco MR: Changes in heart rate variability and fatigue measures following moderate load resistance exercise. J Exerc Physiol Online 2020; 23(5): 24–36.
10. Gronwald T, Rogers B, Hottenrott L, Hoos O, Hottenrott K: Correlation properties of heart rate variability during a marathon race in recreational runners: potential biomarker of complex regulation during endurance exercise. J Sports Sci Med 2021; 20(4): 557–63. 10.52082/jssm.2021.557.
11. Papadakis Z, Forsse JS, Peterson MN: Effects of high-intensity interval exercise and acute partial sleep deprivation on cardiac autonomic modulation. Res Q Exerc Sport 2020; 92: 1–19. 10.1080/02701367.2020.1788206.
12. Papadakis Z, Grandjean PW, Forsse JS: Effects of acute exercise on cardiac autonomic response and recovery in non-dialysis chronic kidney disease patients. Res Q Exerc Sport 2022; 1–14. 10.1080/02701367.2022.2057401.
13. Dong JG: The role of heart rate variability in sports physiology. Exp Ther Med 2016; 11(5): 1531–6. 10.3892/etm.2016.3104.
14. Michael S, Graham KS, Davis GMO: Cardiac autonomic responses during exercise and post-exercise recovery using heart rate variability and systolic time intervals—a review. Front Physiol 2017; 8: 301. 10.3389/fphys.2017.00301.
15. Fortes LS, Ferreira MEC, Paes ST, et al: Effect of resistance training volume on heart rate variability in young adults. Isokinet Exerc Sci 2019; 27(1): 69–77. 10.3233/IES-182207.
16. Proietti R, Di Fronso S, Pereira LA, et al: Heart rate variability discriminates competitive levels in professional soccer players. J Strength Cond Res Lippincott Williams Wilkins 2017; 31(6): 1719–25. 10.1519/JSC.0000000000001795.
17. Holmes CJ, MacDonald HV, Esco MR, Fedewa MV, Wind SA, Winchester LJ: Comparison of heart rate variability responses to varying resistance exercise volume-loads. Res Q Exerc Sport 2022; 93(2): 391–400. 10.1080/02701367.2020.1851351.
18. Chen JL, Yeh DP, Lee JP, et al: Parasympathetic nervous activity mirrors recovery status in weightlifting performance after training. J Strength Cond Res 2011; 25(6): 1546–52. 10.1519/JSC.0b013e3181da7858.
19. Kaikkonen P, Hynynen E, Hautala A, Ahtiainen JP: The effects of an intensive 2-wk resistance training period on strength performance and nocturnal heart rate variability. Int J Sports Physiol Perform 2020; 15(10): 1448–54. 10.1123/ijspp.2019-0531.
20. Torres R, Richardson K, Lowry C, et al: The influence of an acute bout of high-intensity interval exercise on heart rate variability indices and stress index in the absence of cardiometabolic diseases. Res Directs Health Sci 2022; 2(1): 5. 10.53520/rdhs2022.10430.
21. Martínez-Navarro I, Sánchez-Gómez JM, Collado-Boira EJ, Hernando B, Panizo N, Hernando C: Cardiac damage biomarkers and heart rate variability following a 118-km mountain race: relationship with performance and recovery. J Sports Sci Med 2019; 18(4): 615–22.
22. Heileson JL, McGowen JM, Moris JM, et al: Body composition, eicosapentaenoic acid, and vitamin D are associated with army combat fitness test performance. J Int Soc Sports Nutr 2022; 19(1): 349–65. 10.1080/15502783.2022.2094717.
23. Hedelin R, Bjerle P, Henriksson-Larsén K: Heart rate variability in athletes: relationship with central and peripheral performance. Med Sci Sports Exerc 2001; 33(8): 1394–8. 10.1097/00005768-200108000-00023.
24. Heffernan KS, Fahs CA, Shinsako KK, Jae SY, Fernhall B: Heart rate recovery and heart rate complexity following resistance exercise training and detraining in young men. Am J Physiol Heart Circ Physiol 2007; 293(5): H3180–86. 10.1152/ajpheart.00648.2007.
25. Panissa VLG, Cal Abad CC, Julio UF, Andreato LV, Franchini E: High-intensity intermittent exercise and its effects on heart rate variability and subsequent strength performance. Front Physiol 2016; 7: 81. 10.3389/fphys.2016.00081.