Journal of Physical Education and Sport ® (JPES), Vol. 21 (5), Art 363, pp. 2730 – 2736, September 2021
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Heart rate percentage as a method for determining intra-set resting during a post-activation performance enhancement exercise to increase vertical jump performance

SAMUEL MONTALVO[1], DANIEL CONDE[2], MATTHEW P. GONZALEZ[3], MARTIN DIETZE-HERMOSA[4], GABRIEL IBARRA-MEJIA[5], SANDOR DORGO[6]
[1,2]*The University of Texas at El Paso, Doctor of Physical Therapy Program, Rehabilitation Sciences Department*
[2,]*The University of Texas at El Paso, Kinesiology Department, USA*
[6]*The University of Texas at El Paso, Public Health Sciences Department,USA*
[3,7]*The University of Texas at San Antonio, Kinesiology Department,USA*
[4]*Brigham Young University – Idaho, Department of Human Performance and Recreation, USA*

Published online: September 30, 2021
(Accepted for publication September 15, 2021)
DOI:10.7752/jpes.2021.05363

Abstract
BACKGROUND: Post-Activation Performance enhancement methods have been previously studied to potentiate power and plyometric exercises. The purpose of this study were to determine if 1) Heart Rate Percentage (HR%) can be used as an intra-set rest modulator during a post-activation potentiation enhancement (PAPE) training method to improve vertical jump performance, and 2) if there is a relationship between heart rate variability (HRV), and lower body strength, and responses to PAPE as observed in lower body electromyography and vertical jump performance. METHODS: Fourteen resistance-trained subjects participated in this blocked randomized crossover study. Two experimental PAPE conditions were performed: 1) PAPE-Time and 2) PAPE-HR%. Each condition included 5 series of 5 repetitions of the back squat, performed at 87% of the individual's 1RM followed by 1-minute rest between the squats and vertical jump and 3 minutes rest between series in the PAPE-Time. In the PAPE-HR% experimental condition, the rest between the squat and the vertical jump was individualized to 50% of the individual's predicted heart rate maximum. RESULTS: The ANOVA repeated measures analysis indicated that vertical jump performance measures between baseline measures and PAPE conditions were significantly different. For PAPE-Time, vertical jump performance increased by 8.1%, and for PAPE-HR%, by 8.4%, with improvements in vertical jump performing showing non-significant differences between these conditions. Additionally, there was no association between HRV and vertical jump performance, or lower body strength. CONCLUSIONS: Using time and heart rate percentage as an intra-set modulator during PAPE exercises may be a viable option to increase vertical jump height.
Key Words: Post-Activation Performance Enhancement; Countermovement Jump; MyJump2

Introduction

Vertical Jump performance has been regarded as measure of athleticism in sport. Previous studies have demonstrated that vertical jump is associated with metrics of athleticism (i.e., muscular power, agility, reactive strength index, etc.) (Dietze-Hermosa et al., 2020; Dobbs et al., 2019; Montalvo & Dorgo, 2019). Post-activation potentiation enhancement (PAPE) is an acute effect of improved performance resulting from a previous high force maximal voluntary contraction exercise. Recently, PAPE has been proposed as a different concept than post-activation potentiation (PAP), in where PAPE is an acute effect of physical improved performance (i.e., vertical jump) due to increased muscular temperature, muscle tendon stiffness, and muscular activation, while PAP is an acute improvement in muscle twitch contraction due to increases in myosin light chain phosphorylation and increased activity of the Hoffmann reflex (H-reflex) (Blazevich & Babault, 2019; Hodgson et al., 2005). Previously, systematic reviews have described PAPE effects and its application to sports performance (Gouvea et al., 2013; Hodgson et al., 2005; Seitz & Haff, 2016). A meta-analysis by Hodgson, Docherty, & Robbins (2005) explored the differences in protocols and modulation of training parameters (i.e., reps, sets, intensity, volume, gender, age, training status, and others) to induce improved performance attributed to the effect of PAPE in athletes and non-athletes; comprehensive findings indicate that PAPE protocol is an effective method to improve explosive performance. More recently, a dedicated meta-analysis indicated that when applied properly, PAPE protocols are an effective method to improve vertical jump performance (Dobbs et al., 2019). Moreover, PAPE protocols utilize a time window between the maximal effort exercise and the subsequent explosive exercise; previously, a study with soccer players used a 4, 8, 12, 16, and 20 minutes resting time window between 3 repetition maximum squat and a countermovement jump with no difference among protocols , indicating that there is a high individualization for resting time (Mola et al., 2014).

Corresponding Author: SAMUEL MONTALVO, E-mail: smontalvo@utep.edu

Recent attention has been placed on Heart Rate Variability (HRV) and its application to sports and exercise (Areas et al., 2018; Dong, 2016; Karavirta et al., 2013; Sloan et al., 2017; Vitale et al., 2019). HRV is the chronological difference between successive heartbeats measured in milliseconds, representing the vagal nerve pulse activity on the sinoatrial node. Research on HRV focuses primarily on behavioral and mood states, regulation of emotions, cognitive function, brain plasticity, and biological functions, including inflammation processes and metabolic homeostasis (Vitale et al., 2019). Higher values in HRV and lower heart rate are correlated, suggesting that changes in HRV may indicate the development of conditions and diseases such as cardiovascular disease (Rennie et al., 2003). In the same study, HRV also served as a tool to examine physical activity and fitness, suggesting that individuals who engaged in vigorous physical activity had lower resting heart rate and higher HRV compared to sedentary individuals, even after adjusting for Body Mass Index (BMI). Additional authors support that regular aerobic conditioning can increase HRV as well as a decrease in resting heart rate (Karavirta et al., 2013; Sloan et al., 2017). Furthermore, two recent reviews have analyzed the methodological components of post-exercise cardiac recovery and stress. These studies reported HRV as an appropriate tool to measure cardiac recovery (Pecanha et al., 2017; Rauch et al., 2018). Similar to HR, HRV has also been correlated to exercise intensity and duration of exercise (Hunt & Saengsuwan, 2018) (Wiles et al., 2008) which has resulted in heart rate monitors such as the H-10 (Polar) regularly being used to monitor training and exercise intensity, such as in soccer players (Alexandre et al., 2012). Finally, given the nature of the well-established relationship between HR and exercise intensity, guidelines of the American College of Sports Medicine, have categorized 50-63%HRmax as low, 64-76%HRmax as moderate, and 60-84%HRmax as vigorous-intensity (American College of Sports, 2000).

A limitation when performing PAPE exercises is to determine the appropriate rest period for each individual between the "inducing PAPE" exercise and explosive "potentiating" exercise. A previous meta-analysis conducted by Seitz & Haff (2016) indicates that untrained individuals might benefit from a rest period > 8 min after the execution of the maximum voluntary contraction exercises. The rest period then decreases for trained individuals ranging from 1 to 4 minutes. Furthermore, it appears that the resting time window during the PAPE protocols is highly individualizable. Thus, and up to date, it is unknown if HR% could be used to determine the optimal resting time during the PAPE exercise sequence. In this study, the goal was to determine the relationship between time-specific resting periods and HRV on PAPE exercise sequence performance. Therefore, the purposes of this project were: 1) to determine if the application of HR% method for rest time evaluation between a PAPE conditioning and potentiation exercise would result in increased vertical jump performance and muscular activation; 2) to determine if PAPE responses, as measured by vertical jump performance, are associated with HRV and lower body muscular strength. We hypothesized that using HR% as a rest intra-modulator during PAPE exercises would result in similar responses of increased vertical jump performance as a time method. In addition, we also hypothesize that those responses would be correlated with HRV and lower body muscular strength.

Materials and methods

Subjects and Study Design

Fourteen resistance-trained subjects (N = 14; males n = 9, age 22.6 ± 1.5 yrs; females n = 5, 22.0 ± 0.9 yrs) participated in this randomized within-subjects repeated measures study design. The inclusion criteria included: 1) subjects with at least 2 yrs. of resistance training and plyometric (jumping) experience; 2) the ability to demonstrate high relative strength in the 1RM squat, estimated using their 1RM divided by body mass (males > 1.5, and females > 1.2); and 3) without any self-reported musculoskeletal, metabolic, or cardiac condition at the time of the study. Subject's descriptives (age, anthropometrics, HRV, and baseline measures) are displayed in Table 1. This study received Institutional Review Board approval from the University of Texas at El Paso (IRB number: 1231008-3), conformed with the Declaration of Helsinki. Written informed consent was obtained from each subject before data collection. Data from Nibali et al. (2015), found a moderate effect size of d = 0.764 between two PAPE conditions and vertical jump height with 8 participants. Furthermore, these parameters were utilized to estimate the sample size by conducting a priori power analysis in Rstudio using R statistical programming language and the "pwr" package. The *priori* analysis revealed that to find a moderate effect size (d = 0.764) at least thirteen participants were needed to obtain a power (1 - β) of 0.83 at an alpha level of 0.05. These parameters and sample size are consistent with previous research that explored the effects of PAPE and vertical jump performance using within-subject designs (Chen et al., 2017; Elbadry et al., 2019)

Table 1. Subject's Descriptives.

	n	Age (yrs.)	Height (m)	Mass (kg)	BMI (kg/m^2)
All	14	22.07 ± 1.07	1.67 ± 0.09	78.84 ± 16.28	28.01 ± 4.92
Males	9	22.33 ± 1.23	1.71 ± 0.08	84.39 ± 16.78	29.06 ± 5.81
Females	5	21.6 ± 0.55	1.62 ± 0.09	68.86 ± 10.21	26.12 ± 2.05

Procedures

On day 1, anthropometric measures, HRV, 1RM squat, vertical jump height, and maximum voluntary contraction (MVC) of the Recuts Femoris (RF) and Bicep Femoris (BF) as measured by electromyography were obtained. On subsequent days, with at least 48 hrs. in between to ensure full recovery and avoid muscular fatigue, subjects participated in two PAPE protocols in a randomized order: 1) PAPE-Time (PAPE-T), and 2) PAPE-Heart Rate Percentage (HR%). Both protocols consisted of 5 repetitions of the back squat at 87% of the subject's 1RM followed by the condition-specific rest period, and then a maximal countermovement jump (Duthie, Young, & Aitken, 2002). The rest period was determined differently for the two PAPE methods: the PAPE-T session, the rest period was set at 1-minute between the back squat and countermovement jump, with 3 minutes of passive rest between sets. In the PAPE-HR% session, the rest period was dictated by the subjects' HR with the subject performing the countermovement jump after their heart rate dropped to 50% of their estimated maximum heart rate (HRmax = 220 – age); the 50% was selected as this is considered to be a light-moderated intensity (American College of Sports, 2000). Finally, subjects performed 5 sets of the back squat and countermovement jump paired exercise for all conditions.

Instrumentation

HRV was obtained using a Polar-H10 monitor and data were analyzed utilizing Kubios software; HRV was analyzed using the root mean square of the standard deviation (RMSS) of the R to R intervals. Electromyography (EMG) signals captured at a sampling rate of 1500 Hz were transmitted telemetrically in real-time to an 8 channel PC interface receiver (Mini DTS, Noraxon, Scottsdale, AZ, USA) and recorded by a data acquisition system (MyoResearch 3.10, Noraxon, Scottsdale, AZ, USA). Data were filtered using a bandpass with a low frequency of 10 Hz and a high frequency of 500 Hz, data were rectified and smoothed (root mean square) over 150 ms and normalized to %MVC. The skin was prepared by shaving the individual thigh, where the electrodes will be placed, followed by abrading the skin with sandpaper, and cleaning the area with alcohol pads; EMG electrodes were connected to wireless EMG sensors that were strapped using an elastic strap to the individual's skin to avoid movement of the electrodes or sensors. The pre-gelled Ag-AgCl EMG electrodes had an interelectrode distance of 20 mm, were placed parallel to the orientation of the muscle fibers at half the distance between the origin and insertion of the Rectus Femoris (RF) and Bicep Femoris (BF) muscles (Goodwin et al., 1999).

The 1RM back squat was assessed using a standard protocol system that has previously demonstrated high reliability (Baechle & Wathen, 2008; Tagesson & Kvist, 2007). Subjects attempted to achieve their 1RM within 5 working sets, which were structured as follows: 1) 5-10 repetitions at 50% of perceived 1RM, 2) 5-10 repetitions of 75%, 3) 2-3 repetitions at 87%, 4) 1 repetition at 92-93%, and finally, 5) 1 repetition maximum. Rest periods of five minutes between sets were given to the individuals in order to replenish adenosine triphosphate (ATP) stores and allow for recovery of the central nervous system (Baechle & Wathen, 2008); furthermore, subjects reported previous familiarization to the 1RM testing. Subjects were allowed to continue until failure was achieved. Achieving a 90-degree knee angle was visually enforced for each of the trials. Two Certified Strength and Conditioning Specialists supervised each of the 1RM trials. Safety of the participants was enforced throughout the trials.

Vertical Jump performance was recorded using the MyJump2 app for iOS with an iPhone 7 with data recorded at 240 fps. The iPhone was set 3-meters away from the subjects, allowing full visualization of the vertical jump. In addition, the same tester recorded each trial to increase the test-retest reliability of the measurements. This app has been shown to have good validity and reliability when compared to the gold standard assessment using force platforms (Montalvo et al., 2021); The MyJump2app assesses vertical jump performance using the flight time calculation as follows: Vertical Jump Height (cm) = gravity * time flight / 2 (Balsalobre-Fernandez et al., 2016).

Statistical Analysis

Vertical Jump Data from the MyJump2 app, EMG data from the NORAXON MyoMuscle software, and Heart Rate from the Kubios software were all exported individually and imported into Microsoft Excel. Data were then exported to Rstudio (version 1.4.1106) for statistical analysis using R statistical programming language with a custom-built script. A two-way random effects model intra-class correlation (ICC_{2k}) was conducted to determine intra-subject reliability across multiple vertical jump trials for each of the conditions. There was excellent reliability ($ICC_{2k} > 0.94$) for all conditions, thus, the highest vertical jump from all 5 sets of PAPE for each condition was utilized for the analysis. Moreover, data normality was assessed using the Shapiro-Wilk test and using data visualization techniques (Skewness between 1 and -1, and Kurtosis between 3 and -3). All data showed normal distribution; therefore, individual repeated-measures ANOVAs were used for the analysis. Mauchly's test for sphericity showed that sphericity was assumed. The magnitude (effect size) of the repeated-measures ANOVA was reported as partial eta-squared (η_p^2) and interpreted as: small ($\eta^2_p = 0.01$), medium ($\eta^2_p = 0.06$), and large ($\eta^2_p = 0.14$) effects (Cohen, 1988). When appropriate, post-hoc pairwise comparisons were conducted with the p-value adjusted using a Bonferroni correction. Thereafter, the magnitude of the difference (effect size) between the pairwise comparisons was obtained using Cohen's D with hedge's g correction (Bernards et al., 2017; Lakens, 2013) and interpreted as follows; trivial = ≤ 0.20; small = 0.20 to 0.60; moderate = 0.60 to 1.2; large = 1.2 to 2.0; very large = 2.0 to 4.0; very large >4.0 (Hopkins, 2009). In addition, Pearson correlations were performed between Vertical Jump variables, Heart Rate Variability, and lower body strength variables. A priori statistical significance was set at an alpha level of 0.05 for all statistical analyzes.

Results

Mean and standard deviation of the subject's descriptive and baseline measures were presented in Table 1 and 2, respectively. Furthermore, The ANOVA repeated measures found differences in jump height (cm) between baseline, PAP-T and PAPE-HR% conditions ($F(2,26) = 6.933$, $p = 0.004$; η_p^2 (*large*) = 0.348). The Bonferroni post-hoc test showed that both PAP conditions differed from baseline ($p < 0.05$); Jump height in the PAPE-HR% protocol was higher 8.4% than Baseline (36.81 ± 7.45 cm and 34.09 ± 8.43 cm, respective; p. Adjusted = 0.012, Hedge's g (moderate) = 0.730); similarly, the PAPE-Time condition was 8.1% higher than Baseline (36.69 ± 7.45 cm and 34.09 ± 8.43 cm, respectively; p. Adjusted = 0.012, Hedge's g (large) = 0.835). Moreover, PAPE-HR% and PAPE-Time were not different from each other ($p = 0.868$) (Figure 1 & Table 3).

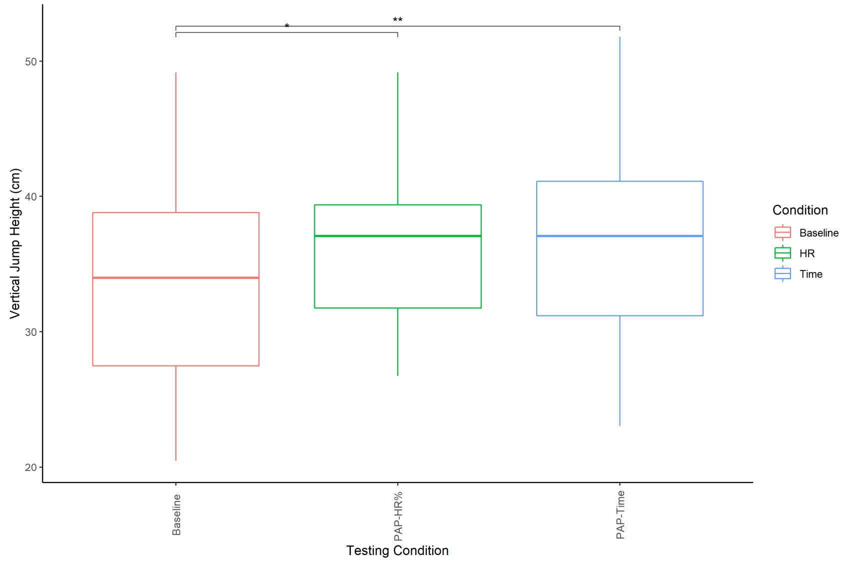

Figure 1. Boxplot of the Vertical Jump height (cm) by each PAPE condition. *denotes significance at p<0.05 and **significance at p<0.01.

There were no differences between the muscle activation of the rectus femoris and/or bicep femoris for either the PAPE-Time (rectus femoris = 79.11 ± 19.22 %MVC; bicep femoris = 70.35 ± 27.05 %MVC) and PAPE-HR% (rectus femoris = 66.33 ± 22.08 %MVC; bicep femoris = 79.47 ± 18.83 %MVC) ($p < 0.05$). Additionally, no correlation was observed between measures of HRV and any of the performance tests. RMSSD from HRV showed no correlation with either 1RM, Relative Strength (RS), or CMJ ($p < 0.05$) (Table 3).

Table 2. Subject's baseline measures.

	1RM (kg)	Relative Strength (RS)	CMJ (cm)	HR (bpm)	HRV SDRR (ms)	HRV RMSSD (ms)
All	119.66±37.63	1.50±0.28	34.09±8.43	68.34± 2.82	59.11±15.85	50.44±16.75
Males	133.93±31.92	1.59±0.18	36.38 ±6.01	68.97±14.33	62.29±18.49	54.87±18.35
Females	93.98±35.81	1.34±0.36	29.98±11.23	68.63±7.90	53.38±8.28	42.47±10.75

Table 3. Vertical Jump Performance at Baseline and Experimental Conditions

	Baseline CMJ (cm)	PAPE HR% CMJ (cm)	PAPE Time CMJ (cm)	Max HR during PAPE HR% protocol (bmp)	Max HR during PAPE Time protocol (bmp)	HRV during PAPE HR% protocol (SSDN)	HRV during PAPE Time protocol (RMSSD)
All	34.09±8.43	36.81±7.45*	36.68±8.56*	144.53±17.35	149.04±22.13	20.15±25.02	28.99±20.31
Males	36.38±6.01	38.34±6.17	39.18±5.78	144.89±15.61	148.03±23.62	28.96±32.93	21.10±25.35
Females	29.97±11.22	34.06±9.46	32.19±11.50	145.17±26.299	147.00±30.08	23.28±15.93	14.06±11.59

*denotes significant difference at p < 0.05 when compared to baseline measures.

Discussion

The primary purpose of this investigation was to determine if using 50% of the individual's maximal Heart Rate (PAPE-HR%) as an intra-rest modulator during PAPE exercises would produce similar results to traditional PAPE resting time periods. The results of this study suggest that using Heart Rate Percentage at 50% of maximal heart rate can yield similar vertical jump height results as using a set time between the PAPE "inducing" activity and PAPE "explosive" activity. There were no differences across all 5 working sets during each of the conditions, thus, an average was found and utilized for comparison. At baseline, during the vertical jump test, individuals showed a 34.09 ± 8.43 cm jump, which was increased to 36.69 ± 8.57 cm in the PAPE-Time and to 36.81 ± 7.45 in the PAPE-HR% conditions. This was 8.44 ± 10.42 % and 9.84 ± 14.64 % improvement for each of the conditions, respectively. Improvements of vertical jump through the PAPE protocol have been previously demonstrated. Duthie and colleagues (2002) demonstrated that using a 3RM squat protocol on a squat machine increased vertical jump performance; however, the authors warrant that these levels are also dependent on the individual's strength levels.

High correlations between vertical jump performance with absolute and relative strength levels as measured by the back squat have been previously reported (Nuzzo et al., 2008). However, there were no correlations between vertical jump height or 1RM and measures of HRV (RMSSD and SDRR) in the present study. Recently, Schneider & Ferrauti (2019) found a very weak and inconsistent relationship between HRV RMSSD with SDRR and lower body strength thus partially supporting the present findings. Potential differences in results may be attributed to the population and protocol used. For example, previous studies have found that individuals with stronger bodymass/strength ratios benefit most from PAPE protocols in vertical jump tests (Wilson et al., 2013), therefore, caution must be taken when extrapolating the results found in this study into other populations. However, similar to the present study, HRV RMSSD has been used as a tool to monitor total exercise volume (Schneider & Ferrauti, 2019), and exercise recovery (Dong, 2016). Previously, HRV was studied during short-time resting intervals (i.e., 1, 2, and 3-minute sections) and compared to a longer and more usual resting period time of 5-mins showing no significant differences between measurements during exercise (Areas et al., 2018). Therefore, it can be expected that individuals with higher physical fitness would return to resting heart rate at a faster rate than less fit individuals due to increased HRV.

Interestingly, no differences in muscle excitation and activation, as measured by surface EMG was observed between PAPE inter-set rest conditions. Although the HRV rest condition was individualized, it did not last more than 3 minutes. Previous literature has indicated that the effects of PAPE can last for up to 10 minutes (Seitz & Haff, 2016; Wilson et al., 2013). In a meta-analysis by Wilson and colleagues (2013) exploring the effect of PAPE and muscular power, higher effect sizes were reported for rest periods of 7-10 minutes (ES = 0.7) after a conditioning activity compared to 3-7 minutes (ES = 0.54) and above 10 minutes (ES = 0.02), suggesting that effects of PAPE can last up to 10 minutes following the conditioning activity. Other literature reported similar findings with longer rest intervals (ES = 0.49) versus shorter rest intervals (ES = 0.17) displaying increased performance following a condition activity. Therefore, this may partially explain why significant differences between intra-set rest conditions were not observed.

Limitations

This study is not without limitations. First, during the PAPE-HR% condition, the subject sat and rested until they achieved 50% of their maximum heart rate. However, the time interval was not measured, although maximum heart rate values during that period are presented in Table 3. It was observed that there was variation in recovery time between the individuals; a recorded time would have allowed the potential to make the connection between HRV and resting time between the squats and the jump. Second, the study sample was composed only of 14 subjects. Due to the inherent high strength requirements necessary for PAPE exercises, there was a limitation in the ability to recruit subjects. However, the repeated measures design allowed the individuals to be compared over conditions, thus, increasing the study's power. Also, 4 female subjects dropped out due to fatigue and being unable to sustain the 5 squatting sets on one of the conditions, thus, reducing the sample size and not allowing a proper assessment of sex differences between PAPE conditions.

Conclusion

Utilizing time and heart rate percentage as an intra-rest modulator during PAPE exercises may be a viable option to increase vertical jump height. In addition, similar muscular activation was observed for both PAPE conditions. Using time-specific rest intervals and 50% of MHR indicates physical preparedness and potentiation between a heavy load back squat and the vertical jump. There was no difference between these methods. Individuals already using heart rate monitors could benefit from tracking their estimated maximum heart rate and implementing the proposed PAPE-HR% method. Finally, it is concluded that using 50% of the estimated maximum heart rate is a viable tool to be used as an intra-set resting tool during PAPE exercises. More research is needed to determine if HRV influences vertical jump ability and the capacity to reduce maximum heart rate during PAPE exercises.

References

Alexandre, D., da Silva, C. D., Hill-Haas, S., Wong, D. P., Natali, A. J., De Lima, J. R. P., Filho, M. G. B. B., Marins, J. J. C. B., Garcia, E. S., & Karim, C. (2012). Heart Rate Monitoring in Soccer: Interest and Limits During Competitive Match Play and Training, Practical Application. *The Journal of Strength & Conditioning Research*, *26*(10), 2890-2906. https://doi.org/10.1519/JSC.0b013e3182429ac7

American College of Sports, M. (2000). *ACSM's guidelines for exercise testing and prescription*. Sixth edition. Philadelphia : Lippincott Williams & Wilkins, [2000] ©2000. https://search.library.wisc.edu/catalog/999931853902121

Areas, G. P. T., Caruso, F. C. R., Simoes, R. P., Castello-Simoes, V., Jaenisch, R. B., Sato, T. O., Cabiddu, R., Mendes, R., Arena, R., & Borghi-Silva, A. (2018). Ultra-short-term heart rate variability during resistance exercise in the elderly. *Braz J Med Biol Res*, *51*(6), e6962. https://doi.org/10.1590/1414-431x20186962

Baechle, T. R. R. W. E., & Wathen, D. (2008). Resistance training. In Essentials of Strength Training and Conditioning.

Balsalobre-Fernandez, C., Kuzdub, M., Poveda-Ortiz, P., & Campo-Vecino, J. D. (2016). Validity and Reliability of the PUSH Wearable Device to Measure Movement Velocity During the Back Squat Exercise. *J Strength Cond Res*, *30*(7), 1968-1974. https://doi.org/10.1519/JSC.0000000000001284 [doi]

Bernards, J. R., Sato, K., Haff, G. G., & Bazyler, C. D. (2017). Current research and statistical practices in sport science and a need for change. *Sports*, *5*(4), 87.

Blazevich, A. J., & Babault, N. (2019). Post-activation Potentiation Versus Post-activation Performance Enhancement in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in physiology*, *10*, 1359-1359. https://doi.org/10.3389/fphys.2019.01359

Chen, Z. R., Lo, S. L., Wang, M. H., Yu, C. F., & Peng, H. T. (2017). Can Different Complex Training Improve the Individual Phenomenon of Post-Activation Potentiation? *J Hum Kinet*, *56*, 167-175. https://doi.org/10.1515/hukin-2017-0034

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. L. Erlbaum Associates.

Dietze-Hermosa, M. S., Montalvo, S., Cubillos, N. R., Gonzalez, M. P., & Dorgo, S. (2020). Association and predictive abilityof vertical countermovement jump performance on unilateral agility in recreationally trained individuals. *Journal of Physical Education and Sport*, *20*, 2076.

Dobbs, W. C., Tolusso, D. V., Fedewa, M. V., & Esco, M. R. (2019). Effect of Postactivation Potentiation on Explosive Vertical Jump: A Systematic Review and Meta-Analysis. *J Strength Cond Res*, *33*(7), 2009-2018. https://doi.org/10.1519/jsc.0000000000002750

Dong, J.-G. (2016). The role of heart rate variability in sports physiology. *Experimental and therapeutic medicine*, *11*(5), 1531-1536. https://doi.org/10.3892/etm.2016.3104

Elbadry, N., Hamza, A., Pietraszewski, P., Alexe, D. I., & Lupu, G. (2019). Effect of the French Contrast Method on Explosive Strength and Kinematic Parameters of the Triple Jump Among Female College Athletes. *J Hum Kinet*, *69*, 225-230. https://doi.org/10.2478/hukin-2019-0047

Goodwin, P. C., Koorts, K., Mack, R., Mai, S., Morrissey, M. C., & Hooper, D. M. (1999). Reliability of leg muscle electromyography in vertical jumping. *Eur J Appl Physiol Occup Physiol*, *79*(4), 374-378. https://doi.org/10.1007/s004210050523

Gouvea, A. L., Fernandes, I. A., Cesar, E. P., Silva, W. A., & Gomes, P. S. (2013). The effects of rest intervals on jumping performance: a meta-analysis on post-activation potentiation studies. *Journal of sports sciences*, *31*(5), 459-467. https://doi.org/10.1080/02640414.2012.738924 [doi]

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation: underlying physiology and implications for motor performance. *Sports medicine (Auckland, N.Z.)*, *35*(7), 585-595. https://doi.org/3574 [pii]

Hopkins, W. (2009). *A scale of magnitude for effect statistics*. Retrieved January 24th from http://www.sportsci.org/resource/stats/index.html

Hunt, K. J., & Saengsuwan, J. (2018). Changes in heart rate variability with respect to exercise intensity and time during treadmill running. *BioMedical Engineering OnLine*, *17*(1), 128. https://doi.org/10.1186/s12938-018-0561-x

Karavirta, L., Costa, M. D., Goldberger, A. L., Tulppo, M. P., Laaksonen, D. E., Nyman, K., Keskitalo, M., Hakkinen, A., & Hakkinen, K. (2013). Heart rate dynamics after combined strength and endurance training in middle-aged women: heterogeneity of responses. *PLoS One*, *8*(8), e72664. https://doi.org/10.1371/journal.pone.0072664

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol*, *4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Mola, J. N., Bruce-Low, S. S., & Burnet, S. J. (2014). Optimal recovery time for postactivation potentiation in professional soccer players. (1533-4287 (Electronic)).

Montalvo, S., & Dorgo, S. (2019). The effect of different stretching protocols on vertical jump measures in college age gymnasts. *The Journal of sports medicine and physical fitness*, *59(12)*(1827-1928 (Electronic)), 1956–1962. https://doi.org/https://doi.org/10.23736/S0022-4707.19.09561-6

Montalvo, S., Gonzalez, M. P., Dietze-Hermosa, M. S., Eggleston, J. D., & Dorgo, S. (2021). Common Vertical Jump and Reactive Strength Index Measuring Devices: A Validity and Reliability Analysis. LID - 10.1519/JSC.0000000000003988 [doi]. (1533-4287 (Electronic)).

Nibali, M. L., Chapman, D. W., Robergs, R. A., & Drinkwater, E. J. (2015). Considerations for determining the time course of post-activation potentiation. (1715-5320 (Electronic)).

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *J Strength Cond Res*, *22*(3), 699-707. https://doi.org/10.1519/JSC.0b013e31816d5eda [doi]

Pecanha, T., Bartels, R., Brito, L. C., Paula-Ribeiro, M., Oliveira, R. S., & Goldberger, J. J. (2017). Methods of assessment of the post-exercise cardiac autonomic recovery: A methodological review. *Int J Cardiol*, *227*, 795-802. https://doi.org/10.1016/j.ijcard.2016.10.057

Rauch, J. T., Loturco, I., Cheesman, N., Thiel, J., Alvarez, M., Miller, N., Carpenter, N., Barakat, C., Velasquez, G., Stanjones, A., Aube, D., Andersen, J. C., & De Souza, E. O. (2018). Similar Strength and Power Adaptations between Two Different Velocity-Based Training Regimens in Collegiate Female Volleyball Players. *Sports (Basel, Switzerland)*, *6*(4), 10.3390/sports6040163. https://doi.org/E163 [pii]

Rennie, K. L., Hemingway, H., Kumari, M., Brunner, E., Malik, M., & Marmot, M. (2003). Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants. *Am J Epidemiol*, *158*(2), 135-143. https://doi.org/10.1093/aje/kwg120

Schneider, C. W. T. R. C. F. A. H. O. H. L. S. O. K. M. M. T. P. M., & Ferrauti, A. (2019). Heart Rate Variability Monitoring During Strength and High-Intensity Interval Training Overload Microcycles. *Frontiers in physiology*, *10*(582).

Seitz, L. B., & Haff, G. G. (2016). Factors Modulating Post-Activation Potentiation of Jump, Sprint, Throw, and Upper-Body Ballistic Performances: A Systematic Review with Meta-Analysis. *Sports medicine (Auckland, N.Z.)*, *46*(2), 231-240. https://doi.org/10.1007/s40279-015-0415-7 [doi]

Sloan, R. P., Schwarz, E., McKinley, P. S., Weinstein, M., Love, G., Ryff, C., Mroczek, D., Choo, T.-H., Lee, S., & Seeman, T. (2017). Vagally-mediated heart rate variability and indices of well-being: Results of a nationally representative study. *Health psychology : official journal of the Division of Health Psychology, American Psychological Association*, *36*(1), 73-81. https://doi.org/10.1037/hea0000397

Tagesson, S. K., & Kvist, J. (2007). Intra- and interrater reliability of the establishment of one repetition maximum on squat and seated knee extension. *J Strength Cond Res*, *21*(3), 801-807. https://doi.org/R-20846 [pii]

Vitale, J. A., Bonato, M., La Torre, A., & Banfi, G. (2019). Heart Rate Variability in Sport Performance: Do Time of Day and Chronotype Play A Role? *J Clin Med*, *8*(5). https://doi.org/10.3390/jcm8050723

Wiles, J. D., Allum, S. R., Coleman, D. A., & Swaine, I. L. (2008). The relationships between exercise intensity, heart rate, and blood pressure during an incremental isometric exercise test. *Journal of sports sciences*, *26*(2), 155-162. https://doi.org/10.1080/02640410701370655

Wilson, J. M., Duncan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Wilson, S. M., Jo, E., Lowery, R. P., & Ugrinowitsch, C. (2013). Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J Strength Cond Res*, *27*(3), 854-859. https://doi.org/10.1519/JSC.0b013e31825c2bdb