Journal of Physical Education and Sport ® (JPES), Vol. 23 (issue 5), Art 134, pp. 1076 - 1085, May 2023
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Training load monitoring and physiological responses to RX CrossFit® training.

LUISA FREIRE DA SILVEIRA CASTANHEIRA[1], EDUARDO MACEDO PENNA[2], EDNA CRISTINA SANTOS FRANCO[3], VICTOR SILVEIRA COSWIG[4]
[1,2,4] Programa de Pós-Graduação em Ciências do Movimento Humano, Instituto de Ciências da Saúde, Universidade Federal do Pará, Pará, BRASIL
[4] Instituto de Educação Física e Esportes, Universidade Federal do Ceará, Fortaleza, Ceará, BRASIL
[3] Seção de Patologia Clínica e Experimental, Instituto Evandro Chagas, Ananindeua, Pará, BRASIL
[3] Faculdade de Educação Física, Departamento de Desporto, Universidade do Estado do Pará, Pará, BRASIL

(Accepted for publication May 15, 2023)
DOI:10.7752/jpes.2023.05134

Abstract:
Approach: CrossFit® is a training program recognized for its rapid growth in popularity in competitive and noncompetitive models and designed to develop different fitness domains simultaneously. In this training model, chronic adaptations are expected to differ from other models due to the high-volume workloads, performed in a self-regulated characteristic. Purpose: Therefore, this study aimed to describe the internal training load imposed on CrossFit® athletes over a three month period and relate it to physical performance indicators. A second goal was to investigate the effect of this training on aerobic fitness indicators. Methods: To this end, competitive athletes were evaluated daily, weekly, and pre and post training. The instruments consisted of daily perceptual measures regarding pain sensations, recovery, sleep quality, heart rate variability, and tests of lower limb power and aerobic power. The data normality was verified by the Shapiro-Wilk test and compared by the ANOVA test for repeated measures, and the correlations between training load indicators and physical performance were tested by Pearson's coefficient. The alpha value was set at 5%. Results and Conclusion: The investigated training program was not enough to induce detectable overreaching or recovery/compensation, at least by the variables evaluated and in a group-based analysis. Also, no relevant changes in aerobic power were found. However, negative correlations between CMJ and HRV with some training load parameters suggest that changes in training loads along the weeks provided neuromuscular and autonomic variations in the expected directions. In summary, the training load imposed in the preparation of elite CrossFit® athletes was relatively stable, despite the constant variation of stimuli and settings. Our findings may help to explain the patterns of the sport, which involves high volume and frequency of training maintained for long periods, which does not match (at least theoretically) with high intensity efforts.
Key Words: **Athletic Performance. Fatigue. Exercise. Cardiorespiratory Fitness.**

Introduction

CrossFit® is a training program recognized for its rapid growth in popularity, having both competitive and noncompetitive structures (Sprey et al., 2016). It is generally characterized by the workouts of the day (WOD), which aim to simultaneously develop different physical conditioning domains (Claudino et al., 2018; Tibana et al., 2017). In general, the practice occurs with high weekly frequency (5.5±0.6 days per week), training volume (120.7±36.7 minutes per session), and intensity (Rating of perceived exertion (RPE) = 8.4±0.9 a.u.) (Claudino et al., 2018; Pritchard et al., 2020), which may counteract the stimulus/recovery balance and lead to relevant physiological disruption over consecutive sessions (Tibana et al., 2017). WODs such as "Fran" and "Cindy" can achieve an intensity corresponding to 95.4±3.0% and 97.4±2.4% of HRmax, 56.7±6.2% and 66.2±4.8% of VO_{2max}, blood lactate of 14±3.3 mmol/L and 14.5±3.2 mmol/L and RPE of 8.4±0.9 u.a. and 8.0±0.9 a.u., respectively, which suggests that high internal training loads are reached (Claudino et al., 2018).

From a chronic perspective, CrossFit® practices have the potential to reduce body fat (~10%) (Bahremand et al., 2020), increase maximal oxygen consumption (13.6% and 11.8% for men and women, respectively) (Smith, 2017), and increase maximal strength (11.1kg and 8.5kg for men and women, respectively) (Cosgrove et al., 2019). These results were found in investigations lasting between 8 weeks and more than 7 months with athletes between the ages of 18 and 40 years, and practice time between 6 and 27 months. Furthermore, these training adaptations have been related to training load assessment and monitoring in the sports sciences community (Claudino et al., 2018; Impellizzeri et al., 2018; West, 2020). In this sense, the data from training load monitoring became relevant information for decision-making about training and competition loads (West, 2020). This process involves the interaction between external loads, such as measures of power and neuromuscular function, and internal loads, such as effort perception, sleep quality, and autonomic control (Halson, 2014).

Corresponding Author: VICTOR SILVEIRA COSWIG, E-mail: vcoswig@ufc.br

However, in this training modality, the knowledge of assessment, monitoring, and the mechanisms to control training load is still relatively recent, which may negatively affect the predictability of adaptation (Smith, 2017). Furthermore, sporting success appears to differ between modalities (West, 2020), and although it seems that CrossFit® performance is related to muscle power, muscle strength, and aerobic fitness (Martínez-Gómez et al., 2019), specific characteristics of the practice may limit the use of the knowledge derived from other modalities. Thus, despite these training load concepts that have been extensively discussed in cyclic and team sports (McLaren et al., 2018), the widely variable and multimodal nature of CrossFit® loads and the self-regulated characteristic of intensity control make it difficult to interpret the correlations between external and internal loads, as well as their subsequent effects.

Alternatively, some perceptual, physical and physiological measures have been used for training monitoring. Regarding perceptual measures, two of the most used are the RPE and the Total Quality Recovery (TQR) scale (Osiecki et al., 2015). Recent studies emphasize the validity and reliability of using these subjective methods of training monitoring, load analysis, and recovery (Horta et al., 2020). Moreover, the validity of the session RPE (multiplied by the duration of the activity) has already been investigated in the CrossFit® context and has been indicated as an easy and valid tool to assess the internal training load (Tibana et al., 2018). From the neuromuscular perspective, one of the most common methods is the countermovement jump (CMJ) test, which has been shown to be valid, reliable, and able to provide information about strength, muscle fatigue, and maximal power (Gajewski et al., 2018). While the cardiovascular responses have been used and analyzed to infer autonomic balance, mainly through heart rate variability (HRV). Moreover, all these measures interact with each other to yield fitness responses.

In summary, training load monitoring can provide a scientific basis for changes in athletes' performances. However, in the training program described here, that is still not entirely clear and different responses are expected due to the sport's particularities. Therefore, this study aimed to describe the internal training load imposed on CrossFit® athletes over three months and relate it to physical performance indicators. Our main hypothesis was that 12 weeks of training would result in i) high RPE values due to the intensity of the modality; ii) positive adaptations in aerobic power, and iii) internal loads with detectable changes throughout the weeks in response to training load variation.

Material & methods

Experimental Approach to the Problem

In this study, data collection occurred daily, weekly, and pre and post-training. Daily, athletes were instructed to fill out questionnaires before and 10 minutes after training. Weekly, on mondays, after active rest (sunday), HRV and CMJ were evaluated. Aerobic power was estimated before and after the three months of monitored training. The same evaluator performed all measurements.

Subjects

All participants were informed about the study objectives and signed a consent form. This study was approved by the local ethics and research committee (#4.136.386) and followed the Helsinki ethical principles for research involving humans. According to the sample calculation, to obtain a statistical power of 0.8, with an effect size of 0.25 and considering an alpha value of 5%, for a design with 12 repeated measures and one group, 13 individuals would be necessary (G*Power software version 3.1.9.7).

Sixteen subjects with a mean age of 31.0±6.8 years, 77.5±9.0 kg of body mass and training time of 2.8±0.8 years were part of the analysis. The sample included participants of both sexes who trained daily at a certified CrossFit® fitness center and who had practiced for at least 2 years without interruption, with no recent injuries that might interfere with the results of the study, or declared use of illicit substances, such as anabolic steroids. Those who competed in the RX category were included. Those who presented diseases or injuries throughout the collections and those who presented some other aspect that could interfere with the research results were excluded from the sample. Also, subjects were asked to maintain their habitual nutritional habits during the intervention.

Procedures

Daily Questionnaires

The proposed daily questionnaires were composed of scales including TQR (Kenttä & Hassmén, 1998), RPE of both the entire session (RPEs) and the WOD (RPEw) through the CR-10 Borg Scale (Kurilla, 2011), the Visual Analog Pain Scale (Lee et al., 1991) and the sleep quality. The questionnaires were printed in a notebook form and delivered to the athletes, who were asked to fulfill them before and ten minutes after each training session.

To quantify the session RPE, the full duration (RPEs) and the WOD duration (RPEw) were considered. The internal load variables, derived from RPE, were calculated according to the following equations: Monotony = average session load/standard deviation; Strain= sum of training loads X monotony; and Session RPE= session RPE X activity duration.

Heart Rate Variability

To measure HRV, the ELITE HRV mobile application was used (Perrotta et al., 2017). Participants performed the test positioned on a chair after heart rate normalization; the first two minutes were recorded and the first one was excluded. Data regarding HRV (R-R intervals) were collected through cardio monitors (PolarH10; Polar$^{®}$) connected to a Smartphone. Subsequently, the R-R intervals were exported and analyzed in a specific software (Kubios HRV; version 3.3.1 -Kubios Oy, Finland). All data underwent visual inspection to remove ectopic beats. The time-domain parameter LnRMSSD (square root of the mean squared differences of successive R-R intervals in milliseconds) was chosen for analysis, as it has good validity and reproducibility in sports context (Esco et al., 2018).

Vertical Jump

The participants performed two CMJ with a ten-second interval between them. Each jump was performed with the hands behind when picking up momentum, raising them while executing the jump. The jumps were filmed using a smartphone and analyzed through the MyJump2 mobile application, following a specific validated protocol (Gallardo-Fuentes et al., 2016).

Aerobic Power

To infer the aerobic power of the subjects, an incremental test to exhaustion was applied. The subjects started the test at 40 rpm, and 5 rpm increments were made every minute. During the test, the RPE was evaluated using the CR-10 Borg Scale (Kurilla, 2011). The test occurred until self-reported exhaustion or failure to maintain the expected rpm due to fatigue. At the end of the last stage, the corresponding rpm and load (W) were collected. The Airbike (Assault -Fortify$^{®}$, Taiwan) was chosen because it mobilizes lower and upper limbs and has become common in CrossFit$^{®}$. Unpublished data from our lab show that the test is reliable (ICC=0.94).

Workouts description

The workouts were prescribed based on the head coach's programming and the structure of the workouts followed AMRAP (as many rounds/repetitions as possible), EMOM (execute an exercise sequence within the minute and rest in the remaining time), RFT (execute X number of rounds in the shortest time possible), and RNFT (execute X number of rounds without worrying about time) models. All sessions were divided into warm-up/mobility, technique, and WOD. It is noteworthy that these training practices do not necessarily follow the CrossFit$^{®}$ usual pattern for ordinary practitioners, but were planned specifically for competition, which increased total training volume. Thus, despite the fact that the practice investigated here may not reflect the daily ordinal practices of CrossFit$^{®}$ boxes for the majority of the practitioners, it is not without precedent, since the training plan described here was similar to others previously described (Pritchard et al., 2020).

Statistical analyses

Statistical procedures followed an intention-to-treat approach. Then, missing data were imputed using the Closest Match method, which showed to be more efficient in repeated measures designs than others, such as listwise deletion, last value carried forward, standardized score imputation, or regression imputation (Elliott & Hawthorne, 2004). Briefly, data imputed were based on the corresponding value of the same time-point of the subject that presented the lowest sum of absolute differences in a given variable. All imputed data are highlighted in the raw data file.

After that, the normality of the data was tested using the Shapiro-Wilk test. The data were presented by mean and standard deviation. Correlations between internal load and physical and physiological variables were tested by Pearson's coefficient, while pre and post-training adaptations were compared by t-test and the weekly monitoring data was checked by the ANOVA test for repeated measures. All analyses were done in SPSS 20.0 software and the alpha value was set at 5%.

Results

Regarding the training sessions, all were composed of periods of mobility/warm-up, technique, and WOD. In general, 18 WODs followed the AMRAP structure (27.3%), 17 the RFT (25.8%), 8 the EMOM (12.1%), and 6 the RNFT (9.1%). There was also a simulated competition, called OPEN (9.1%), and others, such as aerobic training in a rowing ergometer (3.0%) and low-intensity aerobic training (13.6%) (Supplementary file). The average duration of the training sessions was 95.6±16.8 min, and the time devoted to the WOD was 25.5±12.7 min (27.1±13.6% of the session).

Perceptual Variables

Regarding the perceptual variables, the weekly sleep quality ranged from 3.5±0.3 to 3.9±0.8 a.u., which represents a rating between regular and good (Figure I; Panel A). Differences between time points were found ($F=3.16$; $p<0.01$), where values measured in the 11th week were higher than in the 8th ($p=0.04$) and 10th ($p=0.03$). All athletes reported some perception of pain during the 12 weeks.

The average weekly perception ranged from 24±8.5 to 54±29.8 a.u., which represents moderate pain (Figure I; Panel B). The most prevalent pain sites were in the low back (19.4%), shoulders (13.2%), and back (11.7%).

The range of weekly responses to the TQR scale was from 13.1±1.0 to 14.8±1.8 a.u.

(Figure I; Panel C). When comparing time points, a statistical significance was found (F=5.84; p<0.01), and values measured in the 2nd and 3rd weeks were higher than those from the 9th week.

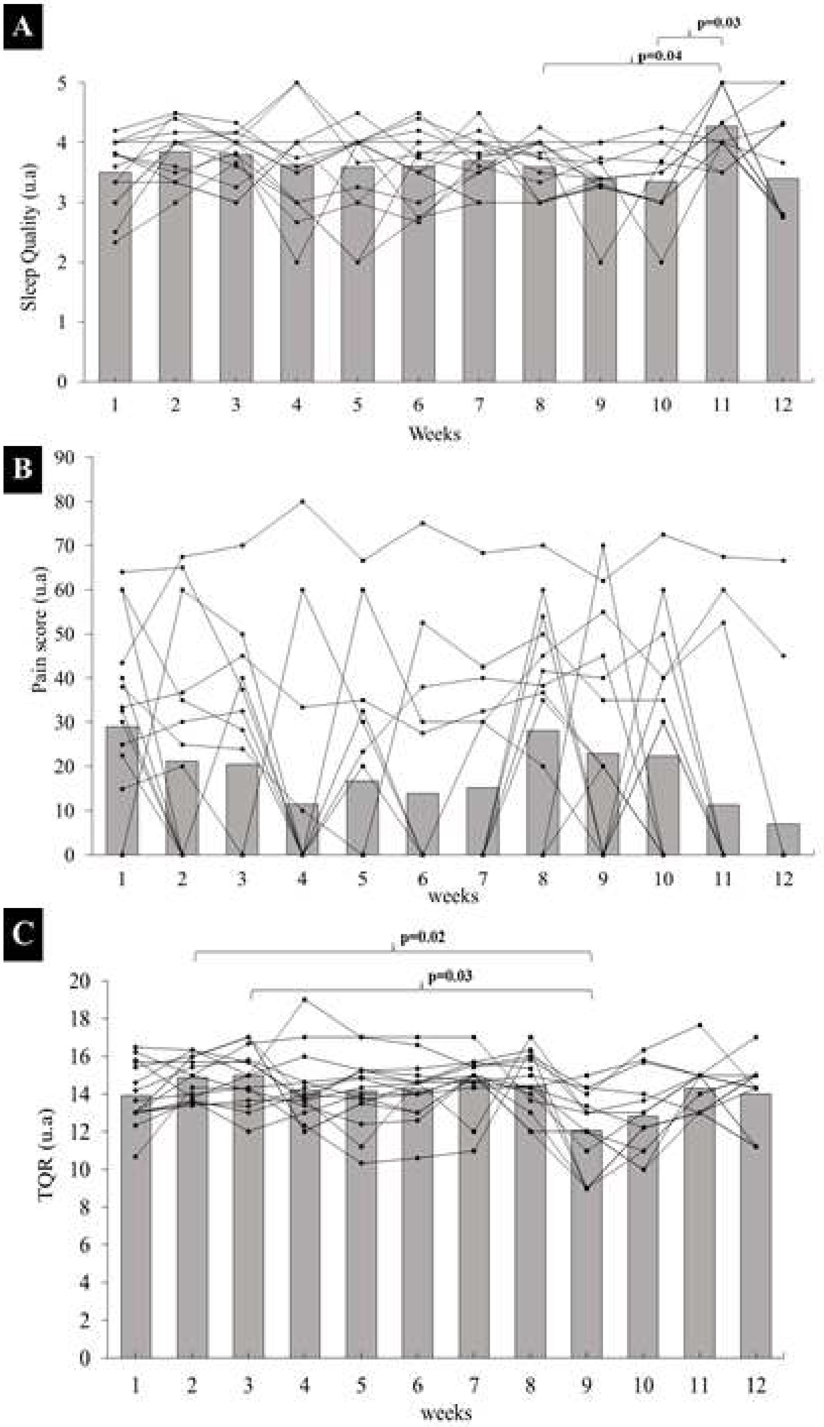


Figure I. Perceptual variables of sleep quality, pain scores and recovery. **Panel A**. Athletes' weekly sleep quality; **Panel B**. Athletes' weekly pain intensity. **Panel C**. Athletes' weekly recovery assessed through TQR.

Regarding the training load, the average RPE over the whole period was 4.8±0.5 a.u. (Minimum=2; Maximum=10). Furthermore, the repeated measures analysis showed that the sum (F=3.39; p<0.01) and average (F=2.56; p<0.01) values of RPEs have significant differences among the time points, as well as the sum (F=7.36; p<0.01) and average (F=5.91; p<0.01) values of RPEw. RPEs measured in the 1st week were higher than in the 2nd, 5th, and 10th weeks, and RPEw values of the 2nd week were higher than in the 3rd, 4th, and 9th weeks.

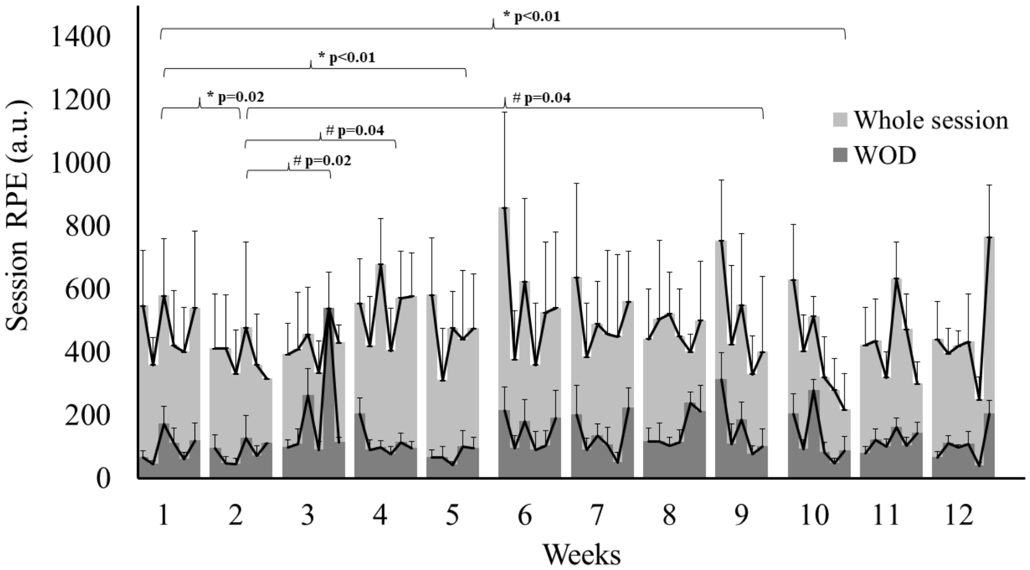


Figure II. Rating of perceived exertion of the session and WOD.

Comparisons of perceptual variables per day.

Regarding comparisons between perceptual variables measured on the same days throughout the twelve weeks, it was observed that both sleep quality (F=0.32; p=0.89) and weekly recovery of athletes (F=1.91; p=0.10) showed no difference. For the overall RPE values, it was observed that Mondays, Wednesdays, and Saturdays were higher than Tuesdays and Thursdays (F=11.3; p<0.01), which suggests a pattern of training load distribution according to days of the week (Figure III).

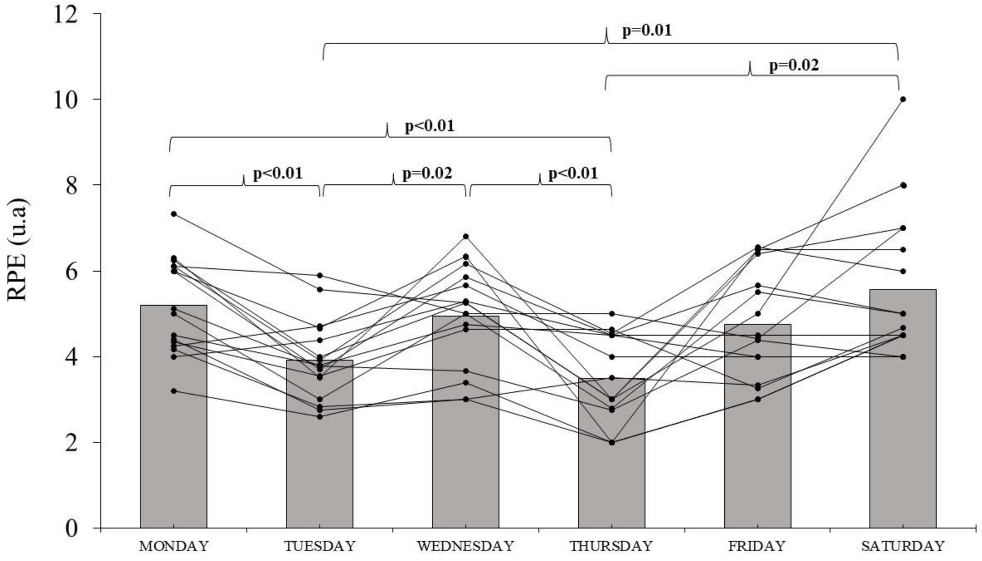


Figure III. Comparison of the athletes' RPE during the same days of the week.

Physical and Physiological Variables.

Regarding CMJ and HRV, data over the weeks are presented in Figures IV and V, respectively, and the lines indicate individual variation per athlete in each measure. The CMJ values measured in the 5th and 11th weeks were higher than those from the 3rd week (F=2.43; p<0.01). Furthermore, at the individual level, on average 3.4% and 11.3% of subjects showed greater changes than the Minimum Detectable Change (MDC) for CMJ and HRV, respectively. Repeated measures analysis showed no differences between time points for HRV (F=1.73; p=0.07) indicating that the imposed loads were not sufficient to induce changes or that the variables were not sensitive to detect them.

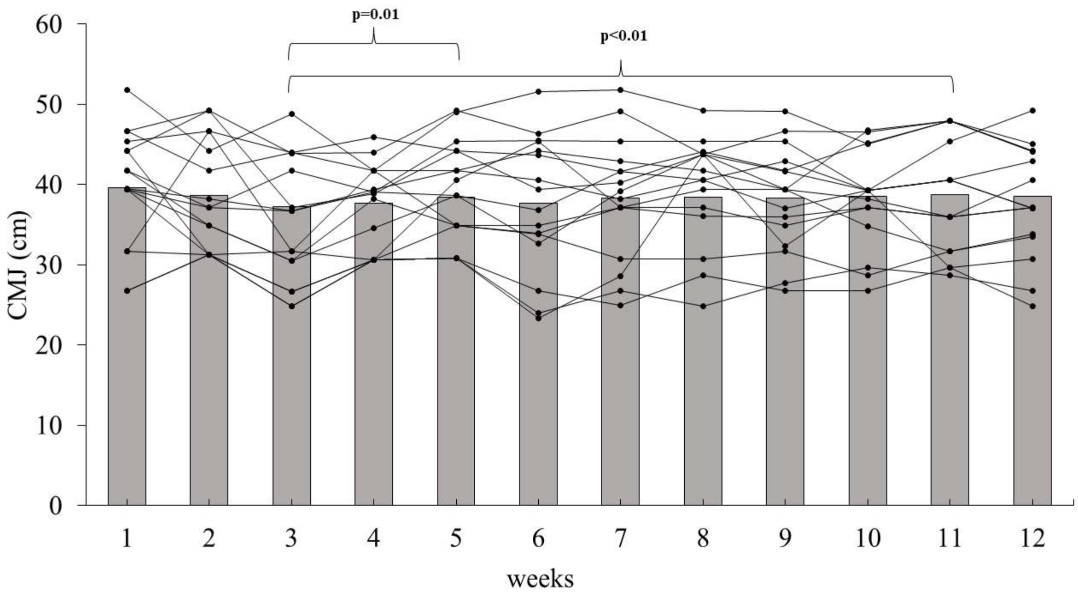
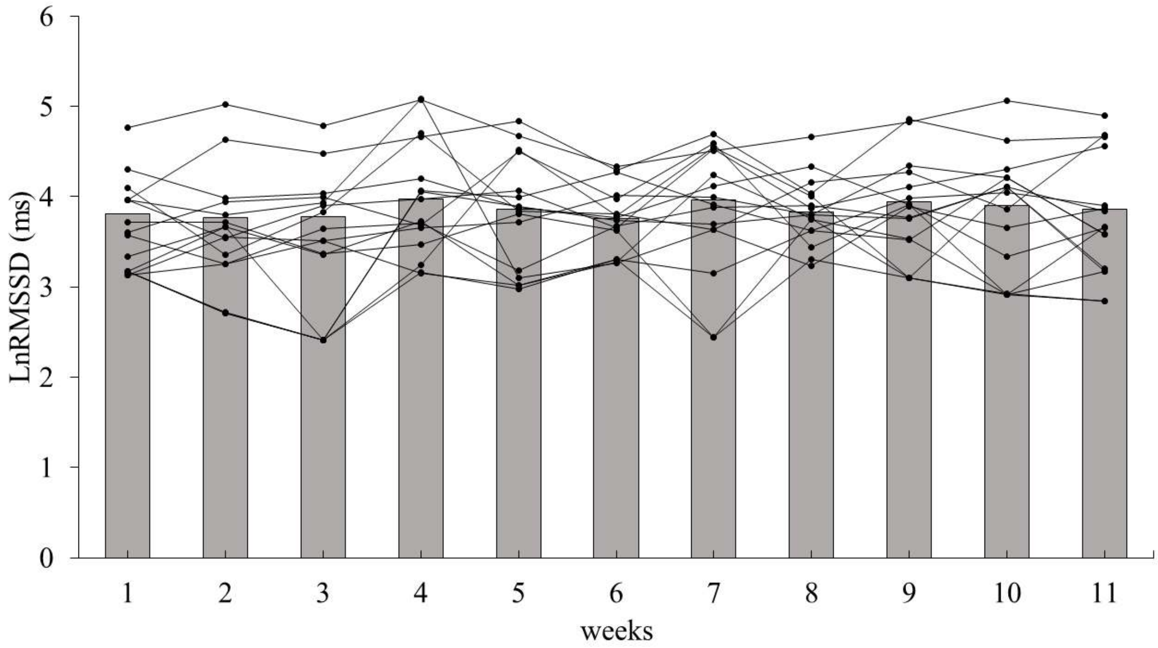


Figure IV. Weekly average of the height of the vertical jump of the athletes



.

Figure V. Average weekly heart rate variability of the athletes.

Regarding the incremental test on the AirBike, the Wilcoxon test suggested that no statistically significant differences were found between the pre and post-values (Z=-0.87; p=0.38).

Correlations

Regarding the correlations, the change of CMJ among the weeks was negatively associated with training load measures (Figure VI; Panels A to C). Furthermore, a negative correlation was found between LnRMSSD and Monotony (Figure VI; Panel D). Together, these findings may suggest that changes in training load may affect the neuromuscular and autonomic status of the athletes.

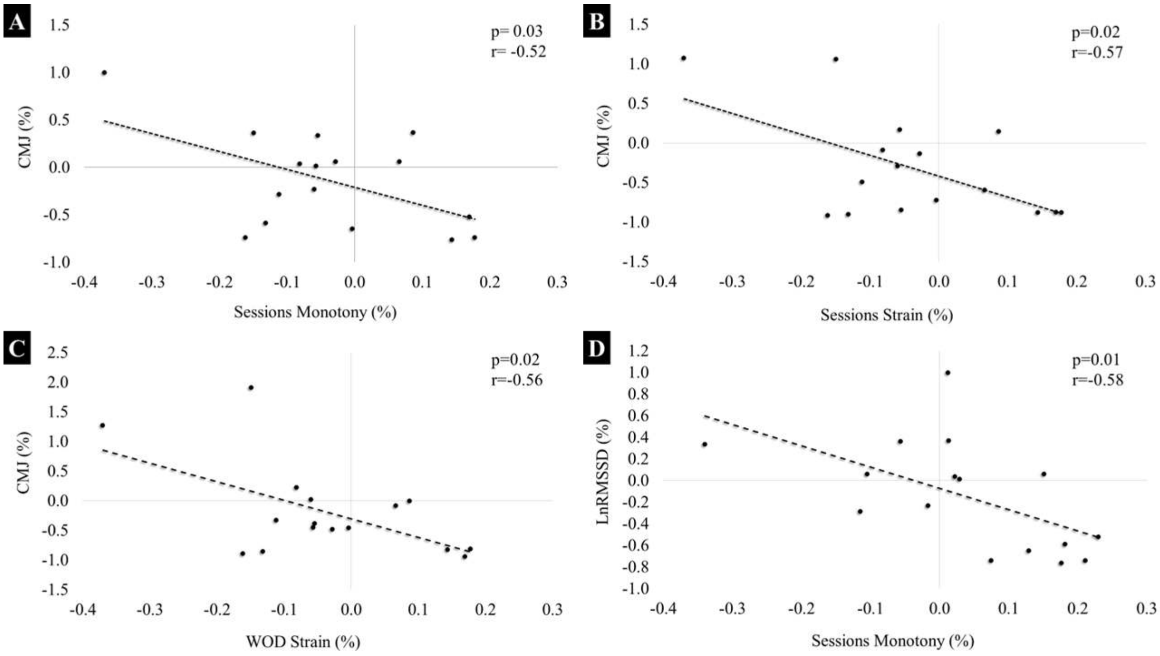


Figure VI. Correlations between neuromuscular, autonomic, and training load delta changes during the weeks

Discussion

This study aimed to describe the internal training load imposed on CrossFit® athletes over three months and relate it to physical performance indicators. The main findings suggest that the imposed training loads were not enough to induce detectable overreaching or recovery/compensation. Also, no relevant changes in aerobic power were found. However, negative correlations between CMJ and HRV with some training load parameters suggest that changes in training loads along the weeks provided neuromuscular and autonomic variations in the expected directions.

Regarding the perceptual variables, higher sleep quality was found in the 11th week when compared to the 8th and 10th weeks. Also, the derivatives of internal load and recovery, in general, showed no variation between the weeks. This perceived stability may have occurred, among other factors, due to the self-regulated effort characteristic of the sport. When self-regulated situations were compared with quantified and constant efforts, the former induced less physiological and perceptual response in 5000 m rowing tasks (Lander et al., 2009). The authors suggest that variations in power output during exercise can be characteristic of regulatory processes to prevent catastrophic fatigue. Additionally, in cyclists who performed an interval training of three ten-minute maximal sessions, this autoregulation seems to be able to control effort in an "optimal" manner, at their own pace, and with identical physiological and neuromuscular responses (Villerius et al., 2008).

This stability between microcycles was also observed in Mixed Martial Arts (MMA) training along eight weeks (Kirk et al., 2021), which may have resulted from similarities between the training practices of the modalities, in which athletes are often engaged in multimodal efforts, contemplating cyclical, specific and resistance training models. Indeed, running high-intensity efforts seems to stress the cardiorespiratory component, while “all-out” bodyweight efforts showed higher blood lactate, muscle soreness, and RPE (Bellissimo et al., 2022). Thus, the nature of the efforts (cyclical vs bodyweight/multimodal) and the load characteristic (self-regulated vs “all-out”) may explain why our training load findings are different from the initial hypothesis, which was mainly based on the literature on traditional endurance and team sports training.

The magnitude of the internal load observed was relatively low (182.1±12.1 a.u.) when compared to those derived from different sports modalities (430.3±110.5 a.u.), however, the reason for such results is unclear (Tibana et al., 2017). Thus, in conjunction with our findings (265.1±40.0 u.a), it is suggested that the initial hypothesis that high RPE values would be expected due to the high metabolic demand (Tibana et al., 2018) and the high volume (120.7±36.7 min/session) (Pritchard et al., 2020) seems to be rejected and perhaps a specific parameterization is needed. In addition to the self-regulation argument already mentioned, the variables that usually support the high-intensity hypothesis, i.e., high values of lactate and heart rate (17.2±2.2 mmol; 186±5 bpm) (Tibana et al., 2018) may stem from the cumulative effect they present within the session, and not necessarily from the characteristic of the specific efforts.

Regarding the perceptual responses analyzed by days of the week, differences in RPE were observed on different days, which indicates a certain pattern in the training load distribution. When the structure of the sessions was analyzed, it was noteworthy that the neuromuscular stimulus (Weightlifting/throwing and gymnastics) was predominant on the first days of the week and was followed by aerobic focused workouts (Metabolic conditioning). Therefore, it is expected that with this configuration the internal load would increase on the days of strength training and Olympic weightlifting, which tends to occur in training sessions of this nature (Tibana et al., 2016).

Regarding the CMJ and LnRMSSD, i) decreases, due to accumulated fatigue resulting from high intensity and short rest intervals (Williams et al., 2017); ii) increases, resulting from adaptive processes and/or indicating adequate recovery (Düking et al., 2020) or; iii) stability, which would relate to high monotony (Miloski et al., 2012), were expected. In this context, the absence of noticeable variations for LnRMSSD, at least from the statistical point of view and the average of the investigated group, could be explained by the characteristic of the loads imposed or by the moment of collection, right after a recuperative training day, which would indicate that the period of 48 hours may be enough to regenerate these indexes (Timón et al., 2019). Also, with the exception of a modest reduction in the third week, CMJ had relatively stable results. However, it is noteworthy that the group values may have hidden changes at the individual level, since 3.4% of the athletes' showed changes that exceeded the MDC thresholds. Regarding the correlations found, CMJ and HRV correlated negatively and moderately with some internal load derivatives, suggesting that changes in the loads imposed may have interfered in lower limbs power and in autonomic control (Williams et al., 2017).

From the chronic perspective, the modality has already shown potential for aerobic power improvements (Murawska-Cialowicz et al., 2015), which supports the hypothesis that after 12 weeks positive adaptations would be found. However, our results did not indicate these adaptations, unlike what was expected of maximal oxygen consumption increases (13.6% and 11.8% for men and women, respectively) (Smith, 2017), which suggests a null effect on the subjects' aerobic power. Moreover, the apparently stable training loads and the high fitness level of the competitors may suggest that, instead of developing different fitness domains simultaneously to increase aerobic power indexes (Claudino et al., 2018; Tibana et al., 2017), specific training for this purpose would be required.

This study has limitations that must be considered. Firstly, only one weekly collection of CMJ and HRV, and only two moments for aerobic fitness measures were applied. Performing these collections more frequently would be important for more precise results. However, this was logistically more feasible and was chosen to avoid over measurement effects. Another important limitation is the lack of nutritional description that may interfere in the performance and, consequently, in the results. However, it is known by the competitors the importance of a good diet for a good performance, which may minimize such limitations. Also, solving the lack of performance measurement of a specific standard training, such as a benchmark, would be of interest to provide competitive performance insights. Finally, a similar research design, focused on individual responses is suggested.

Conclusions

The investigated training program was not enough to induce detectable overreaching or recovery/compensation, at least by the variables evaluated and in a group-based analysis. Also, no relevant changes in aerobic power were found. However, negative correlations between CMJ and HRV with some training load parameters suggest that changes in training loads along the weeks provided neuromuscular and autonomic variations in the expected directions.

In summary, in this study, the training load imposed on elite CrossFit® athletes was relatively stable, despite the constant variation of stimuli and settings. Finally, our findings may help to explain patterns of the sport, which involves high volume and frequency of training maintained for long periods, which does not match (at least theoretically) with high-intensity efforts.

Conflicts of interest - The authors declare that they have no conflict of interest.

References

Bahremand, M., Hakak Dokht, E., & Moazzami, M. (2020). A comparison of CrossFit and concurrent training on myonectin, insulin resistance and physical performance in healthy young women. *Archives of Physiology and Biochemistry*, *0*(0), 1–7. https://doi.org/10.1080/13813455.2020.1853173

Bellissimo, G. F., Ducharme, J., Mang, Z., Millender, D., Smith, J., Stork, M. J., Little, J. P., Deyhle, M. R., Gibson, A. L., de Castro Magalhaes, F., & Amorim, F. (2022). The Acute Physiological and Perceptual Responses Between Bodyweight and Treadmill Running High-Intensity Interval Exercises. *Frontiers in Physiology*, *13*(March). https://doi.org/10.3389/fphys.2022.824154

Claudino, J. G., Gabbett3, T. J., Bourgeois, F., Souza, H. de S., Miranda, R. C., Mezêncio, B., Soncion, R., Filho, C. A. C., Bottaro, M., Hernandez, A. J., Amadio, A. C., & Serrão, J. C. (2018). CrossFit Overview: Systematic Review and Meta-analysis. *Sports Medicine - Open*. https://doi.org/10.1063/1.5002395

Cosgrove, S., Crawford, D., & Heinrich, K. (2019). Multiple fitness improvements noted after 6-months of high intensity functional training. *Sports*, *In Review.*, 1–13.

Düking, P., Zinner, C., Reed, J. L., Holmberg, H. C., & Sperlich, B. (2020). Predefined vs data-guided training prescription based on autonomic nervous system variation: A systematic review. *Scandinavian Journal of Medicine and Science in Sports*, *30*(12), 2291–2304. https://doi.org/10.1111/sms.13802

Elliott, P., & Hawthorne, G. (2004). *Imputing missing repeated measures data : how should we proceed ?*

Esco, M. R., Williford, H. N., Flatt, A. A., Freeborn, T. J., & Nakamura, F. Y. (2018). Ultra-shortened time-domain HRV parameters at rest and following exercise in athletes: an alternative to frequency computation of sympathovagal balance. *European Journal of Applied Physiology*, *118*(1), 175–184. https://doi.org/10.1007/s00421-017-3759-x

Gajewski, J., Michalski, R., Buśko, K., Mazur-Różycka, J., & Staniak, Z. (2018). Countermovement depth - a variable which clarifies the relationship between the maximum power output and height of a vertical jump. *ACTA OF BIOENGINEERING AND BIOMECHANICS*.

Gallardo-Fuentes, F., Gallardo-Fuentes, J., Ramírez-Campillo, R., Balsalobre-Fernández, C., Martínez, C., Caniuqueo, A., Cañas, R., Banzer, W., Loturco, I., Nakamura, F. Y., & Izquierdo, M. (2016). Intersession and intrasession reliability and validity of the my jump app for measuring different jump actions in trained male and female athletes. *Journal of Strength and Conditioning Research*, *30*(7), 2049–2056. https://doi.org/10.1519/JSC.0000000000001304

Halson, S. L. (2014). Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*, *44*, 139–147. https://doi.org/10.1007/s40279-014-0253-z

Horta, T. A. G., de Lima, P. H. P., Matta, G. G., de Freitas, J. V., Dias, B. M., Vianna, J. M., Toledo, H. C., Miranda, R., Timoteo, T. F., & Filho, M. G. B. (2020). Training load impact on recovery status in professional volleyball athletes. *Revista Brasileira de Medicina Do Esporte*, *26*(2), 158–161. https://doi.org/10.1590/1517-869220202602209364

Impellizzeri, F. M., Marcora, S. M., & Coutts, A. J. (2018). Internal and External Training Load : 15 Years On Training Load : Internal and External Load Theoretical Framework : The Training Process. *International Journal of Sports Physiology and Performance*, *14*(2), 270–273.

Kenttä, G., & Hassmén, P. (1998). Overtraining and Recovery: A conceptual model. *Sports Medicine*, *26*(1), 1–16. https://doi.org/10.2165/00007256-199826010-00001

Kirk, C., Langan-Evans, C., Clark, D. R., & Morton, J. P. (2021). Quantification of training load distribution in mixed martial arts athletes: A lack of periodisation and load management. *PLoS ONE*, *16*(5 May 2021). https://doi.org/10.1371/journal.pone.0251266

Kurilla, E. (2011). *Validation of the Adapted Borg-CR-10 Effort Scale as it Relates to Swallowing and Patients with Dysphagia*. *13*(1), 43–50. http://dx.doi.org/10.1038/ni.1913%0Ahttp://dx.doi.org/10.1016/j.dci.2013.08.014%0Ahttp://dx.doi.org/10.1186/s13071-016-1819-4%0Ahttp://dx.doi.org/10.1016/j.actatropica.2017.02.006%0Ahttp://dx.doi.org/10.1038/s41598-017-09955-y%0Ahttp://dx.doi.org/10.1016/

Lander, P. J., Butterly, R. J., & Edwards, A. M. (2009). Self-paced exercise is less physically challenging than enforced constant pace exercise of the same intensity: Influence of complex central metabolic control. *British Journal of Sports Medicine*, *43*(10), 789–795. https://doi.org/10.1136/bjsm.2008.056085

Lee, K. A., Hicks, G., & Nino-Murcia, G. (1991). Validity and Reliability of a Scale to Assess Fatigue. *Psychiatry Research,*.

Martínez-Gómez, R., Valenzuela, P. L., Barranco-Gil, D., Moral-González, S., García-González, A., & Lucia, A. (2019). Full-Squat as a Determinant of Performance in CrossFit. *International Journal of Sports Medicine*, *40*(9), 592–596. https://doi.org/10.1055/a-0960-9717

McLaren, S. J., Macpherson, T. W., Coutts, A. J., Hurst, C., Spears, I. R., & Weston, M. (2018). The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. *Sports Medicine*, *48*(3), 641–658. https://doi.org/10.1007/s40279-017-0830-z

Miloski, B., de Freitas, V. H., & Filho, M. G. B. (2012). Monitoring the internal training load in futsal players throughout a season. *Revista Brasileira de Cineantropometria e Desempenho Humano*, *14*(6), 671–679. https://doi.org/10.5007/1980-0037.2012v14n6p671

Murawska-Cialowicz, E., Wojna, J., & Zuwala-Jagiello, J. (2015). Crossfit training changes brain-derived neurotrophic factor and irisin levels at rest, after wingate and progressive tests, and improves aerobic capacity and body composition of young physically active men and women. *Journal of Physiology and Pharmacology*, *66*(6), 811–821.

Osiecki, R., Rubio, T. B., Coelho, R. L., & Novack, L. F. (2015). *The Total Quality Recovery Scale (TQR) as a Proxy for Determining Athletes? Recovery State after a Professional Soccer Match. October*.

Perrotta, A. S., Jeklin, A. T., Hives, B. A., Meanwell, L. E., & Warburton, D. E. R. (2017). Validity of the Elite HRV Smartphone Application for Examining Heart Rate Variability in a Field-Based Setting. *Journal of Strength and Conditioning Research*, *31*(8), 2296–2302. https://doi.org/10.1519/JSC.0000000000001841

Pritchard, H. J., Keogh, J. W., & Winwood, P. W. (2020). Tapering practices of elite CrossFit athletes. *International Journal of Sports Science and Coaching*, *15*(5–6), 753–761. https://doi.org/10.1177/1747954120934924

Smith, M. M. (2017). CrossFit-based high intensity power training improves maximal aerobic fitness and body composition: retraction. *Journal of Strength and Conditioning Research*, *31*(7), 76.

Sprey, J. W. C., Ferreira, T., de Lima, M. V., Duarte, A., Jorge, P. B., & Santili, C. (2016). An Epidemiological Profile of CrossFit Athletes in Brazil. *Orthopaedic Journal of Sports Medicine*, *4*(8), 1–8. https://doi.org/10.1177/2325967116663706

Tibana, R. A., de Farias, D. L., Nascimento, D. C., Da Silva-Grigoletto, M. E., & Prestes, J. (2016). Relationship of muscle strength with Olympic lifting performance in CrossFit® practitioners. *Revista Andaluza de Medicina Del Deporte*, *11*(2), 84–88. https://doi.org/10.1016/j.ramd.2015.11.005

Tibana, R., de Sousa, N., Cunha, G., Prestes, J., Fett, C., Gabbett, T., & Voltarelli, F. (2018). Validity of Session Rating Perceived Exertion Method for Quantifying Internal Training Load during High-Intensity Functional Training. *Sports*, *6*(3), 68. https://doi.org/10.3390/sports6030068

Tibana, R. A, de Sousa, N. M. F., Prestes, J., & Voltarelli, F. A. (2018). Lactate, heart rate and rating of perceived exertion responses to shorter and longer duration crossfit® training sessions. *Journal of Functional Morphology and Kinesiology*, *3*(4). https://doi.org/10.3390/jfmk3040060

Tibana, R. A, Sousa, N. M. F., & Prestes, J. (2017). Quantifying crossfit training session load through subjective perception of exertion: A case study and literature review. *Revista Brasileira de Ciência e Movimento*, *25*(3), 5–13.

Timón, R., Olcina, G., Camacho-Cardeñosa, M., Camacho-Cardenosa, A., Martinez-Guardado, I., & Marcos-Serrano, M. (2019). 48-hour recovery of biochemical parameters and physical performance after two modalities of CrossFit workouts. *Biology of Sport*, *36*(3), 283–289. https://doi.org/10.5114/biolsport.2019.85458

Villerius, V., Duc, S., & Grappe, F. (2008). Physiological and neuromuscular responses of competitive cyclists during a simulated self-paced interval training session. *International Journal of Sports Medicine*, *29*(9), 770–777. https://doi.org/10.1055/s-2007-989317

West, S. (2020). *More than a Metric : How Training Load is Used in Elite Sport for Athlete Management Authors What Can We Use Training Load Data For ? Models for Framing Training Load Management*. https://doi.org/10.1055/a-1268-8791

Williams, S., Booton, T., Watson, M., Rowland, D., & Altini, M. (2017). Heart rate variability is a moderating factor in the workload-injury relationship of competitive CrossFit® athletes. *Journal of Sports Science and Medicine*, *16*(4), 443–449.

Titles and Subtitles

Panel A. Correlation between sessions monotony and CMJ. **Panel B**. Correlation between sessions strain and CMJ. **Panel C**. Correlation between WOD strain and CMJ. **Panel D**. Correlation between sessions monotony and LnRMSSD.