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The Physiological and Mental Effects of the Fran Benchmark CrossFit Workout at Different Competitive Stages

Abstract

This study investigates the acute effects of CrossFit training on cognition and physiological parameters across different performance stages. We focused on evaluating the impact of such training on both the mental and physical performance of athletes classified as Elite, Advanced, and Beginners. The objective was to explore how CrossFit, known for its high-intensity and varied functional movements, influences cognitive functions and physiological responses in athletes of varying expertise. By comparing these groups both before and after the Workout of the Day (WOD), we aimed to understand the relationship between CrossFit training intensity and cognitive and physiological changes. Methodologically, our approach involved categorizing our sample into three groups: Elite (n=7), Advanced (n=10), and Beginners (n=15). We conducted comprehensive assessments of each participant's cognitive and physiological parameters pre- and post-WOD. The results revealed notable differences in performance time, with Elite athletes showing significantly quicker times compared to Advanced and Beginners. Cognitive functions, particularly executive functions like reading, counting, choice-making, shifting, inhibition, and flexibility, also varied significantly across the groups. Physiological measurements, including lactate stages and heart rate, further highlighted these differences. Remarkably, Elite athletes exhibited a 13.1 mmol average lactate level, lower than their counterparts, and a higher average heart rate of 188.0 bpm. In terms of cognitive functions, differences were observed in various executive tasks, showcasing the nuanced impact of high-intensity exercise on cognitive abilities. In conclusion, our study provides compelling evidence that high-intensity CrossFit training positively influences executive functions. These findings are quantified through substantial variations in performance times, executive function tasks, lactate stages, and heart rates, offering critical insights into the multidimensional benefits of CrossFit training across different competitive stages.

Keywords: sports psychology; cognition; physical activity; language; attention; physical training; cross training; executive function

1 Introduction

In the field of sports psychology, which melds psychological insights with practical skills, the primary aim is to augment athletes' performance, well-being, and overall quality of life (Brown & Fletcher, 2017). In this interdisciplinary field, neuropsychology has carved a niche, establishing itself at the crossroads of psychology and neurology (Brito et al., 2022). This discipline delves into the intricate psychophysiological interplay between the brain, emotions, physiology, and human behavior, particularly in sports settings (Cooke & Ring, 2019). A crucial aspect of this exploration is the evaluation of executive functions in athletes, as these cognitive processes are fundamental in managing complex tasks and decision-making (Miarka et al., 2016). Understanding how these executive functions interact with physiological parameters is essential (Coco et al., 2019). This comprehensive assessment provides a more holistic view of an athlete's performance capabilities. By examining both cognitive and physiological factors, neuropsychology in sports offers insights into optimizing training, enhancing performance under stress, and developing strategies for mental resilience (Slimani et al., 2016). This integrative approach is instrumental in tailoring training regimes and interventions that address both the mind and body, ultimately leading to improved athletic performance and wellbeing.

CrossFit is considered a physical performance modality due to its comprehensive approach to fitness, which encompasses various elements of strength, endurance, agility, and flexibility (James & Gill, 2018). CrossFit training works on the principle of high-intensity functional movement, designed to improve overall physical fitness and performance (Brito et al., 2023). Training programs incorporate elements of High-Intensity Interval Training (HIIT), which involves short bursts of intense activity followed by periods of rest or lower-intensity exercise. This type of training is known to improve cardiovascular fitness, increase metabolism, and enhance fat burning (Brito et al., 2023). The exercises in CrossFit mimic everyday movements, focusing on patterns that involve pushing, pulling, squatting, lifting, and running (Murawska-Cialowicz et al., 2015; Tomporowski & Pesce, 2019). These functional movements are natural, effective, and efficient locomotors of body and external objects (Tomporowski & Pesce, 2019). They engage multiple muscle groups, enhance joint mobility, and improve neuromuscular coordination (Tomporowski & Pesce, 2019). Although CrossFit is inclusive and progressive, there is a limited number of studies that identify the key psychophysiological differences among its participants.

Recent research, including studies by Bellar et al. (2015) and Box et al. (2019), has uncovered distinct individual differences between CrossFit participants, specifically in their primary training methods. These studies have provided insights into the psychological predictors of performance, yet they fall short in thoroughly examining how these aspects interact with the executive functions of the brain (Campos et al., 2016; Meier et al., 2023). This gap highlights the need for a deeper understanding of the role of executive functions, which are central to coordinating and optimizing physical performance.

In sports, psychological factors, including cognition, are frequently recognized as critical determinants of outcomes (James & Gill, 2018). The executive functions of the brain are especially crucial, as they are responsible for establishing, maintaining, supervising, correcting, and executing complex action plans (Campos et al., 2016). These functions play a pivotal role in regulating thoughts, emotions, and actions, particularly in high-pressure scenarios common in sports. In such contexts, cognitive agility and mental resilience often outweigh the importance of physical tactics, techniques, or skills (Brito et al., 2023; Browne et al., 2016; Diamond & Ling, 2016; Dominski et al., 2021). In CrossFit, a comprehensive understanding of these cognitive aspects is vital. This is especially true concerning CrossFit benchmarks, which are not just physical tests but also mental challenges that require sharp executive functioning for optimal performance (Griffin et al., 2011; Murawska-Cialowicz et al., 2015; Tomporowski & Pesce, 2019). Emphasizing the essentiality of brain executive function in CrossFit underscores the interconnectedness of mental and physical prowess in achieving peak athletic performance.

The burgeoning interest in CrossFit, noted for its distinctive approach (Claudino et al., 2018), underscores the need to comprehensively understand its impact on both the cognitive and physiological aspects of athletes. Despite its widespread popularity, there is a notable gap in research concerning how CrossFit influences cognitive functions and physiological responses, along with the potential advantages it offers to practitioners. The complexity and unpredictability of CrossFit activities necessitate a deeper exploration of cognitive roles in such high-intensity exercises (Diamond, 2013). This study, therefore, seeks to thoroughly examine how participation in a CrossFit benchmark, particularly the WOD Fran, affects cognitive processes and physiological parameters. Additionally, it aims to explore the interplay between these elements and how they collectively influence performance times. The investigation is driven by the hypothesis that engaging in the Fran benchmark does not lead to significant cognitive changes in CrossFit athletes, regardless of their competitive level. This research will contribute to a more nuanced understanding of CrossFit's comprehensive impact and could inform training practices and methodologies across varying stages of competition.

2 Methods

2.1 Study design

This study adopts a pre-experimental, interdisciplinary, and cross-sectional design. It emerged from the need for more rigorously controlled research, particularly in the evaluation and manipulation of interventions. This control is vital to ensure the application of the same Workout of the Day (WOD) across three distinct performance level classifications (i.e. Elite, Advanced and Beginner groups). The methodology involved an acute intervention, wherein participants underwent evaluations of cognitive and physiological parameters at two critical junctures: before and after undertaking the benchmark practice, specifically the WOD Fran.

After realize the WOD Fran, participants were subsequently categorized based on their performance times during the benchmark. This research was conducted in adherence to the guidelines outlined by the official CrossFit guide and website. The chosen benchmark for this study was the WOD Fran, recognized as a key parameter for performance assessment (Glassman, 2015). We utilized pre-intervention values as a baseline for comparison with post-intervention values, facilitating a paired analysis across the two time points.

Figure 1 shows the study design.

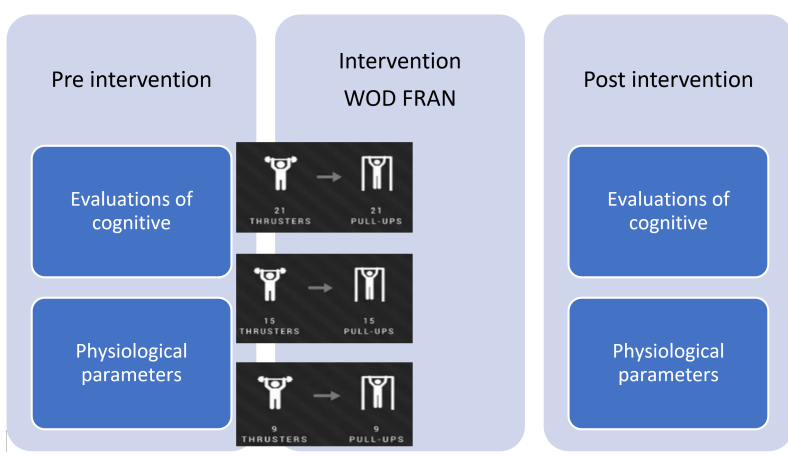


Figure 1. Study design. [Source: Prepared by the author (2020). Caption: Cognition (Five-Digit test) and Physiological parameters (Blood Pressure, Heart Rate and Blood Lactate)].

This design ensures a comprehensive evaluation of the impact of the CrossFit WOD Fran on both cognitive and physiological parameters, thereby contributing valuable insights into the effects of this exercise regimen.

2.2 Sample

For the sample calculation, we applied a post-hoc statistical power $(1 - \beta)$ using the analysis of variance (ANOVA: Repeated measures, within-between interaction) with an Effect size f of 0.25, a significance level of 0.05, and an α error probability of 0.05. Consequently, the statistical power achieved in our sample was 0.83%. This analysis was conducted using G * Power software© version 3.1 (Krakatau Metrics, 2020).

Our sample consisted of 32 CrossFit practitioners, divided into three groups:

Elite Group (E=07): Comprising 28.6% females and 71.4% males. The average age was 28.9±4.7 years, with a body mass of 80.0±10.9 kg and a height of 1.72±0.1 m. Their average practice time was 50.0±13.3 months, with a training volume of 13 hours and 34 minutes per week. Their average WOD execution time was 177.1±29.9 seconds.

Advanced Group (A=10): Including an equal gender distribution of 50% females and 50% males. The average age was 33.4±4.6 years, with a body mass of 71.7±15.5 kg and a height of 1.70±0.1 m. The group had an average practice time of 27.6±13.8 months and a weekly training volume of 8 hours and 34 minutes. Their average WOD execution time was 314.3±46.8 seconds.

Beginner Group (B=15): Consisting of 33.3% females and 66.7% males. The average age was 30.6±7.1 years, with a body mass of 72.3±11.0 kg and a height of 1.70±0.1 m. They had been practicing for an average of 22.9±9.2 months, with a weekly training volume of 4 hours and 42 minutes. Their average WOD execution time was 538.2±102.8 seconds.

All participants were affiliated with CrossFit gyms located in Brazil. The Elite group was defined as athletes who completed the WOD Fran in up to 225 seconds, the Advanced group included those who completed it between 240 to 393 seconds, and the Beginner group comprised individuals who took over 394 seconds.

The inclusion criteria for participants were as follows: aged between 20 and 40 years; a regular training routine of at least three times a week for a minimum of 12 continuous months; affiliation with CrossFit gyms; and for female participants, those undergoing hormonal control, specifically participating during the early to mid-follicular phase (day 1–14 of the cycle) or around ovulation (approximately day 14).

The exclusion criteria applied were: use of drugs that could alter psychophysiological characteristics in the last three months, as per the list of substances considered doping by the World Anti-Doping Agency (Heuberger & Cohen, 2019); failure to complete one of the proposed tests; participation in two or more physical activity programs.

In compliance with Resolution No. 466/12 of the National Health Council, this project received approval from the Local Ethics Committee for Research with Human Beings (Approval No. 13846919.8.0000.5257). In line with ethical research practices, all participants provided their consent by signing an Informed Consent Form before participating in the study.

3 Procedures

Participants were already familiar with the Workout of the Day (WOD) format. Executive Function Evaluation with Five Digit Test and Physiological Parameters were done pre- and post-WOD Fran. The pre-test assessments were conducted prior to the execution of WOD Fran, while post-test evaluations took place immediately after its completion.

Intervention

Benchmark Intervention – WOD Fran

WOD Fran, a benchmark workout in CrossFit, was chosen for this study in order to evaluate athletes' progress over time. This high-intensity workout, known for both its challenge and efficacy, involves a three-round sequence of Thrusters and Pull-Ups, with the objective being to complete the exercises as quickly as possible. The regimen is a classic in CrossFit, known for stimulating aerobic and anaerobic systems effectively (Glassman, 2015).

Workout Structure and Exercises: The workout comprises a couplet of two exercises:

- Thrusters: Combining a front squat with a push press, it is a full-body exercise starting from a standing position with a barbell at shoulder height.
- Pull-ups: Involving an overhand grip, the athlete pulls up from a hanging position until the chin is over the bar.
- The prescribed weights are 95 pounds for men and 65 pounds for women, though adjustments can be made according to the athlete's ability.

Workout Execution and Conditions: The study's assessments were conducted indoors between 6 P.M. and 8 P.M., with environmental conditions maintained at 24.5 to 27 degrees Celsius and 30-50% humidity. Each session began with a 5-minute warm-up, consisting of running and low-intensity movements at around 60% of the maximum heart rate, followed by a 5-minute rest period before starting WOD Fran.

Monitoring and Encouragement: Athletes were continuously monitored for heart rate and were provided verbal encouragement to motivate them to complete the workout without quitting. This behaviour modulation aimed to ensure efficiency and adherence to the workout's timeframe.

Study Protocols and Evaluator Role: For accurate and consistent data, each parameter was assessed by a designated evaluator, using a pilot model for any necessary adjustments. Participants were advised to adhere to their normal lifestyle and diet before and during the study period to minimize external variables' impact. Female participants were specifically instructed to continue their routine hormonal control.

This study design, focusing on the intense WOD Fran, aims to provide comprehensive insights into the athletes' physiological and cognitive responses to high-intensity CrossFit workouts.

Measures

Executive Function Evaluation – Five Digit Test pre- and post-WOD

The Five Digit Test is a tool designed to assess the impact of attentional interference through conflicting information about numbers and quantities. This task is instrumental in evaluating executive capacities, primarily focusing on inhibitory control and cognitive flexibility (Campos et al., 2016). The test comprises four main variables (reading, counting, choosing, and shifting times) and includes two executive indices (inhibition and flexibility).

These indices are critical in providing insights into various mental processes. For instance, processing speed is gauged through reading and counting times. Inhibitory control and selective attention are assessed via choice and inhibition times. Cognitive flexibility and alternating attention are measured through shifting times and flexibility (Campos et al., 2016).

The test generates scores based on execution times in different stages. The inhibition score is calculated from the time difference in the choice/reading step, while the flexibility score is derived from the time difference in the alternation/counting step. According to Campos et al. (2016) and de Paula et al. (2017), scoring guidelines are provided with recommendations for adjusting scores based on the sample's characteristics and the test's intended use. It is important to note that the administration of this test is restricted to qualified psychologists.

Assessments of Physiological Parameters pre- and post-WOD Fran

Heart Rate Measurement: Heart rate was continuously monitored using a chest strap monitor paired with a wristwatch receiver (model: Polar ProTrainer 5, USA). This setup allowed for real-time tracking of heart rate during the intervention and immediate post-intervention periods, providing accurate data on the cardiovascular response to the workout (Maté-Muñoz et al., 2018).

Blood Pressure Assessment: Both systolic and diastolic blood pressures were measured before and shortly after the intervention. This was done using an aneroid sphygmomanometer coupled with a stethoscope (brand: Premium, BRA). To ensure accurate readings, the equipment was regularly calibrated, and a cuff size appropriate for each participant was used. This method is essential for assessing the cardiovascular impact of the workout on the participants (Shaw et al., 2015).

Blood Lactate Concentration: The stages of blood lactate were measured to assess anaerobic metabolism before and immediately after completing the WOD. This was conducted using the Accutrend® lactate analyzer (model: GC/GCT, USA). A small blood sample was obtained from the fingertip for this measurement, providing an insight into the metabolic demands placed on the participants during the workout.

4 Statistical Analysis

The Kolmogorov-Smirnov test was utilized to assess the normality of the data, and the Levene test was applied to verify the homogeneity of variance. Data are presented as mean (M) and standard deviation (SD), along with the calculation of a 95% confidence interval for the difference (CI), using $p \leq 0.05$ as the criterion for significance. To compare the groups, an ANOVA with an independent factor was conducted, while repeated measures ANOVA was employed to evaluate differences both between and within conditions. This was done to compare the dimensions of executive function and physiological parameters at pre- and post-WOD intervals.

When the assumption of sphericity was violated, as verified by the Mauchly test, corrections to the degrees of freedom were made using the Greenhouse-Geisser estimates. The effect size was calculated using eta squared ($\eta p2$) (Cohen, 1992), with the magnitude of the difference categorized as small (0.02), medium (0.1), or large (0.25).

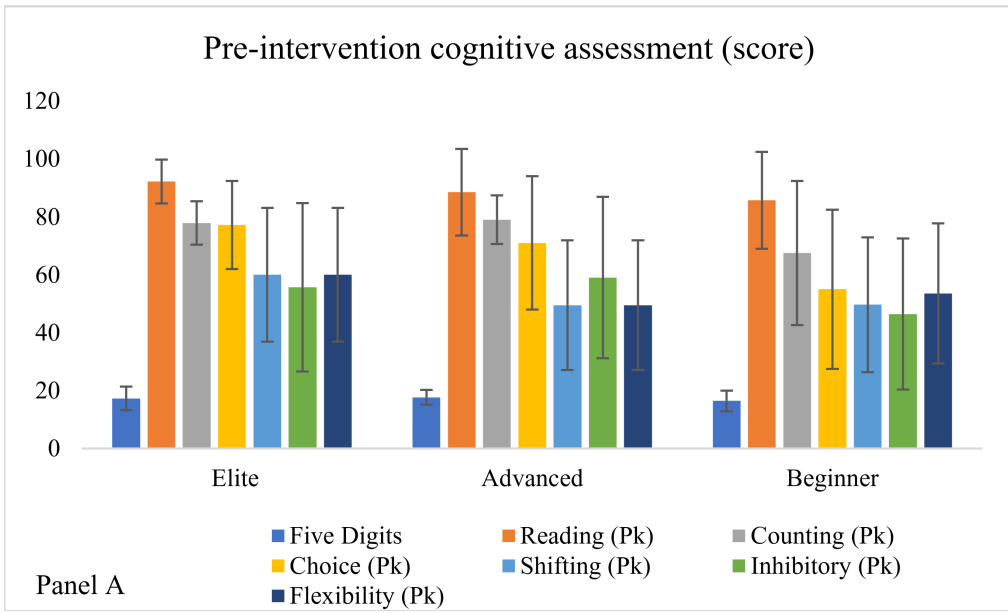
For the executive function test, which is expressed in seconds, we inverted the values of each measurement to a percentile based on the time necessary to complete each task step, in accordance with the table suggested by the test. This inversion provided a clearer interpretation of the results. Pearson's correlation was used to determine the interdependence between executive function and physiological variables. The strength of these correlations was interpreted using the following scale: $r = 0.10$ to 0.30 (weak), $r = 0.40$ to 0.60 (moderate), and $r = 0.70$ to 1.0 (strong), as suggested by Schober et al. (2018).

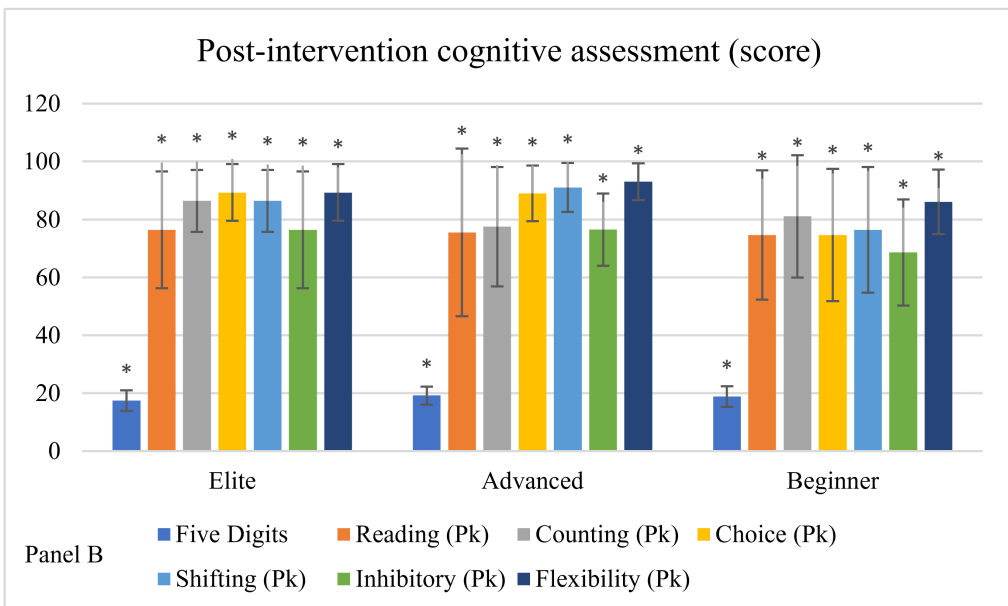
5 Results

The performance of participants in the executive function testing stages is presented in Figure 2.

The statistical analysis for cognition revealed significant differences between the pre- and post-WOD Fran in all factors. This includes the total five digits ($F1.29 = 8.04$; $p = 0.008$; $\eta p2 = 0.217$), reading ($F1.29 = 7.25$; $p = 0.012$; $\eta p2 = 0.200$), counting ($F1.29 = 4.87$; $p = 0.035$; $\eta p2 = 0.144$), choice ($F1.29 = 21.18$; $p = 0.001$; $\eta p2 = 0.422$), shifting ($F1.29 = 74.71$; $p = 0.001$; $\eta p2 = 0.720$), inhibition ($F1.29 = 13.82$; $p = 0.001$; $\eta p2 = 0.323$), and flexibility ($F1.29 = 50.73$; $p = 0.001$; $\eta p2 = 0.636$).

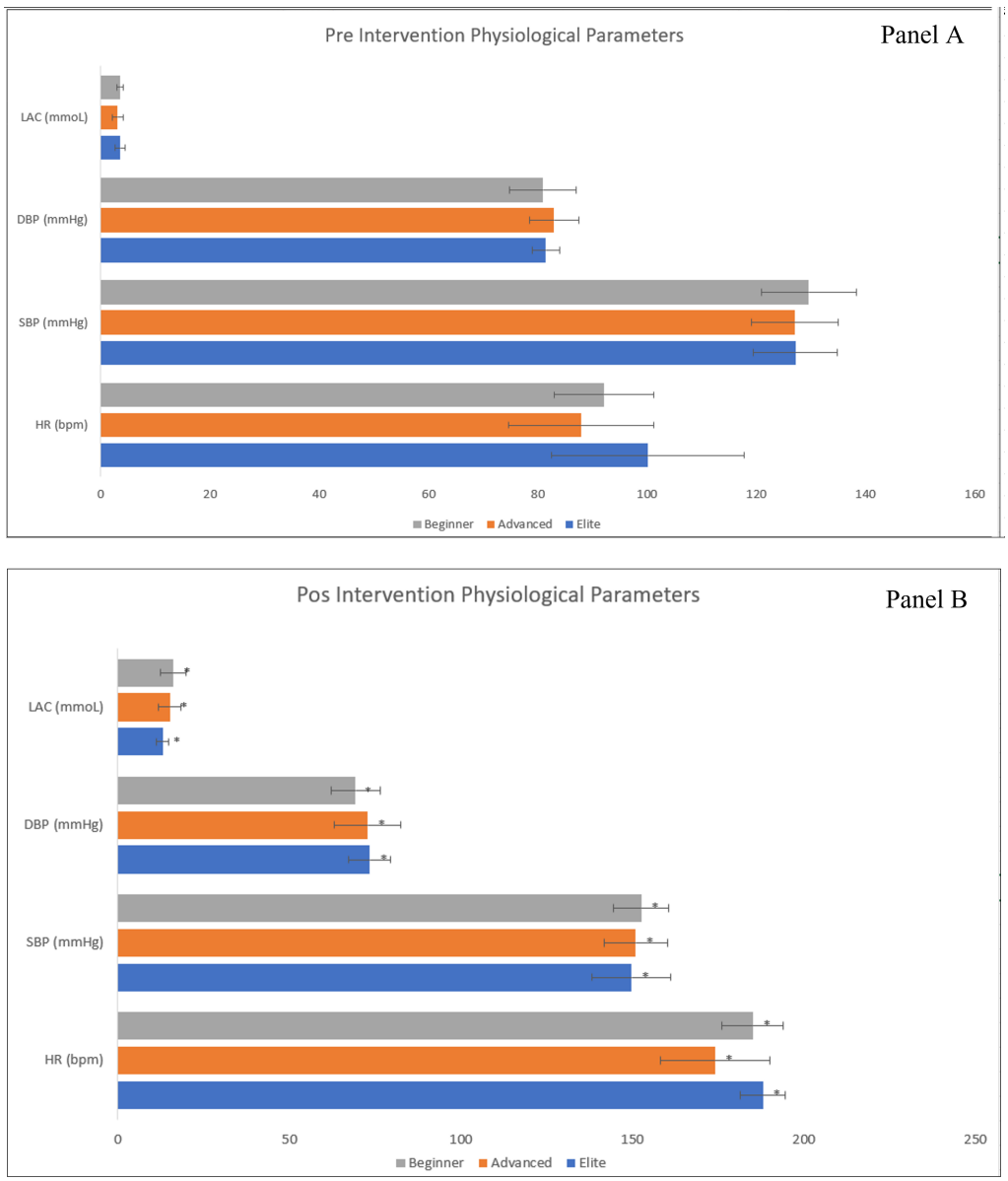
The performance of participants in the physiological parameters testing stages is presented in Figure 3.





Legend: *Difference between pre- and post- of the three groups is significant $p \leq 0.05$

Figure 2. Evaluation of cognition pre- (panel A) and post- (panel B) intervention with WOD Fran.



Legend: *Difference between pre- and post- of the three groups is significant $p \leq 0.05$.
Note: M – Mean; SD – Standard Deviation; HR – Heart Rate; SBP – Systolic Blood Pressure; DBP – Diastolic Blood Pressure; Lac – Blood Lactate.

Figure 3. Evaluation of physiological parameters pre- (panel A) and post- (panel B) the intervention with WOD Fran.

Similarly, the statistical analysis of the physiological parameters indicated significant differences in all groups when comparing pre- and post-WOD measurements for heart rate ($F1.29 = 1091.07$; $p = 0.001$; $\eta p2 = 0.97$), systolic blood pressure ($F1.29 = 138.47$; $p = 0.001$; $\eta p2 = 0.83$), diastolic blood pressure ($F1.29 = 31.35$; $p = 0.001$; $\eta p2 = 0.52$), and blood lactate stages ($F1.29 = 318.19$; $p = 0.001$; $\eta p2 = 0.92$).

The correlations between physiological parameters and cognition for participants in the Elite, Advanced, and Intermediate groups are presented in Figure 4.

In the Elite group, analysis revealed a strong positive correlation between the counting factor and heart rate ($r = 0.769$). Strong negative correlations were observed between the choice factor and heart rate ($r = -0.824$), choice factor and systolic blood pressure ($r = -0.881$), shifting factor and systolic blood pressure ($r = -0.839$), inhibition factor and systolic blood pressure ($r = -0.824$), and flexibility factor and heart rate ($r = -0.805$).

In the Advanced group, there was a strong positive correlation between the reading factor and heart rate ($r = 0.873$), choices factor and heart rate ($r = 0.817$), and total five digits and systolic blood pressure ($r = 0.724$). Moderate positive correlations were found between inhibition and heart rate ($r = 0.686$), total five digits and heart rate ($r = 0.689$), total five digits and systolic blood pressure (r=0.648), and total five digits and lactate ($r = 0.669$).

For the Beginner group, a strong correlation was identified between the flexibility factor and blood lactate ($r = 0.731$). There were also moderate positive correlations between the flexibility factor and blood lactate ($r = 0.641$), the choice factor and lactate ($r = 0.578$), and a moderate negative correlation between the reading factor and WOD execution time ($r = -0.557$).

6 Discussion

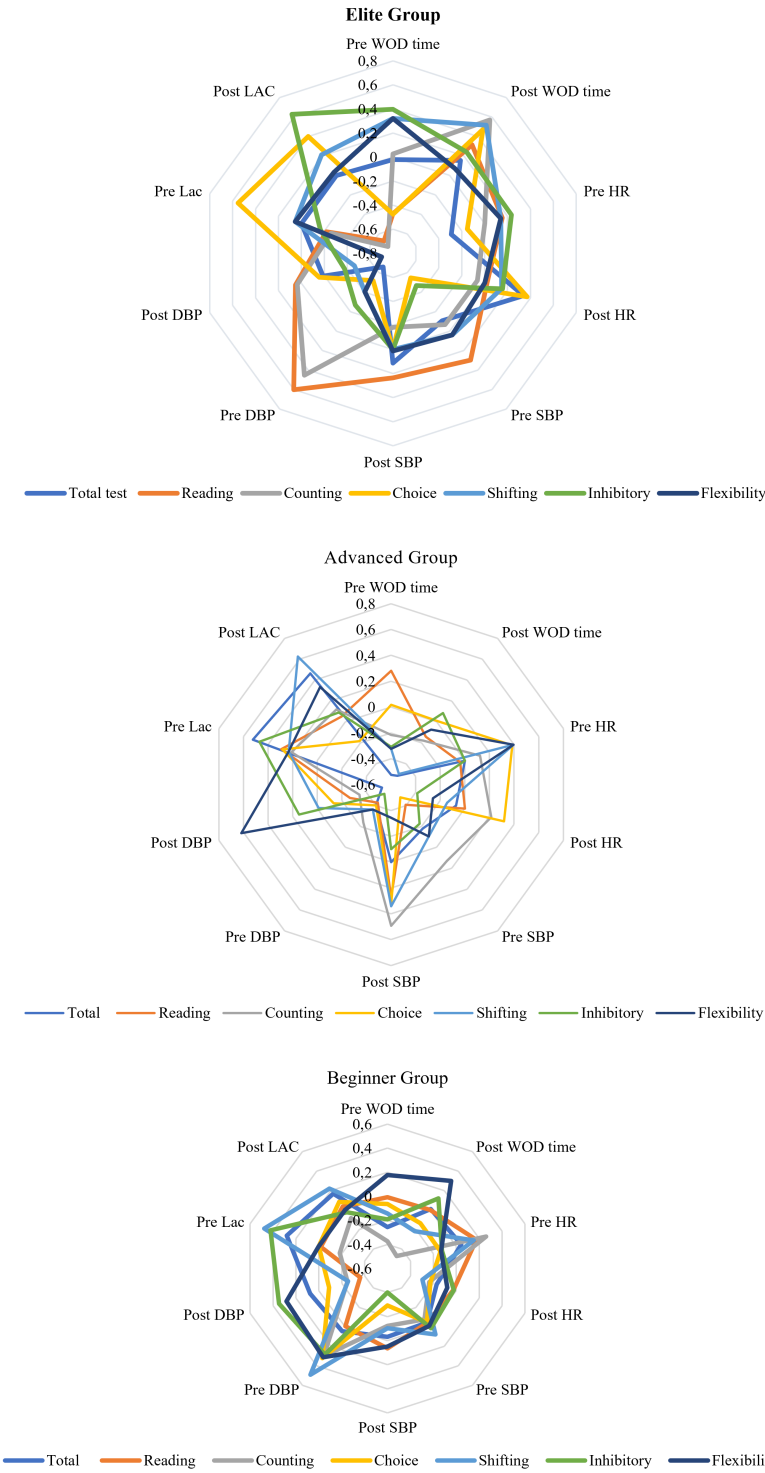
This study addresses a significant gap in current research, which largely lacks investigations into CrossFit's acute effects on cognition in relation to physiological parameters (Claudino et al., 2018). Previous studies have explored attention and lactate (Perciavalle et al., 2016), cognitive functions and lactate (Coco et al., 2019), and memory and lactate (Perciavalle et al., 2015) separately. Our study proposes that psychological aspects are multifactorial and crucial in athlete performance, influenced by various factors that vary according to competitive stages (Basso & Suzuki, 2017; Crust, 2007; Crust & Azadi, 2010).

The results of this research showed that a WOD Fran improves the executive function of CrossFit practitioners. The findings suggest that a WOD Fran session improves the performance of executive functions, elucidating the influence of exercise on the efficiency of executive functions and, therefore, contributing to the improvement of athletic performance (Li et al., 2014; Yanagisawa et al., 2010).

Athletes who have better developed cognitive processes tend to achieve higher stages of performance (Vestberg et al., 2017). We found that acute post-exercise cognitive performance appears to be linked to exercise intensity, as demonstrated in the meta-analysis (Chang et al., 2012; Lambrick et al., 2016; Roy, 2013). Our study presented similar results to the studies mentioned above. An acute intervention was carried out, with high-intensity and short-duration exercise (WOD Fran), varying between athletes, from 145 seconds to 763 seconds. It has been observed that just a single exercise session can promote the performance of executive functions. The Five Digit Test was used (Campos et al., 2016).

Thus, the ability to inhibit prepotent responses or ongoing actions is important for successful performance, as well as greater control of behavior, attention, thought and emotion, allowing the inhibition of automatic and automatic behaviors or routines. the execution of controlled or conscious routines in favor of what is most appropriate or precise (Huijgen et al., 2015; Verburgh et al., 2014).

There is still discussion about the physiological mechanisms that guide acute brain adaptations in relation to executive functions (Chang et al., 2012; Coco et al., 2019; Li et al., 2014; Perciavalle



Note: HR – Heart Rate; SBP – Systolic Blood Pressure; DBP – Diastolic Blood Pressure; LAC – Lactate Blood

Figure 4. Pearson's correlation for physiological parameters and cognition, separated in elite (Panel A), advanced (Panel B) and beginner group (Panel C).

et al., 2016). The existing literature tends to highlight a positive relationship if the exercise is of submaximal intensity, while for exhaustive exercises the effects appear negative (Perciavalle et al., 2015, 2017; Strömmer et al., 2020). Possible hypotheses to explain the improvement in post-exercise executive function include the acute effect of exercise intensity on cognitive response or the increase in cerebral blood flow generated by exercise effort, which can be noted on post-exercise cognitive performance.

Regarding physiological parameters, the data indicate that there was a difference between the groups when comparing pre- and post-WOD measurements for SBP and DBP, indicating interaction between the Elite and Advanced groups. After a training session, the body produces physiological responses classified as immediate acute pre- and post-intervention (Materko et al., 2020). Several studies, such as that by Rezk et al. (2006) and Ferrari et al. (2014), report that DBP decreased 15 and 30 minutes after the exercise session, justifying hypotension. We noticed in our research that hypotension occurred shortly after the intervention. The majority of findings indicate an increase in post-exercise SBP, that is, they corroborate the results obtained in this study (Materko et al., 2020).

This is also in line with a study by Alencar et al. (2018) which investigated the physiological responses to the CrossFit modality and a significant increase in the HR and SBP variables was observed compared to rest, with no changes to DBP. Concluding that a CrossFit session with the characteristics of the present study caused an increase in hemodynamic variables, except for DBP, which points to the high cardiovascular demand in the modality.

There was a significant increase in SBP and a drop in DBP. Due to the increase in the sympathetic nervous system (SNS) and the need to increase cardiac output to perform tasks that involve large muscle groups and oxygen demand, much research has been done in the literature about physical exercise and its impact on physiological mechanisms. BP regulators, such as baroreflex, and autonomic actions on HR, systolic volume, peripheral vascular resistance, cardiac output, by changes in cardiac muscle contraction, with a resulting increase in systemic vascular conductance with the possibility of prolonging this reduction by up to 24 hours (Materko et al., 2020).

Our principal results of the study on CrossFit's acute effects on cognition and physiological parameters observed a positive effect on executive function, particularly in the Elite group, in both pre- and post-WOD (Workout of the Day) moments. This was especially evident in areas of cognitive flexibility and inhibitory control. Post-WOD, there were significant physiological changes across all groups. These included an increase in heart rate and blood lactate stages, a rise in systolic blood pressure, and a decrease in diastolic blood pressure. There were notable differences in the time taken to complete the WOD Fran among the Elite, Advanced, and Beginner groups. These variations were attributed to differences in technical skills, physical aptitude, practice time, and training volume. The study found correlations between various cognitive factors and physiological parameters. For example, in the Elite group, a strong positive correlation was observed between a low heart rate and improved counting factor, but there were inverse correlations between low heart rate and other cognitive factors like choice analysis and cognitive flexibility. Based on the analysis, the study supports the link between exercise intensity and cognitive performance, indicating that higher intensity exercise, like CrossFit, can positively influence cognitive functions.

Contrasting our study, Mangine et al. (2018) developed normative values for benchmark exercises but did not control for essential variables that verify physiological and psychological effects. Our findings highlight significant differences in completing the WOD Fran among Elite, Advanced, and Beginner groups, attributed to varying technical skills and physical aptitude (Bellar et al., 2015).

We observed a positive effect on executive function in the pre- and post-WOD moments, particularly in the Elite group. This suggests that exercises like WOD Fran enhance executive function, especially cognitive flexibility and inhibitory control (Li et al., 2014; Vestberg et al., 2017). Supporting this, a meta-analysis by Chang et al. (2012) links cognitive performance with exercise intensity. Lambrick et al. (2016) also suggest that even 15 minutes of acute exercise can

significantly improve executive functions, a finding supported by our results with the high-intensity, short-duration WOD Fran.

Our results showed significant physiological changes pre- and post-WOD, including increases in heart rate and blood lactate, and variations in blood pressure, aligning with Fernández Fernández et al. (2015). However, these changes, particularly post-intervention hypotension (Ferrari et al., 2014; Rezk et al., 2006), raise safety concerns due to the intensity of the exercises. An increase in blood lactate post-WOD was noted, similar to findings by Perciavalle et al. (2016) and Hall et al. (2016), indicating it as a marker of performance intensity.

In the Elite group, correlations between low heart rate and improved cognitive factors were found, suggesting that optimized physical fitness may enhance executive function. This is consistent with the hypothesis by Coco et al. (2019) that high blood lactate stages induced by exercise could impact executive functions. However, our findings indicate significant improvements in cognitive flexibility and processing speed, contrasting with some studies which suggest more substantial effects on functions supported by the prefrontal cortex (Coco et al., 2019; Laurent et al., 2020; Strömmer et al., 2020).

While this study provides valuable insights into the acute effects of CrossFit training on cognitive functions and physiological parameters, particularly highlighting improvements in executive function and notable physiological changes post-workout, it is not without its limitations. The study's sample size and lack of diversity may limit the generalizability of the findings, and the focus on short-term effects leaves the long-term impacts unexplored. Additionally, the absence of a control group restricts the ability to draw definitive conclusions about the effects of CrossFit compared to other forms of exercise or inactivity. Measurement constraints and potential confounding variables, such as lifestyle factors, could also have influenced the results. Despite these limitations, the study's methodological rigor, particularly in its detailed measurement of cognitive and physiological changes, and its focus on a specific and popular exercise modality, significantly contributes to the understanding of the immediate impact of high-intensity functional training on both the body and the mind.

Regarding practical application, athletes and coaches can use the insights from this study to optimize training regimens for high-intensity functional training like CrossFit. Understanding the immediate impact on cognitive functions, such as cognitive flexibility and inhibitory control, can help tailor training programs to target these specific cognitive skills (Brito et al., 2023). Athletes can integrate cognitive training exercises into their routines to improve performance. Also, psychologists working with athletes can apply the findings to develop cognitive training programs aimed at enhancing cognitive functions critical for athletic success (Coco et al., 2019). Cognitive training can be tailored to individual athletes' needs based on their cognitive strengths and weaknesses, as revealed by the study.

Monitoring physiological parameters like heart rate, blood lactate stages, and blood pressure can serve as valuable indicators of cognitive performance during training sessions. Athletes and coaches can use this information to gauge the effectiveness of training and make adjustments in real time to optimize cognitive and physical efforts. The study also provides normative data for CrossFit performance based on competitive stages. This data can be valuable for assessing an athlete's performance in relation to peers and setting performance benchmarks. This study opens doors for further research on the acute effects of high-intensity functional training on cognition and physiology. Future studies can delve deeper into understanding the underlying mechanisms and long-term effects. Additionally, further investigations into the underlying physiological mechanisms can provide deeper insights into how exercise intensity and type influence cognitive functions.

7 Conclusions

The present study yielded significant findings regarding CrossFit's acute effects on cognition and physiological parameters. Notably, it revealed a positive impact on executive function, particularly

within the Elite group, both before and after engaging in the Workout of the Day (WOD). This improvement was particularly prominent in cognitive flexibility and inhibitory control. Furthermore, post-WOD assessments demonstrated significant physiological changes across all groups, including increased heart rate, elevated blood lactate stages, higher systolic blood pressure, and reduced diastolic blood pressure.

Differences in the time required to complete the WOD Fran were observed among the Elite, Advanced, and Beginner groups, which were attributed to variations in technical skills, physical aptitude, practice time, and training volume. The study also unveiled correlations between various cognitive factors and physiological parameters. For instance, in the Elite group, a robust positive correlation was identified between lower heart rate and enhanced counting ability, while inverse correlations were found between low heart rate and other cognitive factors such as choice analysis and cognitive flexibility.

These findings underscore the relationship between exercise intensity and cognitive performance, highlighting the positive influence of high-intensity exercise, such as CrossFit, on cognitive functions. This research bears substantial relevance for professionals in the fields of sports psychology and physical training, offering valuable insights to the optimization of athlete performance. It reaffirms that high-intensity exercise serves as an effective strategy to significantly impact the physiological mechanisms influencing cognitive performance, particularly in enhancing executive functions.

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