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Hight-Intensity Acute Physical Exercise Impacts The Executive Functions, Motricity and Brain Activity of Young Adults at the University: A Randomized Control Trial

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Abstract

Introduction: *Exhaustive exercise has been associated with transitory injures including in the brain, however, previous studies displayed a controversial data about their effects in in the executive functions, in another hand studies affirm that the intensity and volume of exercise have an important factor.* ***Objective:*** *Was to verify the effects of a short-duration exhaustive exercise session on executive*

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functions (EF), cognition, motor skills, brain-wave pattern of health young adults. ***Methods****: Thirty-six subjects underwent evaluation of their EF, cognition, motricity, and EEG brain waves before and after participating in an exercise session carried out to maximal exhaustion. The Kolmogorov-Smirnov statistical test was performed, followed by Student's paired t-test, Kruskal-Wallis test and ANOVA ONE WAY with Tukey's Post Hoc test all with a significance of 5%.* ***Results:*** *A single both of exhaustive exercise promoted acute improvements in cognition, executive functions, and motor skills; provoke acute enhancement in Alpha, Beta and SMR EEG bands, and the EEG pattern has high or high correlation with the gains verified on cognition, executive functions, and motor skills.* ***Conclusions:*** *Exhaustive exercises were shown as capable to improve the executive functions, cognition, and motor skills, but decreasing the capacity of them in terms of their capacity for acute attention maintenance with brain waves modulation corresponding to improvements of executive functions, cognition, and motricity performances.*

Keywords: Mental Flexibility. Inhibitory Control. Working Memory. Digit Span. Motor Skills. Exhaustive Exercise

INTRODUCTION

Executive functions (EF), also known as executive control or cognitive planning, refers to a family of highly hierarchical mental processes that are part of cerebral functioning and make possible mental planning, the concatenation of ideas, and the reduction of time between thought and action. When we are at demands of cognitive and/or motor tasks requiring attention or also when not engaged in intuitive activities the performance of these tasks without the use of EF can be exceedingly difficult. However, the use of EF requires a greater level of mental effort than when performing any task in an automated way (Diamond, 2013).

There is a consensus in the related neural literature that points at three major neural nuclei commanding the actions related to the EF: (i) inhibition or inhibitory control (Diamond, 2013; Lima et al., 2017), (ii) interference control such as selective attention and working memory (Wambach et al., 2011), and (iii) cognitive flexibility a function closely linked to creativity (Diamond, 2013; Lima et al., 2017). These functions constitute fundamental skills for physical and mental health, educational success, day-to-day tasks, cognitive activity, social interactions, and appropriate psychological development (Collins, Roberts, Dias, Everitt, & Robbins, 1998). There are also a myriad of activities already described as positively influencing the development of EF competencies among which the most commonly cited orient to an effective use of nutrients and exercises (McLellan, Caldwell, & Lieberman, 2016; Santos et al., 2014), mental training by use of biofeedback (Calomeni et al., 2017), physical exercises practices and others exercises that can be applied to different sports modalities (Alves et al., 2012; Lima et al., 2017; Liu-Ambrose et al., 2010; Nouchi et al., 2014; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012).

Physical exercise can exert acute and chronic effects upon the EF and cognitive functions at a short and /or immediate short-term and can be considered as being immediate and potent, conditions that permit the affirmation that EF can be improved even after one only exercise session (Jäger, Schmidt, Conzelmann, & Roebers, 2014; Wen et al., 2018). A variety of evidence has been associating certain practices of exercises to functional and structural improvements throughout the whole brain being that almost always the exercises are recommended within different approaches when applied to different populations which may vary from normal children to others with ADHD, to healthy elderly individuals comparatively to elderlies suffering of degenerative brain diseases such as Alzheimer or dementia (Boone et al., 2017; Jäger et al., 2014; Liu-Ambrose et al., 2010; Liu et al., 2017; Nouchi et al., 2014).

A modulated state of the brain during it function of motor control events is indicated by an EEG of the Alpha (7-11 Hz) and Beta (12-30Hz) rhythm characteristics for events of a cognitive nature, whereas for the motor domain, the Alpha rhythm integrates with the sensory-motor rhythm (SMR) producing an spontaneous EEG which can be associated with general muscles movement and spinal moto neuronal activities as shown, for instance, in events of tonic motor contraction (Bayraktaroglu, von Carlowitz-Ghori, Curio, & Nikulin, 2013; Bazanova & Vernon, 2014). The SMR signals are recorded closer to the sensorimotor area and their amplitude is known to be reduced in relation to unsynchronized neural activities related to motor events, suggesting a possible electrophysiological signal of sensorimotor excitability (Pfurtscheller, Brunner, Schlögl, & Lopes da Silva, 2006). The nature of the SMR functions in movement control must, in fact, require its rhythms being mainly projected at pericentral gyro of the cortex in order of adequately promote the excitability of the cortical-spinal tract, as well as the intracortical disinhibiting of the primary motor cortex (Takemi, Masakado, Liu, & Ushiba, 2013).

The hypothesis that subsided this present investigation was based upon a current and plausible notion that physical exhaustion could cause a decrease in EF, principally in function of a neurological indication that links the mental exhaustion produced by it to depression on the neural circuitry of some brain structures involved in cognition and motor control. However, studies diverging of this neurological point of view have proven that exhaustive physical exercise may not only brings cognitive and mental benefits for its practitioners, but also enormously contribute to corporal, metabolic, cardiovascular, and immunological gain (R. A. Da Silva, Lunardello, De Oliveira, De Olivera, & Valentim-Silva, 2016; Elhakeem et al., 2018; Horowitz et al., 2018; Xiang, Rehm, & Marshall, 2014). Even so, the conformity of the exercises prescriptions has not been well addressed leading to the necessity of research providing knowledge about intensity, frequency and other variants that can optimize the benefits of physical exhaustive training to different classes of people. Going In this direction, the present study sought to fill a gap related to the determination of the acute effects of a short-duration exhaustive exercise session upon the EF and motor skills of healthy young adults.

MATERIALS AND METHODS

Study Ethics

The present study complied with all mandatory requirements in accordance with Law 466/2012 of the Brazilian National Health Council and was approved by the Ethics Council duly consolidated under CAAE number: 44907715.2.0000.5653 on 07/27/2015. All the volunteers signed an informed consent form, were informed about all phases of the study, were informed that they could decline to participate at any moment they desired without incurring any penalty against themselves or any of the researchers. Also, they were advised that their participation would not be remunerated in any way. All procedures followed the instructions implicated in the Helsinki Declaration.

Study type and participants

The study was designed sob form of the experimental type, considering that it had an experimental and a control group selected in a convenient and direct invitation of the researchers. However, for groups' composition the selection was aleatory. The study development occurred in a Higher Education Institution of Rio Branco, Acre, Brazil. The participant volunteers were sixty-eight individuals with age between 18 and 28 years of both sexes, all of whom were university students at a teaching institution in Rio Branco, Acre, Brazil. The control group (CG) was composed by 32 (n=32) subjects and the experimental group (EG) by 36 (n=36). The characteristics of the volunteers are described in Table 1. Finally, the student t test was performed to verify the existence of possible preliminary differences in characteristics of the groups, being that no difference was found.

Table 1: Descriptive characteristics of the study participants.

Variables	Control Group (n=32)	Experimental Group (n=36)	*P* value
Age (years)	23.91±0.95	24.62±1.33	0.087
Body Mass (kg)	73.44±12.78	75.56±16.05	0.061
Height (cm)	165.66±20.39	167.56±23.45	0.063
BMI (kg/m²)	27.0±3.33	26.0±4.67	0.071
VO_2 Max (mL/kg)	33.43±4.76	32.52±5.37	0.059

Legend: Sixty-eight subjects between 18 and 28 years old of both sexes, were selected and divided into control group composed by 32 (n=32) subjects, and the experimental group with 36 (n=36) subjects. (BMI = body mass index), (kg = kilogram), (m = metre), (kg/m² = kilogram per square metre), (mL/kg = millilitres per kilogram). (VO_2 max = maximum oxygen volume, mL/kg = millilitres per kilogram).

Study design, instruments and procedures

To determine the anthropometric measurements, an Omron octopolar scale, model HBF-514-C (OMRON HEALTHCARE, Kyoto, Japan), was used. The volunteers were instructed to wear light clothing, to not perform vigorous physical exercise, and to not consume large amounts of caffeine for at least 12 hours prior to testing. Initially, volunteers were submitted to EF (digit span and Stroop tests) and motor skills (tracking task) tests. Subsequently, five subjects at the once performed at the shuttle run test, which served two purposes: (i) to determine the maximum respiratory capacity (VO2 max in mL/kg-1) and (ii) as an exhaustive practice of physical exercises executed under the short-term conformity. Finally, in an orderly manner, for every five subjects EF and motor performance data were, at a sequenced time period, newly acquired for progressive comparisons. All evaluations followed the same structure and to all effective considerations, the time, order, number of the habituation tries, acquisitions, and all another possible variation were controlled from the first to the subsequent data acquisition moment.

Stroop Test

Participants initially participated in a practice block of 25 trials with feedback, followed by a block of 50 data acquisitions with no feedback (75 total experimental trials). Only the last 50 data acquisitions were used as results, and the first 25 trials were discarded. The aim of the 25 trials was to habituate the volunteers to the test.

This test consists of two tasks, one involving reading and the other involving colour naming. Inconsistency between the printed word and its colour causes an interference effect in naming the colour. This interference is known as the Stroop-colour effect. The Stroop test was used to evaluate selective attention and conflict resolution, and the time difference between naming the colour of the ink in which the words were printed (while ignoring the word itself) and naming the colour displayed in the images that were viewed on the computer monitor was calculated. Lower differences in time indicate better performance.

Participants were tested on computers on which the Stroop test program had been previously installed. The stimuli consisted of the names of words and colours in Portuguese (green (*verde*), yellow (*amarelo*) and red (*vermelho*)) displayed in Arial fonts in green, yellow, and red colours. The words were approximately 2 cm wide and 0.5 cm high. Participants had to react as quickly as possible by indicating the colour of the word, using the index, middle, or ring finger of their dominant hand (right) to press the 'c', 'v' or 'b' keys.

The stimuli were randomized by participant, presented in the centre of the computer screen approximately 50 cm from the participant's eye and remained on display until a response key was pressed. After the response, a grey fixation cross was presented for 750 ms, followed by the next stimulus. The nine possible combinations of colour and word/colour were presented in random order, resulting in 33% congruent combinations and 66% incongruent combinations. For 33% of the trials, the irrelevant word was repeated, while for another 33% of the trials, the relevant colour (response repetition) was repeated. No repetition was present in the other 33% of the trials.

Digit Span

The digit span test consists of evaluating short-term memory through working memory. This defines the functional memory extension, that is, the individual's ability to repeat, in the correct and immediate order, a sequence of items that may be letters, numbers or words, in order to observe their memory space(Wambach et al. 2011). The first sequence starts with two digits. After each correct answer, the program itself adds one digit to the next sequence. The test was scheduled to run until the ninth stage, which would contain nine digits to be repeated. An experiment through stage four was carried out with the aim of habituating the volunteer to the test, and then a completely new test was performed for data acquisition.

Digit Tracking

This task evaluates hand-eye coordination, in which a user faces a monitor and, for a limited time of 10 s, must press three keys previously defined by the program itself on the keyboard as fast as possible and the greatest number of times. After every three digits, the subject alternates the hand that is typing. At the end, the total number of digits typed was computed, and performance was determined based on the number of correctly typed digits.

Attention

All tests have a percentage of correctness of their standards that are considered as attention. In the Stroop Test and the Digit Span, in the pre-test the hit percentage is quantified beyond the speed of response to the stimulus. In this case, the ability to interact with the test and attention about its patterns and produce higher hit levels are quantified by the tests and, therefore, one can say that the participant was able to learn. Then, the quantification of the correct levels between the pre and post-test can be a measure of attention.

Trail Making Test

The cognitive flexibility was assessed using the TMT. The two-part visual task (Trail A and B) was used. Three scores of cognitive flexibility were determined [(BA); (B/A); and B) and in the end, a simple mean was calculated as score to measure the mental flexibility. The TMT Part A is able to analise executive functions and the TMT Part B the Cognitive Process.

Both parts of the Trail Making Test consist of 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1 – 25, and the participants should draw lines to connect the numbers in ascending order. In Part B, the circles include both numbers (1 – 13) and letters (A – L); as in Part A, the participants draws lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The participants should be instructed to connect the circles as quickly as possible, without lifting the pen or pencil from the paper. Time the participants as he or she connects the "trail." If the patient makes an error, point it out immediately and allow the participants to correct it. Errors affect the participant's score only in that the correction of errors is included in the completion time for the task. It is unnecessary to continue the test if the patient has not completed both parts after five minutes have elapsed.

Electroencephalographic data collection

The instrument used for this procedure was Pocomp+ - (Touch Technology-Canada) Biofeedback System (USA) and Biograph Software, version 2.1. The placement of the electrodes for EEG collection was performed in the 10-20 system (Jasper, 1958), as recommended by the Brazilian Society of Clinical Neurophysiology.

The points chosen were the Cz point of reference located strictly at the top of the skull, and the points A1 located in the left ear and A2 in the right ear in order to identify energy emission from each cortical hemisphere. The Alpha, Beta and SMR waves were recorded.

Shuttle Run

The shuttle run test was used to evaluate cardiorespiratory fitness (Léger et al. 2017; Tomkinson et al. 2017). The stress tests were performed at night in the parking lot of the aforementioned educational institution, in a flat place with a mild temperature. All subjects answered a short questionnaire containing personal identification data such as name and age.

To carry out the test, the following elements were necessary: a flat spot at least 25 metres long, a lap top, speakers, 4 cones, masking tape, a stop watch, a scoreboard to record the number of laps and paper for taking notes. The test was applied in groups of 5 people who ran together in a rhythm determined by an audio track especially recorded for this purpose. They crossed a space of 20 metres, delineated by 2 parallel lines. The audio produces a beep at specific intervals for each stage, and with each beep, the evaluated individual was to cross one of the two parallel lines, i.e., running from one of the lines towards the other, and cross the line with at least one foot; when the next beep was heard, he or she ran back to the opposite line.

In the audio, the end of a stage is signalled by 2 consecutive beeps and with a voice announcing the completed stage number. The duration of the test depends on the cardiopulmonary fitness of each person, and, being maximum and progressive, was less intense at the beginning and become more intense at the end with a total possible duration of 21 minutes (stages).

The number of laps was then compared with the reference table to determine the speed reached. After the speed was determined, these data were used in the equation reported below for the calculation of VO_2 max. These procedures were previously described (Hoff et al. 2015; Verburgh et al. 2014), and their validity has been determined by different authors over many years, all of whom found high or very high correlation (r calculated up to 0.96 in a correlation test) (Verburgh et al. 2014; Jo et al. 2018). The equation used by the test is as follows:

$$Y = -24.4 + 6.0(X)$$

Equation 1: Equation for calculating VO_2 max according to shuttle run methodology. Y = VO_2 in ml/kg/min; X = speed in km/h in the final completed stage.

Statistical Analysis

To verify the normality of the data, the Kolmogorov-Smirnov statistical test was performed. For data analysis, Student's paired *t*-test, Kruskal-Wallis test and ANOVA ONE WAY with Tukey's Post Hoc test were the statistical instruments used. All tests were performed with a significance of 5% in the program Prism Stat 5.0.

RESULTS

A single both of exhaustive exercise promoted acute improvements in cognition, executive functions, and motor skills

In regard to working memory, the CG showed no difference between the pre- (4.65±0.92) and the post-exercise time point (4.68±0.96) (p>0.05) (Fig. 1A). To the EG, the comparison between the pre- (4.82±0.91) and the post-exercise time point (5.62±0.93) of one exhaustive exercise session presented differences (p=0.0036) (Fig. 1A). To inhibitory control, the CG presented no difference between the pre- (0.88±0.35) and the post-exercise time point (0.88±0.34) (p>0.05) (Fig. 1B). However, to the EG, the comparison between pre- (0.85±0.46) and post-exercise time point (0.72±0.28) presented differences (p=0.0001) (Fig. 1B). Yet, to hand-eye coordination, the CG displayed no difference between the pre- (17.83±9,14) to the post-exercise time point (17.52±7.88) (p>0.05) (Fig. 1C). To the EG, the comparison between the pre- (18.63±7.54) and post-exercise time point (34.14±15.17) of an exhaustive exercise session showed differences (p=0.0001) (Fig. 1C).

In regard to attention, the hit percentage quantified by Digit Span to the CG displayed no difference between the pre- (93.44±4.77) and the post-exercise time point (92.94±4.95) (p>0.05) (Fig. 1D), moreover, when measured by the Stroop Test a comparison between the pre- (91.87±5.61) and the and the post-exercise time point (93.28±3.64) (p>0.05) (Fig.1D). To the EG, a comparison between the hit percentage quantified by Digit Span pre- (93.44 ± 4.77), and post-exercise time point (90.61±3.97) of one exhaustive exercise session presented differences (p=0.023) (Fig. 1D), and, when measured by Stroop Test a comparison the pre (94.01 ± 3.24), and post (90.11±4.63) time points of one exhaustive exercise session presented differences (p= 0.0004) (Fig. 1D). Finally, to the mental flexibility measured by the TMT A, the CG not reached difference between the pre- (62.42±8.38) and the post-exercise time point (54.86±5.42) (p>0.05) (Fig. 1D), moreover, when measured by the TMT B, the comparison between the pre- (134.1±11.81) and the and the post-exercise time point (135.32±12.19) (p>0.05) (Fig.1D). To the EG a comparison between the pre- (62.41± 8.38), and post-exercise time point (54.86±5.42) of the TMT part A presented differences (p= 0.0001), and to the TMT part B Pre (139±12,25) and post (127±7,85) presented differences (p= 0.0001).

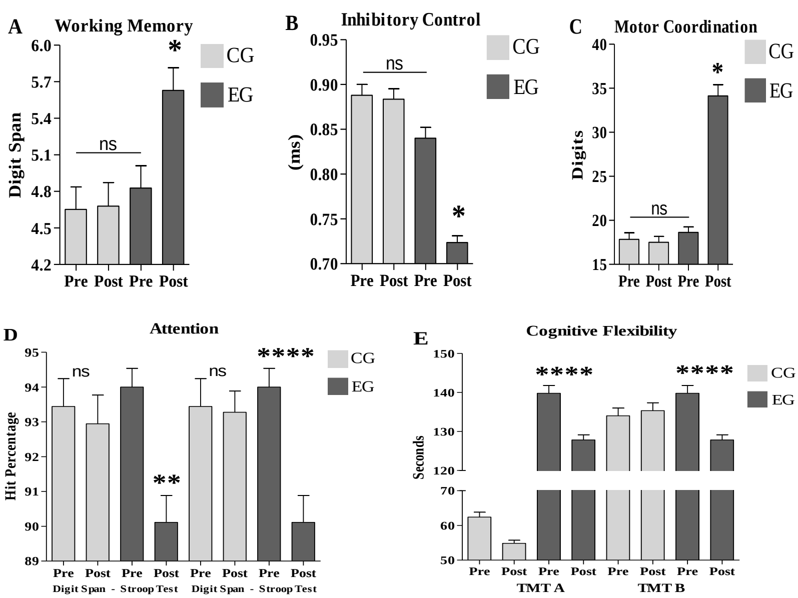

Figure 1: Executive functions and fine motor coordination. Sixty-eight subjects between 18 and 28 years old of both sexes, were selected and divided into control group composed by 32 (n=32) subjects, and the experimental group with 36 (n=36) subjects. (A) Working memory (WM) determined by the digit span test, (B) inhibitory control (IC)

determined by the Stroop test, (C) fine motor coordination (MC) determined by the digit tracking test, (D) The Digit Span Test hit percentage (DS-H), and the Stroop Test hit percentage (ST-H), and (E) Trial Making Test (TMT). To the WM, IC and MC the Student's paired *t*-test was used, and the ANOVA ONE WAY was used to ST-H and TMT both with 5% of significance. Note: (A* p=0.0036; B, C * p=0.0001; D ** p=0.023; **** p=0.0004; E ****= 0.0001); (pre = baseline data; post = comparison data).

A single both of exhaustive exercise provoke acute enhancement in Alpha, Beta and SMR EEG bands

For the Alpha band, the absolute power output of the CG displayed no difference between the pre- (3.99±7.01) and the post-exercise time point (4.48±12.35) (*p*>0.05) (Fig. 2A), however, the EG pre- (4.31±3.77) and the post-exercise time point (12.48±12.35) exhibiting difference between two moments (*p*= 0.0001) (Fig. 2A). To SMR rhythm the absolute power output of the CG reached no difference between the pre- (3.49±2.46) and the post-exercise time point (4.87±7.52) (*p*>0.05) (Fig. 2B), however, the EG the pre- (4.81±2.49) and the the post-exercise time point (8.87±7.50) showing difference (*p*= 0.0001) (Fig. 2B). Finally, to the Beta band, the power output of the CG presented no difference between the pre- (5.98±3.11) and the post-exercise time point (7.26±4.18) (*p*>0.05) (Fig. 2A), however, the EG the pre- (6.98±3.41) and the the post-exercise time point (12.26±5.68) showing difference (*p*= 0.0001) (Fig. 2C).

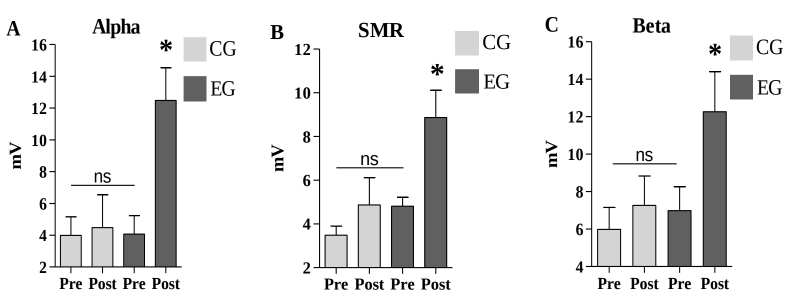

Figure 2: Cortical waves. Sixty-eight subjects between 18 and 28 years old of both sexes, were selected and divided into control group composed by 32 (n=32) subjects, and the experimental group with 36 (n=36) subjects. They are submitted to four minutes of data collection of Alpha, SMR and Beta cortical waves. Alpha (A), SMR (B) and Beta (C). The Kruskal-Wallis test with significance of 5% was used to determinate the differences between Pre and Post moment. Note: (A, B and C * = *p* <0.0001 Resting vs. Activity); (pre = baseline data; post = comparison data)

The enhancement of the EEG pattern has high or very high correlation with the gains verified on cognition, executive functions, and motor skills.

The analysis of the correlation indexes evidenced that the working memory have a very high correlation with alpha, beta and SMR waves, the inhibitory control high correlation with the SMR and Beta, motor coordination very high correlation to SMR and beta waves and mental flexibility very high correlation with SMR and beta and high correlation with alpha waves. Curiously, the attention has a low inverse correlation to SMR, middle to Alpha and high to Beta waves. The data about the CG was no showed because very low correlations ware found to all comparison.

Table 2: Presentation of Spearman correlation indices in the moments of rest and execution of a skillful motor task with cognitive demand.

	Alpha	SMR	Beta
Working Memory	0.84*	0.82*	0.88*
Inhibitory Control	0.22*	0.77*	0.67*
Motor Coordination	0.29	0.94**	0.82*
Attention	-0.33	-0.19	-0.65*
Mental Flexibility	0.77*	0.81*	0.89*

Legend: (*,** Score obtained from the Spearman correlation coefficient). (*= r< 0.05; **=r< 0.01).

DISCUSSION

The present study aimed verify the effects of a short-duration exhaustive exercise session on executive functions (EF), cognition, motor skills, and brain wave pattern of health young adults. To do so, several experiments were performed before and after the occurrence of the mentioned exercise sessions applied to 36 healthy young adults, all of them students from a higher education institution in The Acre State. Experimentally, the Stroop test, which is able to determine inhibitory control and decision-making ability; digit span testing, which measures working memory; the digit tracking test, which quantifies the number of correct keys typed on a computer keyboard and is able to determine fine motor speed, dexterity and precision, the trial making test, which is able to determine the cognition, and EEG data were acquired before and after the practice of the short-duration exhaustive exercises as prevised in the study methodological session.

In regard to the control group, no difference was noted to all comparisons performed, so, the discussion will be centred in the EG, and, in this case, the CG permitted the prove that the experimental situation in fact promoted significant alterations upon the EF variable as well as in the brain waves activity of the group submitted to the experimental methodology. In other words, such a result can validate the results of other studies showing that very intense short-duration exhaustive exercise can promote acute and beneficial improvement on factors of cognition and motricity such the ones that were here researched.

Seeking for the comprehension of the above related gains the analysis of the Stroop Test and the Digit Span test data were interpreted as positively influencing those gains. That is, revealing the existence of a clear relationship between attention, cognition, and other factors within the dimension of the competences related to the EF. In addition, in a great part we can reasonably consider that such gains were also produced by interactions reflected from the increase in cortical power associated to the modifications the training promoted in the alpha wave pattern. Previous research have shown a clear and positive relationship between cortical power output with motor control, EF, and cognition (Calomeni et al., 2017; V. F. da Silva et al., 2016; Hatfield, Haufler, Hung, & Spalding, 2004; Moraes et al., 2007; Raphael et al., 2009), some of those having a high reliability in respect to its results due to the capability of the instruments used for capturing signals at specific moments of cortical functioning (Calomeni et al., 2017; Furtado et al., 2016).

Different activities can improve EF in an acute or chronic way in people of different ages and physical and mental conditions (Boone et al., 2017; Lima et al., 2017; Rattray & Smee, 2016; Wen et al., 2018). In the present study, a marked improvement in working memory was observed, as in other studies, although under different conditions than that observed in previous studies (Hyodo et al., 2012; Yanagisawa et al., 2010), a fact that suggests the present investigation is relatively novel. Several studies have demonstrated the positive effects of exercise on different types of memory. Regarding procedural memory (Byun et al., 2014), an aerobic exercise session was described as decreasing the interference between memory and learning, i.e., an aerobic exercise session was able to facilitate the acquisition of immediate memory for performing motor procedures.

Another study showed that changes in cognitive performance may be implicated in exercise intensity, and this probably has implications for sports, education, and occupations (Tsukamoto et al., 2017), which is important for future research. Here, the cognitions skills were improved by short-duration exhaustive exercise differently from that of previous studies that used primarily resistance or aerobic exercises of moderate to intense intensity, even though both types can benefit several brain functions.

In a same line some other studies have reported that an acute session of aerobic exercise can improve EF, including inhibitory control, in different populations (Crush & Lorezini, 2017; Guiney, Lucas, Cotter, & Machado, 2015; Tsai et al., 2014; Tsai, Pan, Chen, Wang, & Chou, 2016). In addition, it has previously been demonstrated that the improvement in inhibitory control induced by aerobic exercise is related to an improvement in neural activity(Guiney et al., 2015; Tsai et al., 2016) as observed here in the EEG data that showed strong improvement in the Alpha, SMR and Beta power output indicating more brain activity due the participation in a short-duration exhaustive exercise session. Along the same lines, Byun et al. (Byun et al., 2014) demonstrated that increased neural activity induced by aerobic exercise is related to increased neural excitation. Based on these findings, previous studies have proposed that the potential mechanism underlying the improvement in inhibitory control is associated with increased neuronal activation and brain stimulation. This may be a mechanism linked to the behaviours observed herein for EF, motricity, and cognition (Guiney et al., 2015; Tsai et al., 2014, 2016).

This increase in neural excitability may be mediated by a number of different mechanisms such as increased cerebral blood flow(Victor da Fonseca, 2010), neurogenesis, synaptic plasticity, cellular proliferation, acute increase in brain-derived neurotrophic factor (Victor Fonseca, 2010), and associated neural efficiency, which may be partially dependent on cardiorespiratory fitness(Víctor da Fonseca, 2001). Crush and Lorezini (2017), in an extensive investigation that sought to determine the effect of exposure time to moderate intensity exercise, recovery time and different combinations of these two factors, noted that all training regimens benefitted planning ability, memory and inhibitory control and described that there is a dose-dependent effect of exercise and recovery on EF.

As we can see the data shown until now give enough support to the findings observed here showing that short-duration exhaustive exercise promotes immediate positive effects on the inhibitory control of young adults; in fact, the hypothesis that exercise leading to exhaustion could lead to EF impairment is contradicted by the data shown here. Thus, the data observed here showed that short-duration exhaustive exercise can improve inhibitory control and decision making. It is known that exercise aids in the development of motor skills; however, data on the acute effects of exhaustive exercises on motor skills are still very scarce in the literature. Although studies on the effect of an exhaustive exercise session are not abundant in the literature, there is a body of evidence demonstrating the effects of prolonged exercise on human motor skills (Noordstar, van der Net, Voerman, Helders, & Jongmans, 2017; Snow et al., 2016; Statton, Encarnacion, Celnik, & Bastian, 2015; Voyer & Jansen, 2017).

In the present study, it was evident that exercise may produce a potent acute effect on fine motor skills, which are the most hierarchical of the motor functions, controlled primarily by the most developed portion of the cortex, the frontal lobe (Noordstar et al. 2017; Voyer and Jansen 2017). These results are important from an experimental point of view since they demonstrate that an exhaustive exercise, unlike what common sense might dictate, does not diminish one's coordination capacity. However, the data here refer to an acute exhaustive exercise, which is a profoundly different stimulus than a moderate or intense exhaustive physical activity of long duration that might provoke an adverse effect in those observed in this study.

Snow et al.(Snow et al. 2016) found that, compared to rest, exercise seems to facilitate the maintenance of motor performance throughout the acquisition phase; however, moderate intensity exercise does not influence motor skill learning indices, nor does it affect motor memory consolidation. This demonstrates a complex interaction between exercise intensity and motor memory (Roig et al. 2012).

Recent studies have examined the role of acute aerobic exercise in modulating the acquisition and retention of complex motor skills. The first of these studies showed that intermittent high-intensity aerobic exercise in temporal proximity to the practice of motor skills increased measurements indicative of motor skill acquisition and retention(Roig et al. 2012). More recently, Statton et al.(Statton et al. 2015), later corroborated by Snow et al.(Snow et al. 2016), demonstrated that a single session of moderate intensity running increased the acquisition of motor skills. This evidence corroborates the data regarding motor behaviour observed in the present study.

In regard to executive function and cognitive flexibility assessed by TMT, the short-duration exhaustive exercise enhanced both within the several executive functions here investigated. But, to attention, a comparison between the baseline data and the moment after the exercise session showed decreasing in this variable. It can be explained by the theoretical interaction between neural adaptations and exhaustion due the exercise. If the pool of theoretical alterations and adaptations in the neural system could enhance the working memory the inhibitory control, and the motricity, and mental flexibility, perhaps, the exhaustion can explain this result even the exercise here proposed showed enhancement another executive functions.

Previous work has also demonstrated beneficial cognitive effects from an acute 5, 10, and 15-minute of aerobic exercise (Best, 2010; Hogan, Mata, & Carstensen, 2013; Snigdha, de Rivera, Milgram, & Cotman, 2014) corroborating our data. However, low-intensity exercise may not be a strong enough stimulus to trigger the changes above in executive functions, whereas high-intensity exercise may induce neural noise and inhibit positive exercise-induced changes (Loprinzi & Kane, 2015). This relationship suggests that the intensity of acute exercise is a key factor in the regulation of exercise-induced cognitive responses, including the attention. Although this discussion do not is the aim of our work, this data is important to defendant the notion bout the short-duration exhaustive exercise enhance the executive functions, in part corroborating with the data here observed. Although the data in this study demonstrate efficacy, it is recommended that other methods of exhaustive exercise, such as prolonged intense or moderate physical exercise such as running a half marathon or a full marathon, be investigated.

However, it was evident that exercise challenge proposed here provoke modulations in the brain wave. This fact can help to explain a possible mechanism under all behaviours here observed to executive functions and the motricity. Nonetheless, the correlation between the cortical waves and all executive functions and motricity here observed reinforce the evidences that the brain wave modulation due one both of short-duration exhaustive exercise has strong influences upon the execution of a motor activity, attention, inhibitory control and cognition.

Such assertions underpin the theoretical possibility tested in this study that exhaustive exercise may reveal differentiated patterns in the EEG before and after short-duration exhaustive exercise. The first interesting observation is the confirmation that the physical exercise changes the functional setting provoked by increase in the cortical activity after an exercise challenge. This attempt at correlation was supported, where it was demonstrated that the EEG presented activation of the central executive neural networks in answer physical interventions. The data hypothesize that people, after one both of short-duration exhaustive exercise execution, have considerably higher Alpha, SMR and Beta wave activity than that observed before the exercise challenge. This hypothesis seems plausible and justifies the correlation observed.

CONCLUSION

Contrary to what common sense might dictate, short-duration exhaustive exercise was able to improve the EF (working memory, inhibitory control, and mental flexibility), cognition and motor skills of young sedentary adults. Our results are promising because they demonstrate that motor skills and EF can be optimized by brief bouts of exercise even if this leads to physical exhaustion. However, more studies are needed to understand the underlying mechanisms and to explore the effects of different exercises, such as prolonged exercises of moderate intensity as well as the effects of exercise on different populations such as children, healthy elderly individuals, or those with diseases such as Alzheimer's or frailty.

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