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Autonomic Heart Rate Regulation During Maximum Incremental Treadmill Test: A Study Case

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Abstract*— *Background: *Street running has been growing exponentially in recent years. It is among the most popular physical activities, according to global data for adults. Having become a popular and accessible sporting event due to the emergence of sports advisors, with increased demand for specialized training in the longer distance run, half marathon and marathon. The HRV analysis is generally used to assess the ANS functioning in cardiovascular research and in different applications related to human well-being. HRV has been used in countless studies, related to cardiovascular research and different applications in human well-being, as an indirect tool to assess the functioning and balance of the ANS and currently rest measures, during exercise, and recovery after exercise have been used for this purpose.* ***Methods:*** *A volunteer who had been running for more than five years and in competitive activity with time less than 20 minutes for 5 km competitions. Male, 29 years old, 64.1 kg, 179.5 cm in height, with no reports of health restrictions such as musculoskeletal injuries and a cardiovascular history diseases or thyroid disorders. The maximum speed test was calculated using the equation correction for incomplete stages proposed by Kuipers (2003). Heart rate was recorded using a POLAR® RS800cx heart rate monitor, with a sampling rate of 1000 Hz. The R-R-interval data recorded by the portable heart monitor was transferred to Polar Pro trainer 5® software.* ***Results:*** *We can observe the variables referring to the autonomic nervous system parasympathetic activity, mean RR, RMSSD and SD1 intervals, as well as the variables used to calculate the sympathetic activity, mean HR, stress index and SD2 for* *each speed of incremental testing.* ***Conclusion:*** *We conclude that the use of HRV as a tool makes it possible to identify an individual's physical capacity. We also concluded that the HRV variables are sensitive to the physiological changes imposed by the stress of continuous progressive physical exercise, at high exercise intensities the parasympathetic variables PNS, RMSSD, Mean RR and SD1 decrease, as well as SNS, Stress Index and Mean HR that reflects sympathetic activity increase slightly, without achieving complete recovery after 6 minutes post-exercise from baseline.*

I. INTRODUCTION

Street running has been growing exponentially in recent years, consisting in a physical activity that combines performance, health and leisure. These are running events held on streets or roads. It is among the most popular physical, activities according to global data for adults (Hulteen et al. 2017). Having become a popular and accessible sporting event due to the emergence of sports advisors, with increased demand for specialized training in the longer distance run (5 and 10 kilometers), half marathon (21 kilometers) and marathon (42 kilometers) (Salgado and Mikail 2007).

The heart rate variability (HRV) analysis is generally used to assess the autonomic nervous system (ANS) functioning in cardiovascular research and in different applications related to human well-being (Berntson, 1997). HRV is known to be affected, for example stress, certain heart diseases and pathological conditions. She is a result of ANS regulation of the sinoatrial node. The ANS is divided into sympathetic and parasympathetic branches and its influences on heart rate (HR) and HRV are well known. Roughly speaking, sympathetic activity tends to increase HR and decrease HRV, while parasympathetic activity tends to decrease HR and increase HRV. Parasympathetic (PNS Index) and sympathetic nerve activity (SNS Index) are calculated from HRV components (T. Laitio 2007)

Cardiac vagal activity is known to increase the mean RR interval (ie, it decreases HR), so the mean of the R-R-intervals (Mean RR) is a natural choice for calculating the PNS index. Cardiac vagal activity regulates the magnitude of the respiratory sinus arrhythmia component and is observed as a fast changes in the R-R-interval associated with breathing act. These fast changes can best be captured by the root mean square of successive differences (RMSSD), which is why this parameter is the second input for calculating the PNS index. As the SD1 (Poincare Plot Standard Deviation) is known from the vagal modulation of HR, equivalent to the RMSSD (Brennan et al, 2001), the normalized value of SD1 is used in Kubios HRV as the third input parameter for the calculation of the PNS index (Tarvainen 2014).

Mean HR is an obvious choice for calculating the SNS index, as it is known that an increase in HR is linked to an increase in cardiac sympathetic activation. The Baevsky Stress Index is a widely used index of cardiovascular system stress and is strongly linked to sympathetic nerve activity. The normalized plotting parameter, Poincare SD2, provides a robust index of sympathovagal balance and is therefore used as the third input parameter for calculating the SNS index (Task force, 1996)

Heart rate variability has been used in countless studies, related to cardiovascular research and different applications in human well-being, as an indirect tool to assess the functioning and balance of the autonomic nervous system (ANS) and currently rest measures, during exercise, and recovery after exercise have been used for this purpose (Buchheit et al. 2009; Buchheit 2010).

Continuous monitoring of athletes HRV is important to identify general health variables related to adjustments in cardiac autonomic regulation, influenced by training, guiding an adequate choice of methods and adjustments in training loads (Plews et al. 2012). The HRV ultra-short recording appears to be a practical and viable alternative for recording within the daily training routine (Baek et al. 2015; Pereira et al. 2016).

Despite studies related to running training and its implications for performance (Stöggl and Björklund 2017; Wiewelhove et al. 2018) and HRV analysis have been investigated in several research fields (Vanderlei et al. 2009; Kiss et al. 2016; Holzman and Bridgett 2017), it is still unclear how the autonomic components, sympathetic nervous system and parasympathetic, calculated behave during at a maximal incremental test on a treadmill. Therefore, the aim of the present study was to analyze the heart rate variability of a runner during a maximal incremental test on a treadmill.

II. METHODS

The present study is a descriptive study case. He was approved by the Ethics and Research Committee on Human Beings of the Federal University of Uberlândia-

UFU, opinion number: 3.397.582, CAAE: 13624419.2.0000.5152 and the participant signed an Informed Consent Form, according to Resolution CNS 466/ 12, authorizing their participation.

A volunteer participated in the study, who had been running for more than five years and in competitive activity with time less than 20 minutes for 5 km competitions. Male, 29 years old, 64.1 kg, 179.5 cm in height, with no reports of health restrictions such as musculoskeletal injuries and a cardiovascular history diseases or thyroid disorders. The volunteer received all instructions on the procedures to be performed, the benefits and possible risks of the research and signed an informed consent form.

2.1 MAXIMUM INCREMENTAL TEST

The incremental test was performed on a Movement (brand) treadmill, Model E.740. After a warm-up, the test started at a 10 km/h speed, a 1 km/h load increment was performed every 2 minutes, without pauses between stages, the athlete were instructed and verbally encouraged to keep exercising for as long as possible. possible time, until they reach voluntary exhaustion (Chang et al. 2020). The treadmill inclination was maintained at 1% and throughout the test (Jones and Doust 1996).

The maximum speed test was calculated using the equation correction for incomplete stages proposed by Kuipers (2003), also described in the study by Arantes (2017). The VO_{2max} was calculated using the formula proposed by ACSM's (Glass S 2007; Koutlianos et al. 2013). Thus, the maximum speed in kilometers per hour (km/h) obtained in the incremental test was called maximum aerobic speed (MAV).

2.2 HEART RATE VARIABILITY

Heart rate was recorded using a POLAR® RS800cx heart rate monitor, with a sampling rate of 1000 Hz. The R-R-interval data recorded by the portable heart monitor was transferred to Polar Pro trainer 5® software (Kempele, Finland). Before the R-R-intervals analysis, were visually inspected and the artifacts were removed, using digital filtering in a moderate way in the standard software filter, as shown in Figure 1.

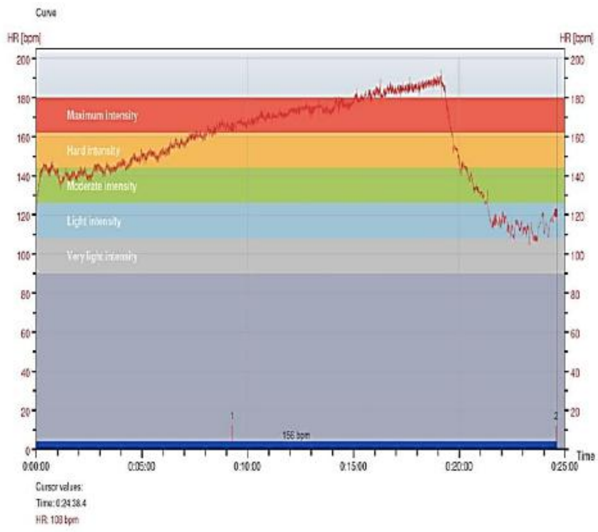

Fig. 1: Heart rate graphic values during maximal incremental test starting at 10 km/h and load increment of 1 km/h every 2 minutes and 6 minutes of post-test recovery (Polar Pro trainer 5®).

Then, 2-minute stretches were selected from the the test beginning and the values of the R-R-intervals were saved in a "txt" format file for each stage, followed by manual filtering in Excel software (Malik et al. 1993; Vanderlei et al. 2009). After data processing, with the ectopic beats and erroneous signals correction, series with more than 95% of sinus beats were included in the study (Godoy, Takakura, and Correa 2005; Vanderlei et al. 2009).

The analysis was performed by the software Kubios® HRV 3.4.3 (Kuopio, Finland) the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS) index were analyzed (Malik et al. 1993).

III. RESULTS

We can observe in Table 1, the variables referring to the autonomic nervous system parasympathetic activity, mean RR, RMSSD and SD1 intervals, as well as the variables used to calculate the sympathetic activity, mean HR, stress index and SD2 for each speed of incremental testing.

Table 2 presents the data referring to the volunteer's values sympathetic and parasympathetic indexes during the maximal incremental test on a treadmill. Adjustments were verified at each stage, as shown in Figures 2 and 3.

Table 1. HRV values variables related to the parasympathetic and sympathetic index at rest, during each stage of the maximal incremental test and in the post-test Interval values between heartbeats (RR); Square root of the mean square differences between successive RR intervals (RMSSD); Poincaré plot standard deviations (SD1); Mean heart rate (HR); stress index (STRESS) and normalized Poincaré plot parameter (SD2); Post test recovery lasting 2 minutes each (R2, R4 and R6).

	PNS			SNS		
Speed (km/h)	**RR (ms)**	**RMSSD (ms)**	**SD1 (%)**	**FC (BPM)**	**Stress**	**SD2 (%)**
Rest	877	31.0	40.3	68	14.9	59.7
10	379	4.2	47.2	158	92.4	52.8
11	425	6.0	44.3	141	68.0	55.7
12	420	5.1	44.6	143	73.8	55.4
13	401	4.6	44.9	150	55.8	55.1
14	362	3.7	49.1	166	96.8	50.9
15	351	3.7	57.3	171	90.3	42.7
16	344	4.4	63.2	174	97.6	36.8
17	335	3.5	52.0	179	111.2	48.0
18	325	3.9	57.1	184	108.6	42.9
19	321	3.4	54.4	187	124.5	45.5
R2	399	4.3	34.0	150	65.4	66.0
R4	506	9.8	39.5	119	45.7	60.5
R6	528	7.7	24.1	114	35.1	75.9

Table 2. Parasympathetic index (PNS) and sympathetic index (SNS) values at rest, during each stage of the maximal incremental test and in post-test recovery.Parasympathetic Index (PNS); sympathetic index (SNS). Normal resting values between -1 and 1 are considered. Post-test recovery lasting 2 minutes each (R2, R4 and R6).

Speed	PNS	SNS
Rest	-0.41	0.93
10 (Km/h)	-4.24	23.07
11 (Km/h)	-3.81	16.62
12 (Km/h)	-3.88	17.90
13 (Km/h)	-4.06	15.24
14 (Km/h)	-4.38	24.64
15 (Km/h)	-4.45	23.80
16 (Km/h)	-4.46	25.50
17 (Km/h)	-4.55	28.54
18 (Km/h)	-4.60	28.49
19 (Km/h)	-4.64	31.77
R2 (2 min)	-4.10	17.14
R4 (2 min)	-2.95	9.84
R6 (2 min)	-2.97	7.62

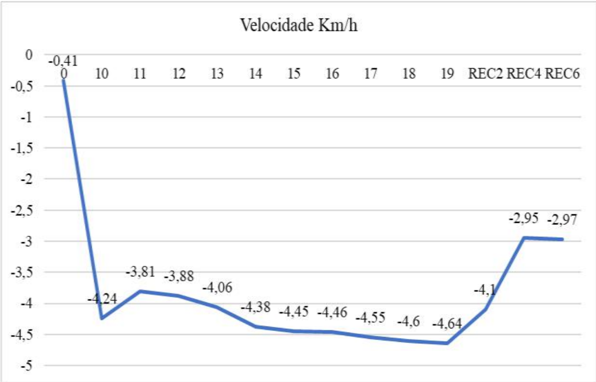

Fig.2. PNS parasympathetic index values at rest, during each stage of maximal incremental testing, and post-test recovery. Parasympathetic Index (PNS). Normal resting values between -1 and 1 are considered. Post-test recovery lasting 2 minutes each (R2, R4 and R6).

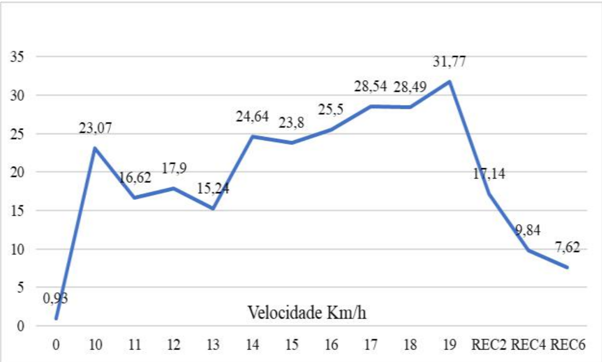

Fig.3. Sympathetic index values during each maximal incremental stage test and post-test recovery. Parasympathetic Index (PNS); sympathetic index (SNS). Normal resting values between -1 and 1 are considered. Post-test recovery lasting 2 minutes each (R2, R4 and R6).

IV. DISCUSSION

Although HRV is typically assessed at rest, recent research suggests that kinetics measurings HRV in response to exercise stressors may have considerable a potential aerobic fitness predictor, exercise performance, and in monitoring training-induced fatigue in elite athletes (Schmitt et al 2013; Schmitt et al 2015). Heart rate variability assessed after exercise cessation has also been used as a parasympathetic reactivation marker to indicate post-exercise recovery status (Michael, Graham & Oam, 2017) and as an training load indicator (intensity and duration of training). exercise) (Kaikkonen, et al 2010; Kaikonnen et al 2012).

In our study, HRV analysis was applied to the stress imposed by physical exercise, in the transition from rest to exercise, during load increments in the maximal incremental test and in recovery after exertion. Our results demonstrate that the HRV variables PNS, SNS, Stress Index followed the intensities of the test, as well the recovery after exhaustion.

We could observe that HRV is a practical, easily accessible, non-invasive and sensitive tool to identify the athlete's training status, observing a parasympathetic predominance (PNS) in relation to sympathetic activity (SNS) at the volunteer rest, as well by the RMSSD, SD1 and HF values, possibly due to their running training adaptations. It has previously been shown that parasympathetic activity increased is associated with improved physical conditioning, as well reduced homeostatic disturbances in response to subsequent stressors (Plews et al 2012; Borresen et al, 2008; Kiviniemi et al 2014).

We also observed that the PNS, SNS and Baevtsky Stress Index, as well as the HRV time domain variables (RMSSD, SD1, SD2, RR and HR), were effective and sensitive to identify the stress imposed by exercise during test load increments. Corroborating our findings, Cruz (2009) et al., analyzed the HRV of 10 athletes under different exercise conditions, and related it to other fatigue indicators, lactate and creatine kinase (CK), and concluded that HRV, as well the CK and lactate concentrations are sensitive markers to detect the fatigue status.

In the post-exertion recovery analysis we found a partial recovery, however, not HRV total recovery variables analyzed 6 minutes after exhaustion, corroborating our findings, Seiler, Haugen & Kuffel (2007), observed in highly trained individuals exposed to intensities below of the anaerobic threshold that the complete HRV values recovery was observed between 10-15 minutes after the exercise's end, in high intensities, a complete recovery can exceed 30 minutes. Kaikkonen, Hynynen, Mann, Rusko & Nummela, (2010) reported that, in the face of high intensity and duration exercises, there is a great decrease in parasympathetic activity (low SD1, and high values of SS and S/PS), and longer duration of exercise recovery in aerobic endurance athletes in running protocols.

We observed that HRV is sensitive to the stress imposed by exercise and we believe that its use in training prescription can help practitioners/coaches to optimize the application time of training stress. It is possible that HRV can be used to predict athlete performance before training and therefore serve as an important indicator of future exercise performance (Chalecon et al 2015).

V. CONCLUSION

We conclude that the use of HRV as a tool makes it possible to identify an individual's physical capacity. We also concluded that the HRV variables are sensitive to the physiological changes imposed by the stress of continuous progressive physical exercise, at high exercise intensities the parasympathetic variables PNS, RMSSD, Mean RR and SD1 decrease, as well as SNS, Stress Index and Mean HR that reflects sympathetic activity increase slightly, without achieving complete recovery after 6 minutes post-exercise from baseline

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