

Autonomic Modulation During Incremental Exercise with Upper Limbs in Individuals with Spinal Cord Injury



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ABSTRACT

Individuals with spinal cord injury (SCI) show alterations in the autonomic regulation at rest which can affect the heart rate variability (HRV) during exercise. The aim of this study was to compare the HRV threshold of a group with SCI with two control groups. Twenty-four men, seven with SCI (24.8 ± 2.0 years, 76.5 ± 6.9kg, 176.3 ± 1.9cm), eight sedentary subjects without SCI (CONSED) (24.1 ± 1.8 years, 75.1 ± 3.6kg, 176.3 ± 3.0cm) and nine athletes without SCI (CONATH) (22.6 ± 1.4 years, 73.8 ± 5.3kg, 175.6 ± 2.5cm) volunteered in this study. The participants performed an upper limb incremental test on a cycle ergometer (17.2W/two minutes) until exhaustion. The SD1 index of HRV was measured every stage, and the HRV threshold was identified at: 1) the first workload that elicited SD1 values lesser than 3ms; 2) the first stage that elicited a difference between SD1 values from two consecutive stages lesser than 1ms. SD1 values at rest or at 30% of W_{max} were higher ($p < 0.05$) in CONSED (45.8 ± 6.8ms) than CONATH group (19.5 ± 4.4ms) but none of them were different ($p > 0.05$) from group SCI (25.8 ± 4.5ms). The 3ms HRV threshold expressed in absolute values or in relative to maximal workload and heart rate was not different between groups. However, the workload of 1ms HRV threshold in control group (68.8 ± 8.3W) was significantly higher ($p < 0.05$) than SCI group (21.5 ± 4.3W), but these groups were not different from CONSED group (41.3 ± 8.7W). These results suggest changes in autonomic control during exercise in subjects with SCI, which might lead to an early parasympathetic withdrawal during incremental exercise.

Keywords: autonomic nervous system, exercise, paraplegia.

INTRODUCTION

The cardiac rhythm, measured by the time passed between two consecutive electrocardiogram R waves and by the cardiac monitor (R-R interval), does not present uniform cycles during the time. Conversely, a temporal variation between the successive R-R intervals, which is called heart rate variability (HRV), occurs⁽¹⁾.

HRV has been used as a non-invasive means of evaluation of the heart neural control⁽²⁻⁵⁾. Increase in the HRV represents higher activity of the parasympathetic nervous system (PNS) and lower activity of the sympathetic nervous system (SNS)⁽⁶⁾. Some studies suggest that higher activity of PNS, represented by higher HRV, would be associated with better physical aptitude and lower incidence of developing cardiac diseases^(7,8). Inversely, higher SNS activity, represented by lower HRV, would be related to higher index of morbidity and mortality⁽⁹⁾.

Acute physical exercise is one of the factors which causes important acute alterations in the cardiac autonomic regulation. These alterations may be measured by an HRV index named SD1⁽¹⁰⁻¹²⁾, which is obtained by the immediate standard deviation of the Poincaré plot. This index quantifies the vagal activity, removing the influence of non-stationary tendencies in the temporal bout, as during incremental exercise. During an incremental exercise, there is gradual reduction of this index with the increase of exertion intensity, up to approximately 50% of peak load, with tendency to stabilization in the subsequent loads⁽¹³⁾. Thus, this stabilization tendency probably occurs due to the fact that HRV decrease during exercise is continuously associated with the same

phenomenon, that is, the removal of the vagal influence on the sinoatrial node. Therefore, the moment of this transition is named HRV threshold (HRVT) and can be an important indicator of the transition from the PNS activity domain to the SNS⁽¹³⁻¹⁶⁾.

The statement that the HRVT represents the transition from the PNS to the SNS lets us investigate how the clinical conditions affect the autonomic regulation during exercise. For example, individuals with spinal cord injury (SCI) present deficit in motor control and limited capacity of performing daily tasks, which increases the incidence of cardiac complications and alterations in the neural control of the cardiac muscle⁽¹⁷⁾. Some studies report that individuals with spinal cord injury present HRV reduction^(18,19) and increase of the heart rate (HR) at rest⁽²⁰⁾. These results suggest increase in the SNS control and PNS decrease in injured individuals at the rest condition.

Although the experimental evidence suggests autonomic alterations at rest derived from the SCI^(18,21,22), little is known about these possible alterations during exercise. Thus, the information obtained in the literature lets us presume that, individuals with SCI would have lower HRV during the incremental exercise test and, therefore, HRVL occurring in lower workloads, in comparison to a group of non-injured individuals. However, until the present moment, none study has compared the HRV during exercise between individuals with and without SCI. Thus, the aim of the present study was to analyze the HRV response and the HRVL during a maximal upper limbs progressive test on a cycle ergometer (ULPT). The hypothesis of the present study is that individuals with SCI would have lower HRV when compared with individuals without SCI, resulting in decrease of intensity corresponding to the HRVT.

METHODS

Participants

24 male individuals were evaluated, who were divided in: 1) men with SCI, wheelchair basketball practitioners (n = 7); 2) non-injured men, sedentary for upper limb activities (CONSED, n = 8); and 3) non-injured men, combat sports which involve upper limbs athletes (CONATH, n = 9). The SCI group was composed of two subjects with partial injury and five with total injury. Out of these, four had injury above T6 and three below it. The two last groups (CONSED and CONATH) were used as control groups, being a control group considered untrained and the other trained for upper limbs activities (ULPT). The physical characteristics of the three groups are described in table 1. Each of the participants was informed about the risks associated with the study protocol and signed a consent form agreeing on participating in the experiment. This study was approved by the Ethics in Research Committee of the Federal University of Alagoas.

Table 1. Characteristics of the investigated individuals.

| | SCI (n = 7) | CONSED (n = 8) | CONATH (n = 9) |
|--------------|-------------|----------------|----------------|
| Age (years) | 24.8 ± 2.0 | 24.1 ± 1.8 | 22.6 ± 1.4 |
| Stature (cm) | 176.3 ± 1.9 | 176.3 ± 3.0 | 175.6 ± 2.5 |
| Weight (kg) | 76.5 ± 6.9 | 75.1 ± 3.6 | 73.8 ± 5.3 |

Values are expressed in mean ± MSE. SCI: group with spinal cord injury; CONSED: group control sedentary; CONATH: group control athletes.

Experimental outlining

Data collection procedure was performed in three occasions. On the first, the individuals answered a questionnaire corresponding to their health status. On the second, the individuals went through an anthropometric evaluation for measurement of body mass (kg) and stature (cm), being used, respectively, mechanical scale and a stadiometer (Welmy-Industry and Sales LTDA, Model R-110). The body mass and stature measurement of the individuals with SCI was performed through the patients' self-report, who had a medical follow-up. On the third, the individuals performed a ULPT. The individuals received recommendation not to perform vigorous physical activity, not to ingest caffeinated (coffee, chocolate, mate, guaraná powder or Coke) or alcoholic substances in the 24 hours preceding the tests.

Incremental test

The individuals arrived at the laboratory and wore an elastic band with a wrist cardiac monitor (Polar S810i, Polar Electro OY®, Kempele, Finland). They remained laid for five minutes for recording of the HRV at rest. Subsequently, a two-minute warm-up was performed using only the inertial resistance of the cycle ergometer adapted to upper limbs (Monark®, Stockholm Sweden) and an increment of 17W was given at every two minutes until exhaustion. Exhaustion was determined when the individual could not keep the pre-set rhythm, which was of approximately 70rpm. HR was monitored beat-after-beat during the entire incremental test. Subjective perceived exertion was measured through the Borg's scale (15 points) at the end of each stage⁽²³⁾.

Maximal HR (HR_{max}) was considered as the highest value reached during the test. The maximum load reached (W_{max}) was considered as the last complete stage in the test before voluntary

exhaustion. When the last reached stage was not completed, the W_{max} was obtained from the following modified equation⁽²⁴⁾:

$$W_{max} = W_{complete} + (\text{final time } 120 \times 17.2W)$$

Where W_{max} is equal to the maximum load reached in the test, W_{complete} corresponds to the load of the last complete stage, and final time to the time of the last incomplete stage.

DATA ANALYSIS

After the end of the test, the data were stored in the monitor, transferred to a computer and assessed with the use of specific software (Polar Precision Performance, Polar Electro OY®, Kempele, Finland). Each R-R interval was plotted in relation to the previous R-R interval (Poincaré plot) in a time window corresponding to the last rest minute and of each stage of the incremental test. These intervals generate a sequence of points in an ellipse shape. The transversal axis of the ellipse, termed standard deviation "1" (SD1), represents the immediate variability of the R-R intervals^(13,14,25,26).

The SD1 index of each stage was then plotted in relation to the intensity. The HRVT was identified from two criteria: 1) on the first load corresponding to a value lower than three milliseconds^(5,15), termed HRVT3ms; and 2) on the first stage in which the difference between the SD1 of two consecutive stages was lower than one millisecond, termed HRVT1ms⁽²⁵⁾. The HR corresponding to the threshold load was obtained from the linear correlation between HR-intensity. The thresholds were expressed in absolute values (W and bpm) and related to the W_{max} and HR_{max} (% W_{max} and % HR_{max} respectively).

In order to verify possible alterations in the autonomic regulation during each stage of the test between the different groups, the SD1 index was also compared at rest, in the absolute workloads referring to the warm-up, 17.2W and 34.4W, as well as in the loads concerning the maximum load (30%, 60%, 90% and 100%). These loads were chosen for comparison for representing the distinct phases of the incremental test (low, moderate and high intensities).

STATISTICAL ANALYSIS

Data were expressed as mean ± mean standard error (MSE). Analysis of variance repeated measures one-way ANOVA was used to verify the differences of the dependent variables (HR_{max}, W_{max}, HRVT3ms, HRVT1ms) between groups. Repeated measures 3 x 4 ANOVA (intensity x group) was also performed to compare the absolute and relative loads between groups. When differences were identified through ANOVA, the comparisons were followed by the Scheffé *post hoc* test. The analyses were performed using the statistical package SPSS (version 13.0), and significance level lower than 5% was adopted (p < 0.05).

RESULTS

The age, stature and body mass values did not present significant differences among the SCI, CONSED and CONATH groups (p > 0.05).

Significant differences in the HR_{max} and W_{max} between groups (p > 0.05) were not found in the comparisons of the variables obtained during the incremental test (table 2). The HRVT3ms, both in absolute (W and bpm) and relative values (%W_{max} and %HR_{max}), were not significantly different between groups (p > 0.05). However, the HRVT1ms, when expressed in absolute load (W), was significantly

higher in the CONATH group ($p < 0.05$) than in the SCI group, but no significant differences have been found between CONSED and CONATH groups, or between CONSED and SCI groups ($p > 0.05$).

When SD1 was compared in different intensities, significant differences were found between groups only at rest (figure 1). The CONSED group presented SD1 values significantly higher than the CONATH group ($p < 0.05$), but none of them was different from the SCI group ($p > 0.05$). Likewise, the SD1 at 30% of W_{max} was significantly lower in the CONATH group than in the CONSED group ($p < 0.05$). However, significant differences have not been found between CONATH and SCI groups or between CONSED and SCI groups ($p > 0.05$) (figure 2).

Table 2. Comparison of the physiological responses during the tests between groups.

| Variables | SCI | CONSED | CONATH |
|------------------|------------|-------------|-------------|
| HRmax (bpm) | 165 ± 5.5 | 160 ± 8.8 | 182 ± 4.8 |
| Wmax (W) | 62 ± 9.2 | 71.5 ± 3.8 | 89.1 ± 8.8 |
| HRVT3ms(W) | 27.5 ± 6.8 | 51 ± 9.1 | 55.4 ± 10.6 |
| HRVT1ms(W) | 21.5 ± 4.3 | 41.3 ± 8.7 | 68.8 ± 8.3* |
| HRVT3ms (bpm) | 146 ± 4.5 | 140 ± 6.1 | 148 ± 6.4 |
| HRVT1ms (bpm) | 146 ± 5.8 | 137 ± 4.6 | 155 ± 7.1 |
| HRVT3ms (%Wmax) | 47 ± 9.7 | 61.3 ± 13.4 | 61 ± 10.4 |
| HRVT1ms (%Wmax) | 38.8 ± 6.8 | 60.2 ± 12.7 | 52.8 ± 10.6 |
| HRVT3ms (%FCmax) | 89 ± 5.4 | 85 ± 3.6 | 81 ± 3.4 |
| HRVT1ms (%FCmax) | 87 ± 6.4 | 80 ± 2.6 | 66 ± 12.7 |

Values are expressed in mean ± mean standard error (MSE).

*Significantly different from the SCI group ($p < 0.05$). SCI: group with spinal cord injury; CONSED: group control sedentary; CONATH: group control athletes. HRmax: maximum heart rate; Wmax: maximum load; HRVT3ms: heart rate variability threshold of 3ms; HRVT1ms: heart rate variability threshold of 1ms.

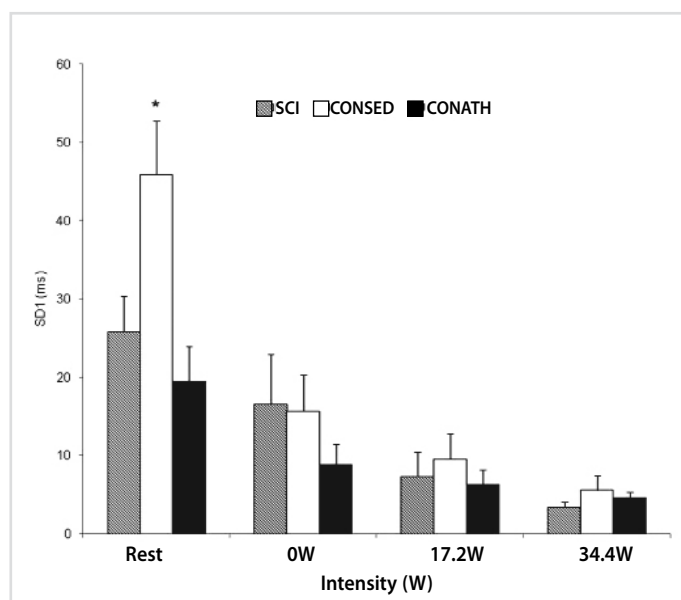


Figure 1. SD1 index concerning the exercise absolute intensity (W) for the SCI (spinal cord injury), CONSED (control sedentary) and CONATH (control athletes) groups.

*Significantly different from the CONATH group. Values are expressed in mean and mean standard error (MSE).

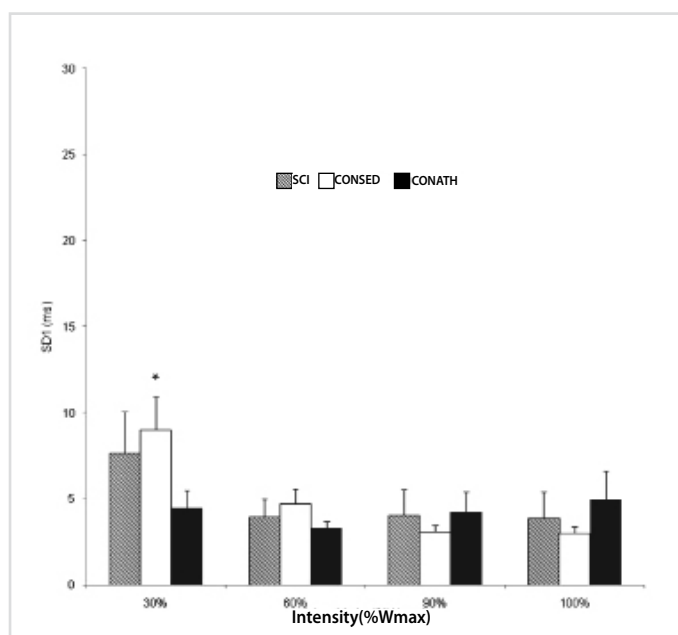


Figure 2. SD1 index concerning the exercise relative intensity (W_{max}) for the SCI (spinal cord injury), CONSED (control sedentary) and CONATH (control athletes) groups.

*Significantly different from the CONATH group. Values are expressed in mean and mean standard error (MSE).

DISCUSSION

The aim of this study was to compare the HRV and the HRVT between among the SCI, CONSED and CONATH groups. It was found that the CONSED group presented higher SD1 values than the CONATH group both at rest and at 30% of W_{max} , but in none of these groups the values were different from the ones found in the SCI group. The HRVT3ms expressed in absolute (W and bpm) and relative values (% W_{max} and % HR_{max}) was not different between groups; however, the HRVT1ms load in the CONATH group was significantly higher than in the SCI group.

In the present investigation, the HRVT3ms did not present significant differences between groups. However, the HRVT1ms load in the SCI group was lower than in the CONATH group, suggesting PNS removal and SNS early activation in this group. These findings are in agreement with the ones found by Jacobs *et al.*⁽²⁰⁾, who compared HR in individuals with and without SCI, demonstrating that the individuals with SCI had higher HR during exercise. A probable physiological explanation for this would be the low peripheral vasoconstriction of individuals with SCI and the absence of a lower limb active muscle pump⁽²⁷⁾, both being able to limit the venous return to the cardiac muscle, leading to reduction in the final ventricular diastolic volume as well as cardiac contraction efficiency restriction^(28,29). In a trial to make up for these alterations, there may be an early SNS activation in the cardiac muscle of individuals with SCI, justifying the HRVT1ms in lower loads in the SCI group.

Another explanation for these findings is that the CONATH group would present higher training level than the SCI group. Data by Fronchetti *et al.*⁽⁵⁾ demonstrated that the HRVT increases significantly after a three-week period of high-intensity interval training. Therefore, the SD1 vs. intensity curve was dislocated to the right and to the top, suggesting that this kind of training results in delay in PNS removal during the progressive exercise. Nevertheless, in the present study, both groups (SCI and CONATH)

were composed of individuals trained for upper limbs, in a trial to control the training effects in the comparisons performed. Since the HRVT1ms of both groups was not different from the ones found in the CONSED group, the differences found between SCI and CONATH groups cannot be explained by the training level. Such statement corroborates the previous justification that SCI individuals present autonomic imbalance, and consequently, overload in the cardiac pump, increasing hence the SNS activity.

At rest and at 30% of W_{max} conditions, the CONSED group presented SD1 significantly higher than in the CONATH group. Apparently, there is not a logical explanation for these results, since it is well demonstrated in the literature that trained individuals would have higher HRV than sedentary ones⁽¹⁶⁾. However, some studies also suggest that when trained individuals surpass a suitable training limit, alterations in the autonomic balance are observed, which reflect on HR increase and HRV decrease⁽⁶⁾. Yet, measurements which mark training excess have not been performed in this investigation, since this was not the focus of this investigation. Consequently, it is not possible to state that these differences have been actually derived from this phenomenon.

On the other hand, it was expected that the SCI group presented lower HRV values at rest than the other groups^(18,19). However, significant differences between the SCI and the other groups have not been found for the HRV at rest in the present study. Probably,

these controversial results compared to the literature^(18,19) may be due to the physical fitness level of the individuals from the SCI group, who were wheelchair basketball practitioners. Some studies suggest that individuals with better physical fitness present higher HRV at rest⁽²⁵⁾. Corroborating this statement, Dixon *et al.* and Janssen *et al.*^(8,30) verified that trained individuals, when being compared with untrained individuals, present higher HRV during rest. Thus, the fact the SCI group is composed of wheelchair athletes may explain the reason why the SD1 values at rest were similar to the ones found in the other groups.

In conclusion, the results of the present study suggest that the subjects with SCI present a HRVT1ms in lower loads and, therefore, it seems reasonable to state that there are alterations in the autonomic control during exertion in this group, suggesting early PNS removal during the incremental exercise.

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