Original Article

Discontinuous Sets of Knee Extensions Induce Higher Cardiovascular Responses in Comparison to Continuous Ones

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Summary

Background: The strength training can promote significant cardiovascular responses during its performance and it is interesting to devise strategies to reduce them, without compromising the strength production.

Objective: To compare the acute cardiovascular responses of systolic arterial pressure (SAP), diastolic arterial pressure (DAP), heart rate (HR) and double product (DP) during the unilateral knee extension (four series of 8 maximum repetitions) performed continuously or discontinuously. Both protocols involved a 2-minute interval between the series and the discontinuous protocol had an extra interval of 2 seconds between the 4th and the 5th repetitions.

Methods: Eight healthy men trained in muscular strength (aged 26 ± 6 years) participated in the data collection and were randomly divided in two non-consecutive days. The cardiovascular responses were measured by photoplethysmography (Finapres, Ohmeda, Louisville, CO, USA) at rest, at the end of each series and 2 minutes after the performance of each protocol.

Results: The discontinuous series showed significantly higher values when compared to the protocol of the continuous series for: SAP (mmHg) at the 2nd (173.1 ± 5.4 *vs* 152.0 ± 4.0; p=0.001), 3rd (188.9 ± 8.6 *vs* 162.4 ± 6.0; p=0.000) and 4th series (193.1 ± 8.1 *vs* 161.6 ± 5.9; p=0.000); DAP (mmHg) at the 3rd (103.8 ± 4.1 *vs* 86.1 ± 3.3; p=0.000) and 4th series (104.1 ± 2.7 *vs* 83.4 ± 3.3; p=0.000); DP (mmHg.bpm) at the 2nd ($17,907.5\pm1,350.7$ *vs* $14,541.9\pm1,848.0$; p=0.03), 3rd ($19,687.3\pm1,444.3$ *vs* $15,612.1\pm1,180.3$; p=0.008) and 4th series ($21,271.0\pm1,794.2$ *vs* $15,992.0\pm1,093.4$; p=0.001).

Conclusion: The discontinuous protocol promoted higher increase in pressure responses when compared to the continuous one. However, due to the characteristics of the study design, further studies are necessary to support these findings. (Arq Bras Cardiol 2008; 90(6): 350-355)

Key words: Blood pressure; heart rate; photoplethysmography; muscle strength.

Introduction

The strength training can promote significant increases in heart rate and blood pressure through the adrenergic and metabolic responses and the vascular compression caused by the exercise[1,2]. Several factors can determine the magnitude of the cardiovascular response in situations of elevated strength production, such as velocity of movement[3], number of series[4], percentage of maximum load[5], type of muscular contraction and involved muscular mass[2,6], number of repetitions[2], types of exercise[1], interval of recovery between the series[7] and training status[8,9].

Regardless of the cardiovascular demand related to the strength training, this activity can be a part of the training routine

of people presenting heart diseases with relative safety[10]. One way to decrease the cardiovascular exertion is the submaximum combination of loads and repetitions[5], but it could compromise a significant development of muscular strength.

Another strategy is related to the interruption throughout the performance of an exercise, instead of performing it continuously. This procedure was used in three studies[11-13] and the results indicated a decrease in the cardiovascular responses. However, some methodological differences were identified that could discharacterize the strength training program, such as a discontinuous series characterized by the inclusion of another exercise[11]; a too-long interval (15 seconds) and measurement of heart rate, only, which is limited to infer on the cardiovascular demand during the strength training[12] and interval occurring at each repetition[13].

We believe that, in order to maximize muscular strength, an exercise must be performed at sufficient intensity to generate discomfort and, in trained persons, its end must occur at a moment near that of fatigue.

That did not occur in any of the three aforementioned experiments or the evaluated cardiovascular response was not the best one. Therefore, we chose an interval of 2 sec during a series with maximum repetitions, considering that the cardiovascular responses must decrease 1-2 sec after the end of the exercise[14]. Our hypotheses was that 2 sec would be enough to cause the decrease in the cardiovascular responses without compromising intensity.

Therefore, the objective of this study was to compare the systolic arterial pressure (SAP), diastolic arterial pressure (DAP), heart rate (HR) and double product (DP) during four series of eight maximum repetitions (8MR) in the unilateral knee extension with and without the 2-second interval.

Methods

The sample size was calculated in a previous pilot study, considering 0.80 as the statistical power and supposing a minimum detected difference of 32 mmHg with a standard deviation (SD) of 18 mmHg for SAP in four series of the exercise. Eight men (mean age±SD: 26±6 years; mean height:173.9±6.3 cm; mean weight:75.4±11.7 kg), non-athletes, with at least one year of experience in strength training were volunteers in the study. All participants signed a free and informed consent form. The sample was advised not to consume caffeine or alcohol 24 hours prior to the data collection and maintain a postprandial fast of 3 hours on the day of data collection.

Exclusion criteria were: use of ergogenic substance or any cardiovascular action drug; osteomyoarticular injuries; diagnosis of arterial hypertension.

Figure 1 shows the study design used. After sample selection, the data collection was started with the 8MR test performance during the unilateral knee-extension exercise in the dominant limb (right limb in all volunteers), using specific equipment (hyperextension chair, Life Fitness, Brunswick, Atlantic, USA). The exercise was performed with individuals sitting up straight at a 90-degree angle between the seat and back of the hyperextension chair. The angle of movement was calculated based on the knee flexion at 90°, ending with total extension, with a 2-second duration for the concentric and eccentric movement timed by a metronome. The choice of unilateral performance was due to the fact that some subjects could elevate 100% of the equipment load in a bilateral performance and because it was more comfortable to stabilize the body by maintaining one hand free to have the blood pressure measured. Load attainment was obtained after three days of training, with 48-hr intervals, in order for the sample to get acquainted with the protocol. On each day, the subjects had up to 5 attempts to perform no more than 8 repetitions at the defined angulation, with an interval between attempts of at least 5 minutes. No interval was allowed between the concentric and eccentric phases or between repetitions; the sample was also instructed on the correct positioning on the equipment, in order to allow the measurement of the blood pressure and not to perform the Valsalva maneuver.

After the 8MR test, the subjects visited the laboratory on two different occasions with a 48-hr interval between them, between 2 and 4 PM. The subjects randomly performed either

the continuous or the discontinuous protocol on each day. Both protocols involved four series of 8MR with a 2-minute interval between the series. The choice of number of series, repetitions and interval duration used those suggested by the American College of Sports Medicine, as reference[15]. In the discontinuous protocol, a 2-second interval was inserted between the 4th and 5th repetition. During the interval, the subjects remained immobile on the equipment.

The blood pressure at rest was recorded after 10 minutes in sitting position, at the equipment, maintaining the subject immobile, calm and without talking. Both at rest and during the exercise, the blood pressure was measured by photoplethysmography (Finapres™ 2350, Ohmeda, WI, USA), which can be considered a noninvasive procedure that is more adequate for the measurement of SAP and DAP during
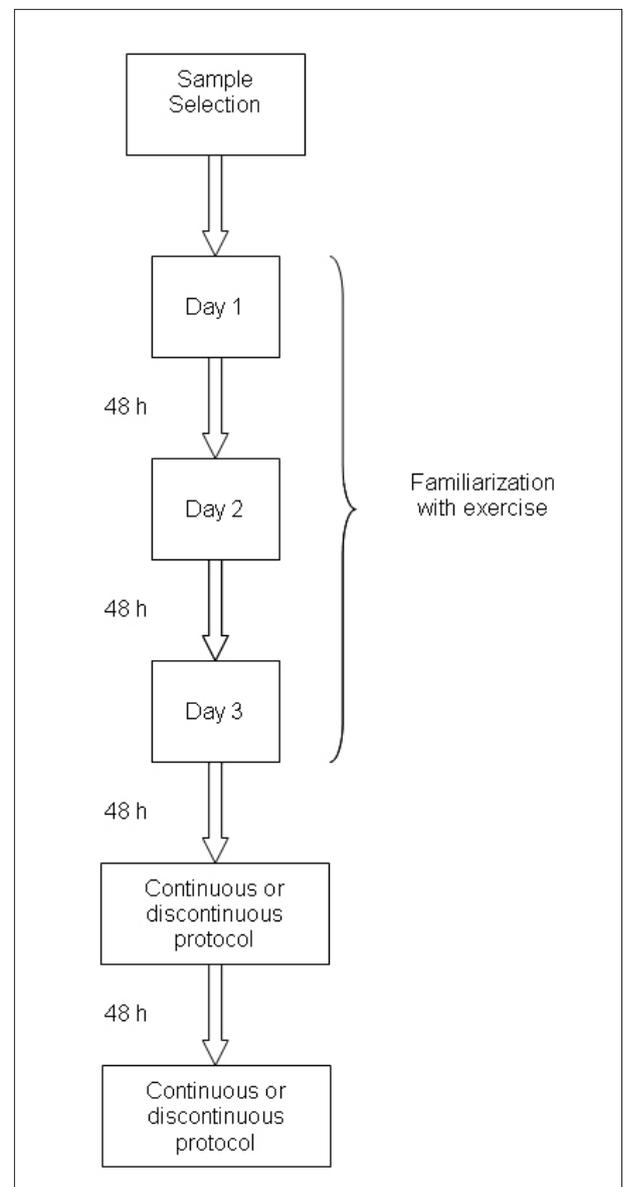

Fig. 1 - *Experimental design used in the present study.*

strength exercises[4,16]. A cuff was applied to the middle finger of the left hand to detect the distension of the digital artery. To prevent possible interferences of gravity on the measurement site[17], the left hand was positioned close to the heart through a support and the subjects were instructed not to perform any contraction or movement involving the left fingers, wrist, elbow or shoulder. All cardiovascular variables related to physical exercise were recorded immediately after the end of each series (end of the movement) and 2 minutes after the end of the exercise. To help the sample get familiarized with the adequate position when performing the exercise, the blood pressure was measured during the 8MR test. High intraclass correlation coefficients were observed in the last two days of 8MR tests, both at rest [HR=0.93 (p=0.000); SAP=0.92 (p=0.000); DAP=0,84 (p=0.000)] and during exercise [HR=0.89 (p=0.001); SAP=0.91(p=0.000); DAP=0.82 (p=0.001)].

The same equipment that measured arterial pressure was used to record the HR. The DP was calculated through the equation: DP=SAP x HR.

The data were analyzed by the mean descriptive method and mean standard error to express the results. The inferential treatment was carried out by Student's t test for dependent samples in order to compare the cardiovascular values at rest on both days of data collection. Two-way ANOVA (protocol used and number of measurements – rest, series, post-exercise) with repeated measurements in the second factor was used to compare the cardiovascular responses before, during and after the exercise, followed by Bonferroni post-hoc test to detect significant differences (p<0.05). The data were analyzed with the Statistica™ software (version 6.0, Statsoft, OK, USA).

Results

Both protocols showed that the values of SAP, DAP, HR and DP in all the series of the exercise were significantly higher (p<0.05) than values at rest (Tables 1 and 2). All the variables returned to values close to those at rest 2 minutes after the end of the exercise. When analyzing each protocol separately, it is possible to observe that, despite the tendency to elevation regarding the cardiovascular responses during the series in the continuous protocol (especially SAP), the values were not statistically different between the 1st and the 4th series (Table 1). On the other hand, in the protocol of the discontinuous series, there were significant increases throughout the series, especially for SAP, DAP and DP (Table 2).

When comparing the values observed in both protocols, there was no difference between at-rest and recovery values. However, during the exercise, the protocol of the discontinuous series showed significantly higher values

Table 1 - Blood pressure, heart rate and double product at the different moments of the protocol of the continuous series (mean ± standard error)

	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)	Heart Rate (bpm)	Double Product (mmHg.bpm)
Rest	119.0 ± 1.7*	65.8 ± 1.6*	66.5 ± 1.9*	7,895.8 ± 161.1*
1st series	148.8 ± 2.3	80.1 ± 3.0	92.6 ± 4.3	13,791.4 ± 713.3
2nd series	152.0 ± 4.0	84.1 ± 5.4	95.9 ± 4.1	14,541.9 ± 1,848.0
3rd series	162.4 ± 6.0	86.1 ± 3.3	95.4 ± 4.0	15,612.1 ± 1,180.3
4th series	161.6 ± 5.9	83.4 ± 3.3	98.3 ± 3.7	15,992.0 ± 1,093.4
Recovery (2 min after the end)	118.3 ± 3.3*	66.8 ± 2.4*	71.8 ± 2.6*	8,444.0 ± 246.8*

significant difference (p<0.05) for series 1, 2, 3 and 4.

Table 2 - Blood pressure, heart rate and double product at the different moments of the protocol of the discontinuous series (mean ± standard error)

	Systolic Blood Pressure (mmHg)	Diastolic Blood Pressure (mmHg)	Heart Rate (bpm)	Double Product (mmHg.bpm)
Rest	122.4 ± 3.0*	63.8 ± 2.0*	69.6 ± 1.8*	9,360.1 ± 341.4*
1st series	156.1 ± 2.6†	77.1 ± 1.9†	95.0 ± 7.3§	14,941.9 ± 1,376.5‡
2nd series	173.1 ± 5.4‡	90.0 ± 2.8‡	102.5 ± 4.8	17,907.5 ± 1,350.7//
3rd series	188.9 ± 8.6	103.8 ± 4.1	106.3 ± 4.0	19,687.3 ± 1,444.3
4th series	193.1 ± 8.1	104.1 ± 2.7	109.4 ± 5.6	21,271.0 ± 1,794.2
Recovery (2 min after the end)	132.9 ± 3.5*	69.6 ± 3.4*	79.8 ± 4.3*	10,672.0 ± 811.2*

significant difference (p<0.05) for series 1, 2, 3 and 4; † significant difference (p<0.05) for series 2, 3 and 4; ‡ significant difference (p<0.05) for series 3 and 4; § significant difference (p<0.05) for the 4th series; // significant difference (p<0.05) for the 4th series.

when compared to the continuous series for SAP at the 2nd (173.1±5.4 *vs* 152.0±4.0 mmHg; p=0.001), 3rd (188.9±8.6 *vs* 162.4±6.0 mmHg; p=0.000) and 4th series (193.1±8.1 *vs* 161.6±5.9 mmHg; p=0.000). The difference between the protocols remained statistically high in the discontinuous series protocol regarding DAP at the 3rd (103.8±4.1 *vs* 86.1±3.3 mmHg; p=0.000) and 4th series (104.1±2.7 *vs* 83.4±3.3 mmHg; p=0.000). The HR was the only variable that presented no differences between the protocols. The DP, as it calculated from the HR and SAP, was influenced by the latter and presented higher values in the discontinuous series protocol when compared to the continuous one at the 2nd (17,907.5±1,350.7 *vs* 14,541.9±1,848.0 mmHg. bpm; p=0.03), 3rd (19,687.3±1,444.3 *vs* 15,612.1±1,180.3 mmHg.bpm; p=0.008) and 4th series (21,271.0±1,794.2 *vs* 15,992.0±1,093.4 mmHg.bpm; p=0.001).

Figure 2 shows the behavior of SAP, DAP and HR in a study individual (case 3).

Discussion

The initial hypothesis of the present experiment was that the protocol with a 2-second interval between the repetitions would result in less cardiovascular demand than the continuous one. This fact is based on the possibility that, during a brief interval, a higher vascular perfusion occurs after a period of blood flow restriction caused by the exercise, in addition to starting the baroreflex response, compensating the pressure increase[14]. However, the 2-second interval resulted in a higher cardiovascular response during the exercise. One possible explanation for the results observed in the present study resides in the characteristics of the exercise itself. We used the unilateral knee extension, which is initiated by the concentric phase of the movement. This characteristic requires some effort to move the load, caused by the absence of the stretching-shortening cycle, i.e., the muscle does not use the elastic energy resulting from the eccentric movement and needs to produce a higher force of contraction[18,19].

Regarding the cardiovascular behavior, studies have shown that during the concentric phase of the exercise, the pressure responses tend to be higher than those observed during the eccentric phase[9,20]. Based on that, the interval during the series, even if it decreased the cardiovascular responses, might have required a high degree of physical effort for the re-start of the movement. Therefore, both the degree of effort and the synergist muscle demand might have contributed to the increase in pressure responses[2,5]. This hypothesis is supported by the fact that the cardiovascular responses are influenced by the motor cortex stimulus, inducing the up-regulation of the cardiovascular responses in relation to the motor units recruited during the exercise[21].

Regardless of the hypotheses that were raised, it is necessary to mention the possible limitations of the present study. The values of SAP, DAP and HR were not recorded during the 2-second interval of the discontinuous series protocol, due to the fact that the Finapres equipment eventually carries out the self-calibration, which prevents the reading of values for a short period. This occurred with some subjects during the 2-second interval and the sample would not be able to return in order to replicate the experiment. Additionally, electromyography was not used to detect the degree of muscular demand in both protocols. Moreover, it cannot be guaranteed that the Valsalva maneuver was not performed, especially in the discontinuous protocol.

However, considering the scarce amount of information on discontinuous series and strength exercises, the present investigation can be useful for the understanding of pressure behavior during high-intensity physical effort. For instance, despite the difference observed in the last series between the protocols for SAP, DAP and DP, the values measured 2 minutes after the exercise were not statistically different. Thus, regardless of the values observed, the post-effort decrease tends to be the same, probably caused by the higher vascular perfusion and baroreflex action[14].

During each protocol, increases in all cardiovascular variables were observed in relation to at-rest values, with a tendency to elevation (in the continuous protocol) and significant increase (in the discontinuous protocol) from the first series to the last ones in SA, DAP and DP. These increases are due to the aforementioned mechanisms of cardiovascular adjustment, i.e., the accumulated fatigue in one series might have intervened in the pressure response increase. HR, on the other hand, showed no inter-protocol difference and little intra-protocol difference. A possible explanation is that HR is mediated by mechanisms that are similar to those of blood pressure[21,22], but its behavior depends on striking increases in muscle mass[23], exercise duration[24] and intensity[8], which were not the focus of the present study.

In conclusion, knee extension series, when performed discontinuously, can result in higher cardiovascular responses when compared to continuous series. However, these results must not be considered definitive and further experiments using different exercises and intensities are necessary.
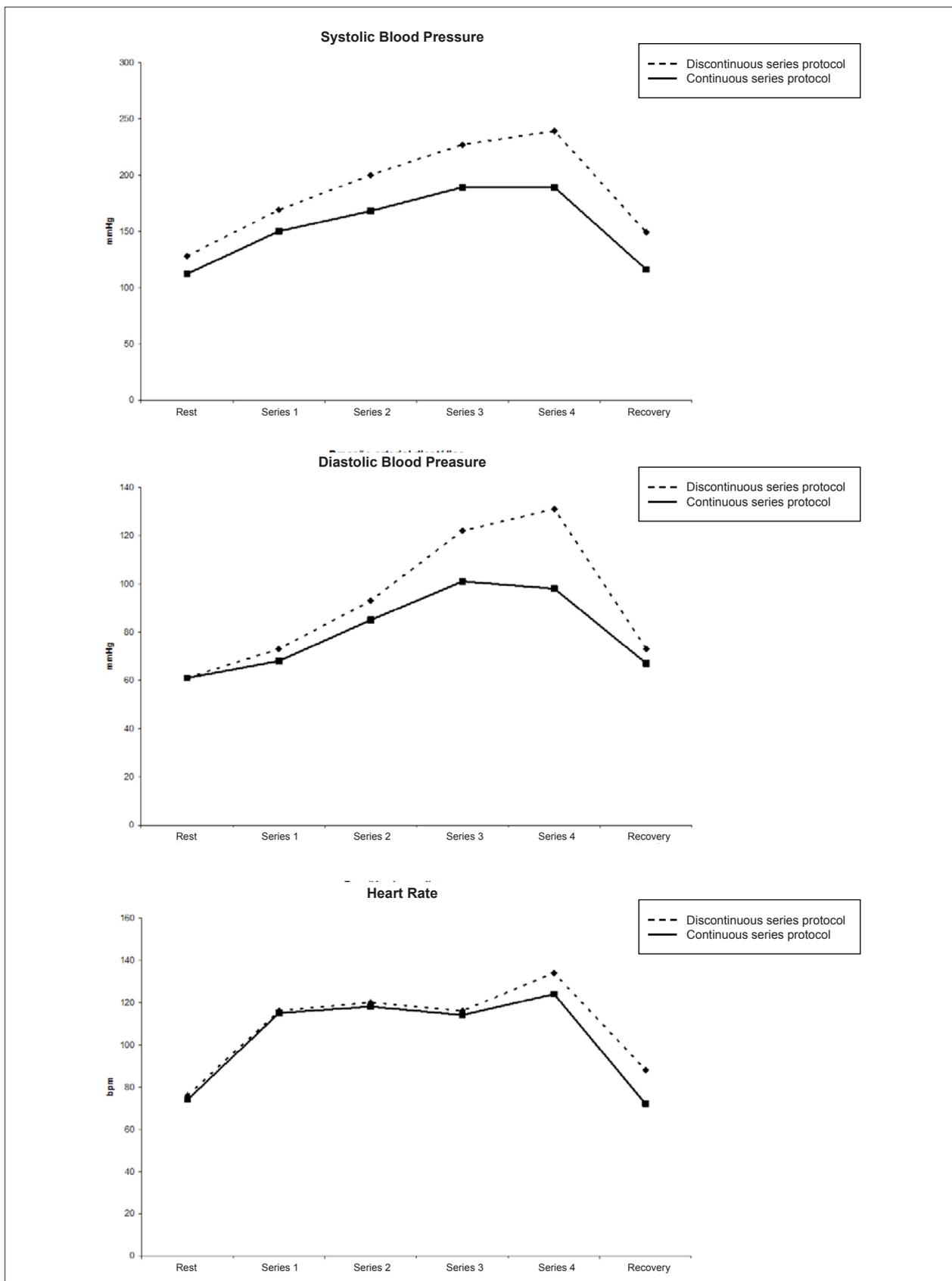
Fig. 2 - *Behavior of systolic blood pressure, diastolic blood pressure and heart rate in one study individual (case 3).*

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