

CHANGING RELATIONSHIPS BETWEEN SKIN BLOOD FLOW AND ARTERIAL PRESSURE IN MILD EXERCISE AND RECOVERY

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Abstract-The beat-by-beat variability of heart period (RR), systolic arterial pressure (SAP), diastolic arterial pressure (DAP) and skin microvascular conductance (G) in the palmar region of 23 healthy volunteers were analyzed during rest (R), clinostatic exercise at 10% maximum level (EXE1), 20% (EXE2) 30% (EXE3) and recovery (REC). G was obtained as the ratio between mean flow (laser Doppler) over one heart period and mean arterial pressure (Finapres). Exercise was accompanied by tachycardia, hypertension and skin vasoconstriction. Spectral analysis revealed an activation of the low frequency (LF, ~0.1 Hz) in RR and SAP during EXE2 and EXE3. Recovery reestablished basal conditions in this regard. Vasomotor activity appeared as a LF component in G shifted at a lower frequency (~0.7 Hz at R). At R SAP and DAP appeared pulled toward the vasomotor frequency compared to RR and this frequency change appeared to be enhanced by exercise. Conversely, during REC and uncoupling between systemic LF and vasomotor waves appeared. A comparison between the LF waves observed at the levels of heart, arteries and microcirculation appears a key element in understanding the role of vasomotion in the autonomic control of circulation and its responses to exercise. **Keywords** - Cardiovascular variability, vasomotion, clinostatic exercise, autonomic control of circulation.

I. INTRODUCTION

Arterial pressure (AP) Mayer waves in the low frequency (LF) range around 0.1 Hz have been intensively investigated as a probe of the general status of autonomic cardiovascular regulation mechanisms [1, 2]. Also, since the first observations of these spontaneous waves, it has been debated about their possible sources and many authors have recognized that they cannot be ascribed to a single mechanism but are influenced by the coupling of different and distributed sources either vascular or neural [3]. Restricting the field to circulation, it can be important to compare LF waves in AP at systemic level with the slow changes in peripheral flow [4] due to vasomotion, which display a similar but not necessarily equal frequency. Mild exercise performed in clinostatic position [5] is used as a stimulus able both to activate AP regulation mechanisms and to change the patterns of peripheral flow in the absence of the strong reflexes responding to orthostatism.

II. METHODOLOGY

23 healthy volunteers, age 36 ± 2.5 (mean $\pm$ SE), were enrolled and gave their informed consent to the study. During recordings subjects were in a clinostatic position over an armchair equipped with a cycloergometer. Each session included a prerecording habituation period at rest, 5 minutes recording at rest (R), 5 min pedaling at 10% of maximum effort (EXE1), 5 min at 20% (EXE2), 5 min at 30% (EXE3) and 5 min recovery (REC) immediately after stopping the physical effort.

Telemetric precordial (V2) ECG, finger pletismographic arterial pressure (AP, Finapres, Ohmeda, Englewood, CO), respiration via a thoracic belt (Marazza, Monza, Italy) and skin blood flow in the palmar region via a laser Doppler sensor (Periflux, Perimed, Sweden) were recorded. The signals were sampled (300 Hz, 12 bit precision) and stored on a PC for further processing. AP pressure was calibrated according to sphygmo-manometer measurements carried out immediately before and after the trial with the subject positioned on the armchair; self-calibration of Finapres equipment was excluded. Flow signal was calibrated by the equipment and expressed in laser Doppler units [ldu] of the equipment; calibration parameters were maintained fixed through the whole trial so that the unknown proportion with regional blood flow could be considered constant.

R peaks were detected by means of a classical derivative threshold algorithm and the RR intervals between two successive R peaks were recorded as measures of the varying heart period. AP waves were detected searching for the pressure rise after the instant of an R peak; the beginning of the rise was considered as diastolic AP (DAP) value number (i-1) while the following maximum was taken as i-th systolic AP (SAP) value. The i-th respiration beat-by-beat value was sampled at the beginning of the i-th cycle. Measures of both the i-th flow and pressure mean values (MFL(i) and MAP(i), respectively) were computed over an AP cycle starting at DAP(i-1) and ending at DAP(i). Beat-by-beat average conductance G(i) was estimated as $MFL(i)/MAP(i)$ [$gu = ldu/mmHg$].

The beat-by-beat series RR(i), DAP(i), SAP(i) and G(i) were processed on windows of 250-300 samples where all series were found free of artifacts. Autoregressive (AR) power spectral analysis and decomposition was performed, fixing the model order according to the minimum of Akaike's figure of merit and verifying the residual whiteness. Spectral components were grouped according to the position of their central frequency at very low frequency (VLF < 0.03 Hz), low frequency (LF, 0.03-0.15 Hz) and high frequency (HF > 0.15 Hz). The absolute power relevant to each band was found summing all the detected components, while the central frequency was obtained as their baricenter. Relative power of LF and HF bands was expressed in normalized units (nu) as percentage of total power (i.e., variance) minus the VLF power.

The reciprocal of conductance, resistance $RES(i) = 1/G(i)$ was also considered [6]. Nonetheless, the presence of single beats or short sequences of few beats in which vasoconstriction virtually nullified flow introduced arbitrarily high peaks in RES. As a consequence this leads to an over estimate of power (signal variance) and to broad band spectra in which rhythmical activity was masked. Results directly drawn from the analysis of mean flow, MFL(i), were also compared: this analysis produced tracings and spectral

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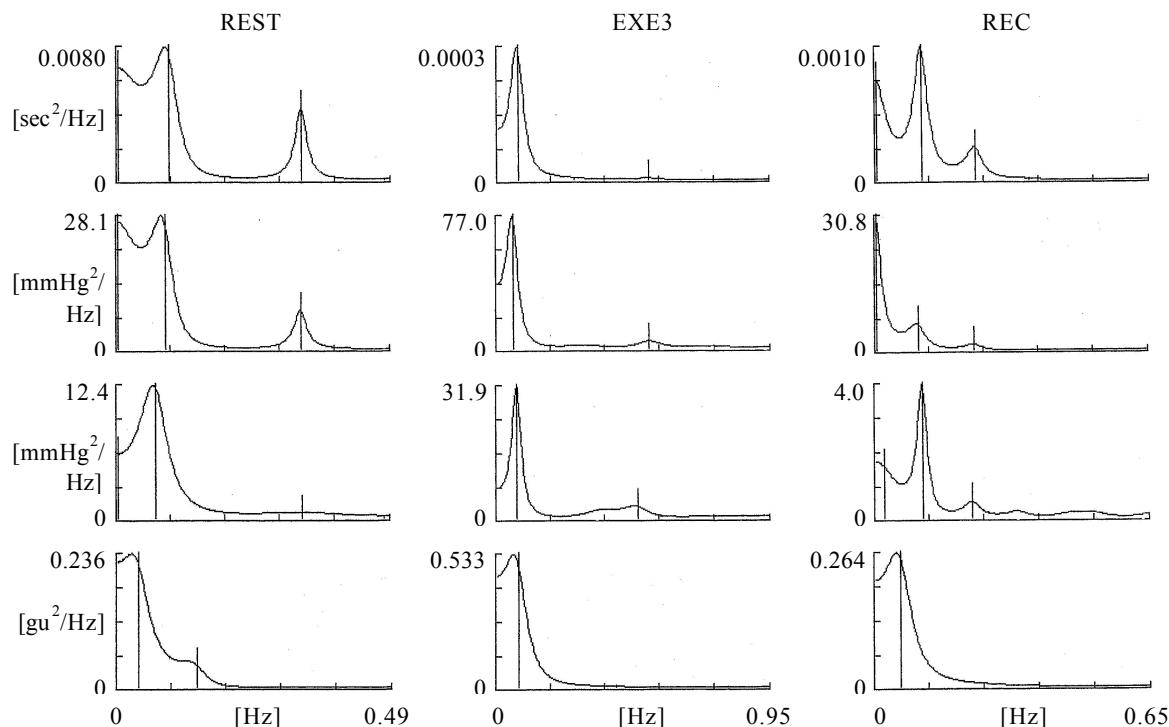


Fig. 1. Spectra of RR, SAP, DAP and G (from top to bottom) at rest, 30% clinostatic exercise (EXE3) and recovery REC.

contents similar to those of G(i). Nonetheless, the beat-by-beat normalization by the mean pressure MAP(i) appeared to partially compensate respiratory changes of peripheral flow ascribed to AP variability and not to vasomotion.

Cross-spectral analysis was performed via bivariate AR identification. Multivariate version of Akaike's figure of merit was used and the whiteness and uncorrelation of residuals was tested. The peak values of squared coherence, $K^2(f)$, in the LF and HF bands were considered and the threshold for significance was set at $K^2 > 0.5$.

III. RESULTS

Exercise onset at EXE1 shortened RR duration from 0.85 ± 0.032 sec (i.e., 71 beats/min) at rest to 0.67 ± 0.017 sec (i.e., 90 beats/min), increased AP from $116.6 \pm 4.3/77.0 \pm 2.1$ mmHg to $132.6 \pm 5.4/82.5 \pm 1.9$; in addition, a remarkable

decrease in palmar conductance G from 0.763 ± 0.139 gu to 0.479 ± 0.121 was noticed. Higher loads induced further and progressive shortening of RR (EXE2: 0.60 ± 0.016 ; EXE3: 0.54 ± 0.013 msec) and pressure increments (EXE2: $140.6 \pm 5.6/83.8 \pm 1.3$; EXE3: $145.7 \pm 5.9/86.1 \pm 1.9$). G had a slight further reduction at EXE2 (0.411 ± 0.079 gu) but not at EXE3 (0.482 ± 0.093 gu). Recovery reestablished RR (803 ± 25.9 sec) and AP ($119.2 \pm 3.4/78.9 \pm 1.6$ mmHg) as well as G (0.872 ± 0.156 gu) to baseline values.

RR variability decreased abruptly with exercise and the variability index ($VI = \text{rms variability}/\text{mean value} \%$) passed from $4.85 \pm 0.05\%$ at rest to 1.87 ± 0.10 at EXE3. The VI of SAP and DAP had modest changes around a value of 2.5. Noticeably, G displayed a very high VI (10 fold or more that of AP) ranging from $24.9 \pm 3.1\%$ at rest to $36.4 \pm 5.6\%$ at EXE2.

As shown in Fig.1, both the HF and LF spectral peaks were clearly recognizable in RR, SAP and DAP, while in G the power was mainly concentrate at LF at a slightly lower frequency than in the other series and a spurious HF peak is rarely detectable. The LF normalized power of RR was significantly increased by clinostatic exercise from 67.0 ± 3.9 nu at rest to 82.4 ± 2.9 at EXE3. Similarly, the absolute value of LF augmented from 5.4 ± 1.3 mmHg² to 12.5 ± 2.9 . Basal spectral distribution was regained during recovery. G displayed a stable spectral pattern concentrated in the LF band with a large LF normalized power always around 90 nu and negligible spurious peaks in HF of about 5 nu.

Beyond the above mentioned changes related to exercise activation, attention is focused on the differences and changes in the position of LF central frequency, as shown in Fig.2. At

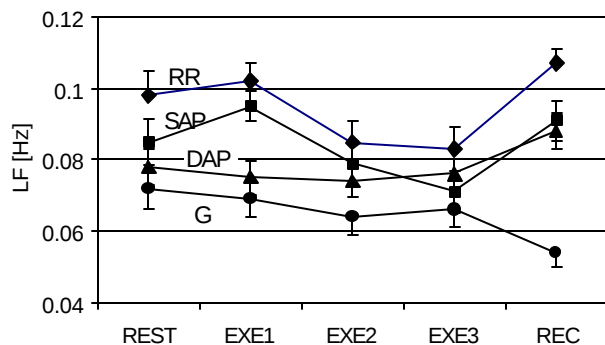


Fig. 2. Position of LF in RR (diamonds), SAP (squares), DAP (triangles) and G (circles) at rest, exercise and recovery.

rest the LF component of G is placed at a significantly lower position (0.072 ± 0.006 Hz) than that of RR (0.098 ± 0.007). LF waves in AP are in an intermediate position with DAP more shifted toward the frequency of vasomotion (0.078 ± 0.005 Hz) than SAP (0.095 ± 0.004).

These reciprocal positions are generally maintained with the only exception of a slight inversion between SAP and DAP at EXE3, in a condition where all LF components seem to be pulled toward the vasomotion frequency. In fact, at moderate exercise levels EXE2 and EXE3, a trend toward an alignment of the LF of RR and SAP to the lower values displayed by DAP and G is shown. On the contrary, the first exercise step EXE1 appears to accentuate the distance from vasomotion of the LF of RR and SAP (both differences are significant in this condition).

A remarkable result is found during recovery, when a general decoupling of systemic LF waves from vasomotor LF components is shown. The LF central frequencies of RR (0.107 ± 0.004 Hz), SAP (0.091 ± 0.006) and even DAP (0.088 ± 0.005) are significantly above that of G (0.054 ± 0.004 Hz). Particularly noticeable and significant is the shift toward a higher frequency of the LF of SAP displayed at the end of exercise.

The analysis of squared coherence with G confirmed a low correlation between RR and G. On the contrary, in about 50% of subject SAP and DAP displayed a $K^2 > 0.5$ in correspondence to the peak of vasomotor activity. The % of subjects with coherence at rest was 57% and 43% for SAP and DAP respectively; it reached a maximum of 68% and 50% at EXE2 and was minimum during recovery with a 44% and 28% for SAP and DAP respectively.

IV. DISCUSSION

Mild levels of exercise in clinostatic position appear to be a reliable condition for the study of autonomic activation and are marked by the obvious tachycardia and hypertensive effects but also by an increase in the LF waves observed at systemic level in nu as to RR and absolute units as to SAP [5]. In addition, the protocol permits to observe a vasoconstriction response in the skin microcirculation that reaches a maximum at 20% of exercise load (EXE2), with all likelihood before the initiation of thermoregulatory mechanisms, considering the modest amount of exercise and of heart rate changes.

Rhythmic vasomotor activity is best observed in conductance, G, beat by beat series rather than in resistance or flow. The amount of variability is strikingly high, as indicated by the VI, and suggests that vasomotion can be one of the major sources of variability at systemic level when many districts are properly coordinated in order to compose their effects. Unfortunately, the present data analyze a single district and can not provide any further information in this regard.

The observed vasomotor activity is tuned inside the LF at a frequency slightly lower than that of RR and AP. The LF of SAP and even more that of DAP appear to be pulled toward this lower frequency, if compared to the LF of RR. This pulling effect appears to be increased by the 20 and 30% exercise levels and seem partially reflected also on RR. These

results are partially supported also by the coherence analysis that indicates a more frequent correlation in correspondence to vasomotor rhythm in SAP and DAP and an increase of this with exercise. Nonetheless, squared coherence is too sensitive to the presence of noise in order to verify the exact role of mechanisms which probably account for a limited part of the power of variability signals; e.g., it can be argued that DAP probably displays less coherence than SAP just because DAP values are measured with a less favorable signal to noise ratio.

A major finding is the prompt uncoupling between AP and skin arterial conductance verified during recovery immediately after exercise. In this condition, basal levels of mean values and variability components appear to be recovered; but, on the contrary, the vasomotor activity appears to be tuned at a lower frequency than the 0.1 Hz kept by SAP and DAP, with a larger displacement compared to rest. A role of enhanced vagal drive during recovery, although possible, was not directly tested in this study.

V. CONCLUSION

A comparative analysis of the variability observed at sinoatrial, arteries and microcirculation levels can provide information about the role played by vasomotion in the autonomic control of circulation. Mild levels of clinostatic exercise appear as a convenient stimulation procedure in this regard which may be useful both in non invasive physiological studies and in clinical trials. The swinging of vasomotor and arterial pressure control mechanisms between coupled and uncoupled modes can be an important key in the understanding of pathophysiological responses of circulation to exercise.

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