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Physical activity influences heart rate variability and very-low-frequency components in Holter electrocardiograms [1]

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Abstract

Objective: A major proportion of RR interval variability in long-term recordings is due to slow (< 0.03 Hz) fluctuations, which seem to be a good predictor of survival after myocardial infarction, whose origin remains unclear. **Methods:** To study the effect of physical activity we compared by spectral analysis of the RR interval in 10 healthy human subjects (aged 28[s.e. 2] years) during 1-h periods each of rest (no activity), alternating rest and mild exercise (rhythmic activity), and normal spontaneous (random) activity. **Results:** Compared to rest, during both random and rhythmic activities, the RR variance increased significantly (from 5802[1030] to 13388[1448] ms^2, $P < 0.05$, and to 24959[2901], $P < 0.001$) due to an increase in power below 0.03 Hz (from 3017[467] to 9606[966] ms^2, $P < 0.01$, and to 21 103[2298] ms^2, $P < 0.001$) which explained 55.4, 73.2 and 86.1% of total RR variance, respectively. **Conclusions:** The amount of RR variability and its slower fluctuations largely depend on physical activity, regardless of its regular or irregular occurrence. Attempts to predict cardiovascular prognosis on the basis of RR fluctuations should therefore take account of the confounding effect of physical activity since healthier subjects would probably be more active.

Keywords: Heart rate variability; Autonomic nervous system; Spectral analysis; Exercise; Human

1. Introduction

Recent studies have emphasised the importance of the components of RR interval variability as markers of autonomic regulation of the cardiovascular system [1], the so-called high-frequency (related to respiration/vagal activity, HF) and low-frequency (those in the range of 6 cycles/min, or 0.1 Hz, related to sympathetic and vagal activity, LF). Changes in the relative power of these components have been described after acute myocardial infarction (less HF and more LF, [2]). But the greatest part of heart rate variability is frequently due to slower fluctuations (say, below 0.03 Hz, VLF), particularly in Holter recordings [3]; this VLF has been found to be an equal or better marker of prognosis than the 'autonomic' indices in the HF and LF spectra [3].

The causes of VLF fluctuations are not clear, although it has been suggested that temperature or the renin–angiotensin system [4] may play some role. The fluctuations in this frequency range are erratic and often irregular, and are typical features of 24-h ambulatory recordings. Conversely, a predominance in the 'classical' oscillatory pattern, with predominance in the LF-HF region and little or any VLF, is more often observed in the laboratory setting where the subject remains in the same position (supine or upright), hopefully relaxed, and does not perform any change in activity during a recording that is normally of short duration (minutes only, [1–5]).

This suggests that other factors more related to external events than to inherent cardiovascular regulatory mechanisms may be responsible for at least part of the variability in the VLF band. Among these, physical activity might be a possible determinant of these changes in RR interval.

The present investigation was undertaken to elucidate the effect of physical activity on the RR interval spectrum

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and to evaluate whether such changes are responsible for the relative changes in VLF.

2. Methods

Ten healthy subjects (aged 28.5[SE 2.8] years, 9 male, 1 female) were studied. The study was approved by the local institutional review committee and all subjects gave their informed consent. Recordings of continuous Holter ECG were obtained by a TR1 2-channel Tracker Recorder (Reynolds Medical Ltd., Hertford, UK). After application of the recorder the subjects remained supine at rest for 1 h; then, for 1 h, they performed every 3 min a cycle of rest/activity consisting of rest in the supine position alternating with getting up, taking 7 steps up and down, a brief walk (10 s) and then back to rest in the supine position. Next, the subjects performed ordinary random activity for 1 h with no predetermined order and duration. Activity included some or all of the following: sitting, reading, walking, climbing stairs, eating snacks and drinking tea. The Holter tape was then analysed on a MacIntosh II computer, to obtain the entire series of RR intervals (1 ms resolution [6]) and the separate RR-interval series for 'no activity', 'rhythmic activity' and 'random activity'. Mean RR interval and RR-interval variance (index of total variability) were computed. The power spectra of the RR-interval sequences were obtained using a standard Fast Fourier Transform algorithm with appropriate zero-padding to the data series [7]. In order to obtain a reliable estimate for the lower harmonic components, we computed a single spectrum for each complete series (i.e., comprising 3000–8000 RR intervals). The oscillatory power was calculated as the area of the spectrum in three frequency bands: a VLF band, spanning from the first harmonic above zero to 0.03 Hz, and the 'classical' spectral band, including both the so-called high- and low-frequency components, and spanning from 0.03 to 0.40 Hz (LF, from 0.03 to 0.15 Hz; HF, from 0.15 to 0.40 Hz). Results were expressed as mean (standard error) of the mean (s.e.m.). Differences from rest were assessed by paired t-tests.

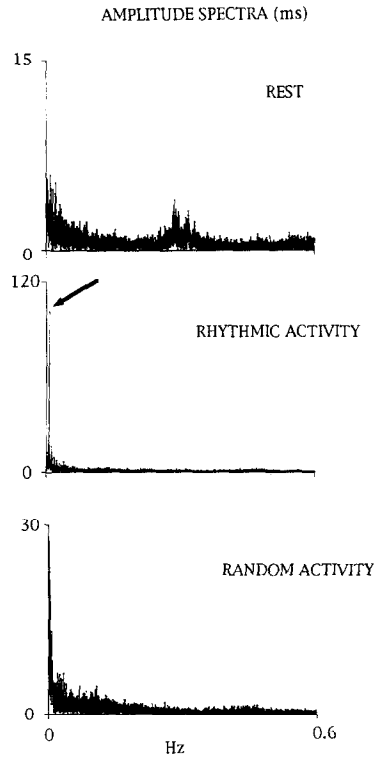

Fig. 1. Amplitude spectra obtained from one subject at rest (no activity) and during rhythmic and random activity. The scales of the three graphs differ due to the large differences in the spectral shapes: the region of lower frequency shows an increased amplitude during both rhythmic and random activity compared to rest; in the random activity spectrum the harmonics are broadly distributed, but in the rhythmic activity spectrum a single very narrow component is predominant (corresponding to the 3-min rest/activity cycle, marked by the arrow). Note also the predominance of high-frequency components at rest, which is reduced during activity.

Table 1
Results (mean[s.e.m.], $n = 10$)

	Rest (no activity)	Rhythmic activity	Random activity
RR mean (ms)	982 (45)	843 (38) * *	770 (26) * *
RR variance (ms^2)	5802 (1030)	24959 (2901) * * *	13388 (1448) *
VLF power (ms^2)	3017 (467)	21103 (2298) * * *	9606 (966) * *
LF power (ms^2)	1756 (321)	2813 (548)	3112 (523)
HF power (ms^2)	912 (314)	834 (186) * * *	522 (135) * * *
VLF% of variance	55.4 (2.8)	86.1 (1.5) * * *	73.2 (2.3) * * *
LF + HF% of variance	44.5 (2.8)	13.8 (1.5) * * *	26.8 (2.3) * * *
VLF frequency (Hz)	0.00037 (0.00004)	0.00566 (0.00004) * * *	0.00160 (0.00054)
Range	0.00025–0.00044	0.00562–0.00581	0.00016–0.00304

* $P < 0.05$, * * $P < 0.01$, * * * $P < 0.001$, vs. rest, paired t-test.
RR = RR interval; VLF, LF, HF = power in the very low (up to 0.03 Hz), low (0.03–0.15 Hz) and high frequency (0.15–0.40 Hz) bands of the RR interval power spectrum.

3. Results

The mean results obtained are reported in Table 1. While the mean RR decreased from rest to either rhythmic or random activity ($P < 0.01$ for both), the total RR interval variability increased ($P < 0.001$ during rhythmic, $P < 0.05$ during random activity). The increase in variability was due to an increase in the VLF power, whereas the sum of LF + HF powers remained nearly unchanged (although with both random and rhythmic activity we observed a relative increase in LF and a relative decrease in HF). Thus, VLF was responsible for a significantly higher proportion of variability during activity than during rest (see Table 1, VLF, LF and HF components expressed as % of variance). The frequency of the VLF (0.00566[0.00004] Hz) during the rhythmic activity recording coincided (with a difference of ~0.0001 Hz) with the frequency corresponding to the 3-min activity cycle (equivalent to 0.0055 Hz). In contrast, the 'random activity' showed a broadened VLF band in the RR interval spectrum. In fact, the duration of the random activities varied from subject to subject and from one period to another, ranging from 20–30 s to several minutes.

Fig. 1 shows the spectra obtained in the three conditions in the youngest subject; qualitatively identical results were obtained in all subjects regardless of their age. An increase in VLF was evident in both rhythmic and random activity panels; the 'rhythmic activity' spectrum revealed only one narrow component whose frequency was identical to that of the 3-min cycle of rhythmic activity (0.0055 Hz), whereas the random activity showed a broader VLF band.

4. Discussion

Heart rate variability (or, similarly, the RR interval variability, as in the present study), expressed as the variance or by other related indices, is often greater when vagal tone is higher or where vagal tone predominates over the sympathetic [8]. But in the conditions examined in the present study we have found that an increased variance parallels a decrease in mean RR interval, which argues against an increase in vagal activity. Changes in the levels of physical activity are thus a major modulator of heart rate variability if such changes occur in the period of analysis. In previous studies of 24-h distribution of variance in hypertensive [9], diabetic [6] or normal subjects [5,8], it can be observed that the peak of heart rate variability occurred in the morning and was very close in time to the morning increase in LF, an index of sympathetic predominance [10]. The results of the present study can explain this apparent contradiction by suggesting that the greatest autonomic activity associated with changes in physical activity probably occurs after awakening [11]. Conversely, only in the absence of changes in physical activity within the time period analysed might heart rate variability be an index of vagal activity, as normally occurs in short-term laboratory investigations—e.g., of the various degrees of diabetic autonomic neuropathy [12] or during exercise studies [13,14]. When short-term recordings are obtained and analyzed, each during steady-state conditions and at a different exercise load, it was consistently found that with increasing load the RR interval variance decreased, and the variance paralleled the relative increase in sympathetic tone [13,14]). But these conditions only apply to laboratory recordings where the levels of activity are known and predetermined. During Holter recordings, and in the present study, the time window used to analyse the RR interval variability is longer than in steady-state laboratory studies [3,6,15], and hence usually contains periods of both rest and different levels of activity. Our results demonstrate that this variation in activity is associated with an increase in heart rate variability and in VLF components; this increase is greatest in fixed alternating cycles of activity, but is also evident during irregular random activity. The duration of the 'ordinary' random activities of our subjects in most cases ranged from 20–30 s to several minutes, so they fell into the VLF band. Activity which is performed rhythmically generates a narrow spectrum; if it is more irregular (as normally happens during everyday life), the VLF spectrum would show a broader power distribution. In both cases the VLF power and the overall heart rate variability are increased by physical activity. During everyday life, activity is likely to be far more random than rhythmic; our study demonstrates that random activity changes are quite sufficient to increase substantially the level of VLF power.

The so-called 'very-low-frequency' fluctuations of RR interval have been attributed to various factors, including the renin–angiotensin system [4], thermoregulation [4], and chaotic regulation of heart period [16]. Although these other hypotheses remain valid, and although there is no doubt that the presence of autonomic dysfunction alters the power of all spectral components (including the VLF), the presence of physical activity, and perhaps its degree (not precisely assessed in the present study) should be considered before any other patho-physiologic assumptions are made on the basis of the slowest components of RR interval variability. Although previous studies have suggested that the absence of VLF on Holter recordings of RR interval is a marker for a poor prognosis after acute myocardial infarction [3], this might be due to inability to exercise, together with disturbed cardiovascular regulation. Although the age of subjects undergoing myocardial infarction is usually higher than that of the subjects evaluated in the present study, and although it is well known that ageing decreases heart rate variability, we would expect exercise to have similar qualitative effects at older age, even if quantitatively it may be somewhat less. In any case, we showed that Holter analysis of heart rate variability was readily altered by exercise versus rest, regardless of the age of the subjects. Further studies seem necessary

to distinguish between this confounding effect of exercise ability (and perhaps of other factors, such as the environment where the recording is performed) and prognosis after myocardial infarction; unless VLF analyses are unconfounded by activity, it would seem wise to prefer the better validated measures of autonomic activity (HF, LF or their ratio). These practical observations are particularly important as commercially developed monitors which also include spectral analysis become more widely available and allow uncritical use of such techniques. These results may clarify some of the conflicting results in interpreting heart rate variability obtained in long-term recordings [17].

In conclusion, this simple study shows that in long-term recordings the heart rate variability and its VLF component are highly dependent on the presence of changes in physical activity (either regular or irregular), rather than simply reflecting autonomic tone. The presence of changes in physical activity, either regular or irregular, during the period of recording, determine major increases in the VLF power, and so these are not to be regarded only as the result of internal autonomic rhythms. Obviously, these results do not exclude the presence and the importance of such rhythms, nor exclude other possible factors responsible for VLF fluctuations, but emphasize the importance of activity as a major confounding factor. Attempts to predict cardiovascular risks on the basis of this variable (as an index of vagal activity) should therefore avoid the confounding effect of physical activity since healthier subjects would be probably more active.

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