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'Fire of Life' analysis of heart rate variability during alpine skiing in Austria

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Abstract
Background: Skiing is a very popular sport in Austria. Nevertheless, there is little information concerning online monitoring of bio-signals during alpine skiing in the mountains. Within the last years innovative scientific monitoring tools for evaluating features of neurocardial fitness have been developed. **Aims**: The goal of this study was to demonstrate the new 'Fire of Life' heart rate variability analysis for the first time during alpine skiing. **Volunteers and Methods**: Continuous electrocardiographic monitoring over a period of 12 hours was performed simultaneously in two healthy volunteers using the same type of equipment (medilog AR12 systems). Two healthy volunteers (female, 20 years, and male, 51 years), both hobby skiers, were monitored simultaneously and continuously during two resting periods before and after active sport and also during alpine skiing. Altogether each participant covered 9,084 meters altitude difference within a time period of 6:14 hours. Total length of the downhill skiing was 45 kilometers. **Results**: Data acquisition was performed without any technical problems in both subjects. Poincaré plots of sequential R-R intervals (beat to beat variability) show two ellipses of different shape and magnitude. During resting periods respiratory sinus arrhythmia and blood pressure effects can be clearly seen in the young female. The same effects, however markedly reduced, are obvious in the older volunteer. **Conclusions**: The present investigations during alpine skiing highlight the potential value of the 'Fire of Life' heart rate variability monitoring even under difficult environmental conditions. The innovative kind of analysis helps to show how well the human body reacts to sport, stress and recovery.

Keywords: Heart rate, heart rate variability, autonomic nervous system, alpine skiing, sport.

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Introduction
In recent years computer analysis of heart rate (HR) and heart rate variability (HRV) has allowed the identification of specific patterns in the fluctuations of the electrocardiogram (ECG) which reflects the effects of individual mechanisms involved in cardiovascular regulation. Based on the automatic assessment of these patterns, new and scientific tools for evaluating the features of cardiovascular control have been developed.

HRV has been investigated in normal subjects of various age groups [1,2] and also in different cardiovascular diseases such as acute myocardial infarction, congestive heart failure, arterial hypertension, diabetes mellitus and different autonomic dysfunctions [3]. Beside HRV power spectral analysis the so-called 'Fire of Life' ™ analysis (Huntleigh Health Care, Cardiff, UK) is a totally new method of visualization of HRV, which has been described in very few scientific publications [4,5] by our research group.

Skiing is one of the most popular sports in Austria and is famous throughout Austrian history. An Austrian citizen with no skiing ambitions cannot be considered a ‘true Austrian’. However, intensive investigations concerning online cardiac monitoring and biological data analyses during alpine skiing are very rare.

The aim of this study was to demonstrate the new ‘Fire of Life’ HRV analysis for the first time in two healthy volunteers of different age (female: 20 years, male: 51 years) during alpine skiing in the forthcoming alpine world ski championship region 2013 in Schladming in Austria. The same downhill courses and the same type of monitoring equipment was used in parallel in both hobby skiers (Fig. 1).

Fig. 1 Electrocardiographic monitoring using two HRV medilog AR12 systems. Recordings were performed during alpine skiing in the forthcoming alpine world ski championship region 2013 in Schladming, Austria.

Materials and Methods

Online HR and HRV monitoring

Two identical HRV Medilog® AR12 (Huntleigh Healthcare, Cardiff, UK, and Leupamed GmbH, Graz, Austria) systems were used for cardiac monitoring. The systems are designed for a monitoring period of more than 24 hours. The sampling rates of the new recorders are 4096 samples per second. Therefore R-waves can be detected extremely accurately. All raw data are stored digitally on special memory cards. After removing the cards from the portable systems, the data can be read by an appropriate card reader connected with a standard computer. R-peak time resolution is 244 microseconds and the P and T time resolution 1,953 microseconds. The dimensions of the used HRV recorder are 70 x 100 x 22 millimeters, the weight is about 95 grams with batteries.

HR and HRV data analysis

HRV is measured as the percentage change in sequential chamber complexes, so-called RR-intervals, in the ECG. The registration of HRV is performed using three electrodes on the chest. In the clinical environment it is important to simultaneously record respiration and if possible continuous blood pressure. The RR-intervals in the ECG are controlled by the blood pressure control system, influenced by the hypothalamus and in particular controlled by the vagal cardiovascular center in the lower brainstem. HRV can be quantified over time using registration of percentage changes in RR-intervals in the time domain as well as the changes in the frequency range by analysis of electrocardiographic power spectra. Parameters are recommended by the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [3]. Calculation of ECG power spectra is thought to provide an understanding of the effects of sympathetic and parasympathetic systems on HRV. Early work pointed out a few bands in the spectrum of HRV that could be interpreted as markers of physiological relevance. Associated mechanisms are thermoregulation which can be found in the very low frequency band, blood pressure and respiratory effects.

With the new ‘Fire of Life’ software the HRV is analyzed and displayed in a new way to help judge the function of the autonomic nervous system. Viewing this innovative kind of analysis helps to show how well the human body reacts to sport, stress and recovery. For offline visual inspection all ECG raw data can be displayed on a screen.

Healthy volunteers

The investigations were performed with the two authors (DL: female, 20 years, 160 cm, 53 kg; and GL: male, 51 years, 173 cm, 75 kg), both hobby skiers and not elite athletes. Both subjects were free of neurological or cardiovascular disorders and were not taking any medication. The registration of the non-invasive parameters was in accordance with the Declaration of Helsinki of the World Medical Association.

Procedure

The identical study design was used in both volunteers and included the following steps: the recording sessions started in both persons at 6:00 a.m. Three ‘Skintact Premier F-55’ ECG-electrodes (Leonhard Lang GmbH, Innsbruck, Austria) were fixed on the chest. The study consisted of two resting periods (7:00 – 9:30 a.m. and 4:30 – 7:00 p.m. and an active sport period (9:45 a.m. – 4:00 p.m.). From 12:00 – 12:45 p.m. a recovery phase took place.

Results

Altitude profile and HR monitoring

Data acquisition was performed without any technical problems. The authors were able to capture data under extreme environmental conditions (temperature at 1,500 meters altitude -13°C and motion artefacts during skiing).

Figure 2 (upper panel) shows the altitude profile during skiing. Altogether, 9,084 meters of altitude difference were covered within a time period of 6:14 hours. Total length of the downhill skiing courses was 45 kilometers, and 25 different ski-lifts were used.

The HR data from the younger subject (DL, 20 years) over a period of 12 hours are shown in Figure 2b (middle panel). At the beginning of the recording session (6 a.m.), both volunteers took a car ride to a bus. There are some artefacts during this period caused by carrying the skiing equipment. In the following resting period, the two persons were sitting comfortably in a coach that took them to the ski region. The mean HR during this period was 75/min in the younger (Fig. 2b) and 73/min in the older subject (Fig. 2c). At 9:37, the first cable car ride started. At the first downhill run, the mean HR increased in both subjects significantly (green line at 9:45; DL: 132/min, GL: 114/min). After finishing this first run, HR decreased rapidly in both subjects (DL: 82/min, GL: 80/min). This pattern was then repeated 25 times in a similar manner. Between 12:00 and 12:45 a recovery phase took place. The last downhill run was performed at 3:45 p.m. After that, movement and mechanical artefacts appear again due to ski transport. The coach departed at 4:30 p.m. (compare low mean HR in Fig. 2, right side). The last part of the recording session shows the same artefacts as those at the beginning. After 12 hours, the recording sessions were finished in both participants.

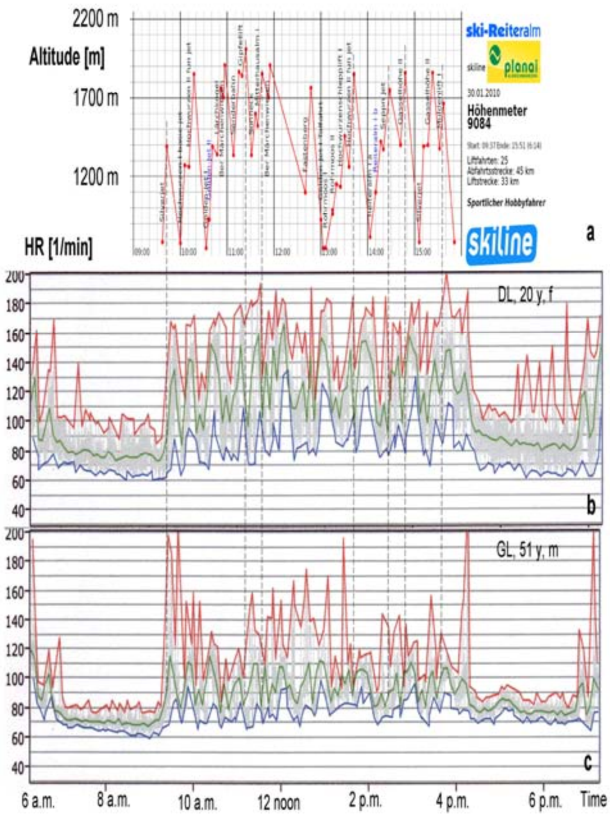

Fig. 2 Altitude profile and HR trends. The diagram shows the altitude profile (a) in a schematical presentation. Below that, the trend of the heart rate (HR) is shown in beats per minute (green: mean HR, red: max HR, blue: min HR) in the younger (b) and older (c) healthy volunteer.

HRV-scatterplots

The 'Poincaré' plot is a technique taken from non-linear dynamics. Figure 3 shows two Poincaré scatter grams in which each RR-interval is plotted as a function of the previous RR-interval. These graphical representations of cardiovascular dynamics result in elliptical types of shape. The ellipse is fitted onto the so-called 'line of identity'. Standard deviation of the points perpendicular to the line of identity, denoted by SD1, describes short term RR variability due to the respiratory component of HRV. The standard deviation along the line of identity, denoted by SD2, describes long-term variability [6]. In Figure 3 (a and b) the two different persons produced two ellipses of different shape and magnitude. The young subject (Fig. 3a) showed a higher HRV associated with a big ellipse. The older subject (Fig. 3b) produced a much more reduced ellipse in which the RR points gravitate around the mean RR and the line of identity.

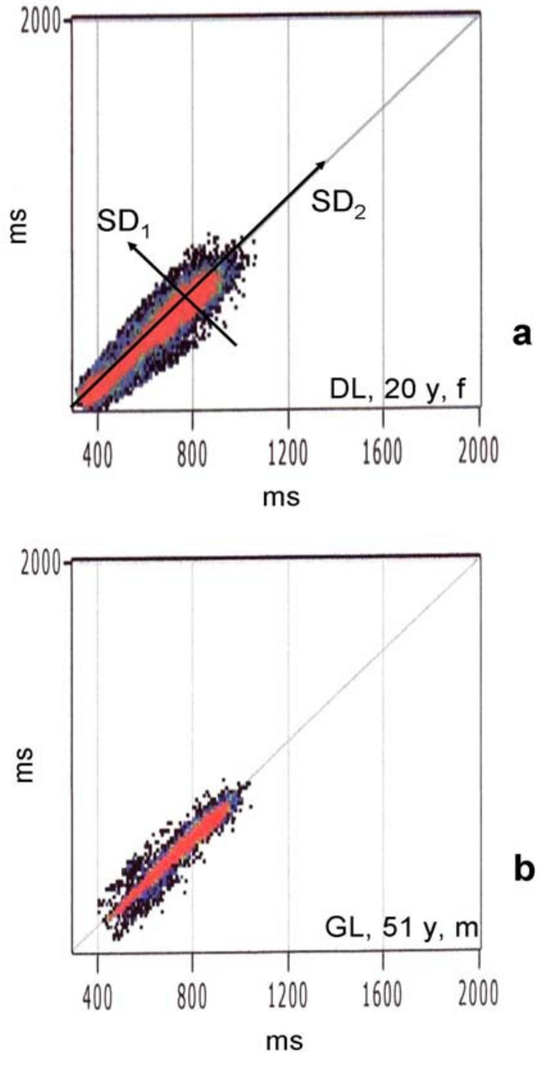

Fig.3 Quantitative beat-to-beat analysis of RR-intervals (Poincaré plot). The results of the young participant (a: DL, 20 years) are directly comparable to those of the older participant (b: GL, 51 years). Note the different shapes of the ellipses resulting in a different total heart rate variability.

HRV – frequency domain ('Fire of Life' analysis)

The results of the 'Fire of Life' HRV analysis of both subjects are shown together with the altitude profile in Fig. 4.

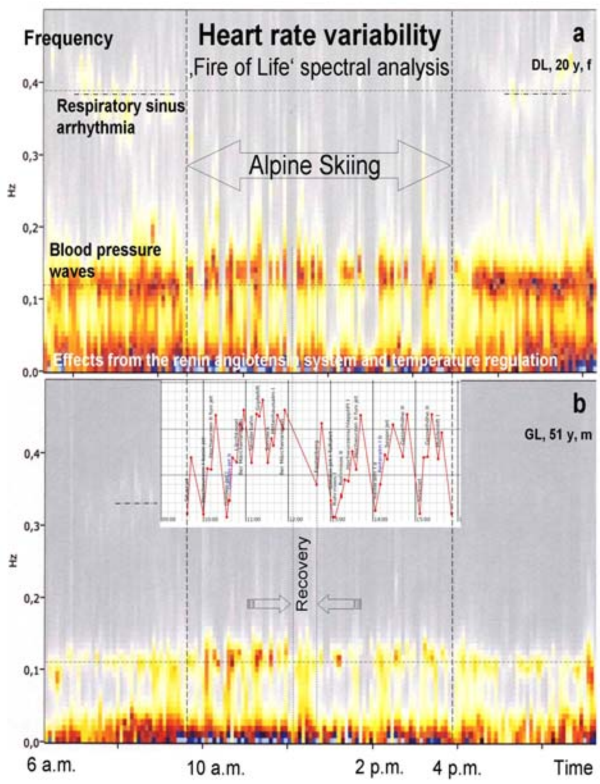

Fig.4 'Fire of Life' power frequency analyses. Heart rate variability (HRV) data of 12 hours from the young participant (a) and the older participant (b) are shown. In addition, once again the altitude profile (comp. Fig. 2) is implemented.

At the beginning of the recording (first resting period) a clear influence of respiratory sinus arrhythmia (frequency range 0.35-0.40 Hz) is barely recognizable in the young volunteer (Fig. 4a; left side). In addition the influence of blood pressure waves (frequency ~ 0.12 Hz) can be observed. The frequency range < 0.05 Hz may also contain slowly changing effects from the renin angiotensin system and temperature regulation. During the resting periods (ski lift rides and recovery around noon) the blood pressure effects (~ 0.13 Hz) can be clearly seen in the young female. After skiing, during the second resting period (Fig. 4, right side) the three main components of HRV analysis (respiratory sinus arrhythmia, blood pressure influence and thermoregulatory effects) are prominent again. The same effects, however markedly reduced, are shown in Fig. 4b in the older volunteer. In general a proportional age-related decrease of all components can be seen in the older subject. Not only total variability (reduction of the 'Fire of Life'), but also specific frequency component decreases (e.g. respiratory sinus arrhythmia) are noticeable. Even in the resting periods during ski lift rides and recovery at noon the neuromodulation of HRV is not as pronounced as in the younger healthy volunteer. The 'Fire of Life' burns much brighter in the younger than in the older participant which can be seen in Fig. 4 at the first glance.

Discussion

Some of the most significant advancements in fitness assessment have been made possible by the development of highly sophisticated monitoring equipment and analysis techniques. HR measurement has been greatly facilitated and made more accurate by the use of very small, mobile heart rate systems. In fact, the development of such systems, which now include the ability to make accurate measurements of beat-to-beat HRV, is proving to be useful in the analysis of cardiovascular response to exercise and training effects [7].

HRV is an index value of the neurocontrol of the heart. HRV can be quantified by simple calculation of the standard deviation of RR-intervals of the cardiac cycles (total HRV) in the time domain [8,9]. In addition, complex analyses of HRV in the frequency domain using different spectral analysis methods are possible [10]. It is interpreted as a brainstem reflex with an afferent arc via the vagus and glossopharyngeal nerves and an efferent arc mainly via vagal fibers [9]. HRV has stochastic and rhythmic components. With spectral analysis variability can be classified into individual ranges which represent biological rhythms. The following influences can be distinguished for different ranges of HRV: (i) Respiratory sinus arrhythmia (approx. 0.15-0.5 Hz); centrally nervous respiratory impulses and interaction with pulmonary afferents; (ii) The so-called "10-s-rhythm" (approx. 0.05 – 0.15 Hz); natural rhythm of cardiovascular active neurons in the lower brainstem (circulatory center and its modulation by feedback with natural vasomotoric rhythms via baroreceptor feedback); (iii) Longer wave HRV-rhythms (approx. < 0.05 Hz); effects from the renin angiotensin system or temperature regulation as well as metabolic processes [3,7-12].

The scope of HRV is not yet completely clear, but it is known that there are intraindividual and interindividual variances and that HRV depends on age, circadian variations (sleep-wake-cycle), physical condition and mental and physical exertion. HRV can also be affected by diverse conditions such as age-related diseases (diabetic neuropathy, renal failure, essential hypertension, cardiac disorders, coronary artery disease, intracranial lesions) and different medications. The narrowness of HRV after heart transplantation [10] is similar to that seen in deep comatose patients and in brain-dead subjects [9] in whom complex reflex mechanisms are no longer generated or regulated in the brain. In contrast, heart transplantation totally interrupts peripheral autonomic afferences and efferences.

Within this publication, an innovative method of HRV analysis and data before, during and after alpine skiing from two persons belonging to different age groups are presented. As mentioned before, a decrease in HRV appears to occur with increasing age. The interbeat variation in HR has been demonstrated to be a function of conditioning status in young subjects. Although the involvement of the autonomic nervous system during sport and physical training is well documented, to our knowledge there are no continuously registrated and directly comparable scientific HRV data in young and older subjects available in scientific literature during alpine skiing.

HRV can be used as reliable indicator of the state of health. It becomes less random with the aging process and the appearance of age-related diseases. However, it has been demonstrated that in special syndromes like fatigue and stress one can counteract this process using different preventive methods like sport [7] or acupuncture [13]. The latter has been demonstrated in recent investigations (in 2009 and 2010) concerning patients with burn-out syndrome as performed in a common teleacupuncture study between Beijing and Graz [4].

Conclusion

The present pilot study of HR and HRV analysis during alpine skiing in Austria demonstrates a new method for the quantification of HRV parameters ('Fire of Life' analysis). It shows very clearly age-related differences during sport. Innovative research including artificial intelligence techniques is needed to detect subjects at risk of cardiovascular disease, so that appropriate training is possible.

Acknowledgement

Both GL and DL carried out the data collection. GL performed the design, analysis and coordination of the scientific work. Both authors read and approved the final manuscript. Conflict of interest disclosures: none.

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