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ΤΙΤΛΟΣ:

ΕΞΕΤΑΣΗ ΤΗΣ ΕΓΚΥΡΟΤΗΤΑΣ ΤΟΥ POLAR RS800CX ΓΙΑ ΤΗΝ ΑΞΙΟΛΟΓΗΣΗ ΤΗΣ ΜΕΤΑΒΛΗΤΟΤΗΤΑΣ ΤΟΥ ΚΑΡΔΙΑΚΟΥ ΠΑΛΜΟΥ ΣΕ ΗΡΕΜΙΑ ΑΣΚΗΣΗ ΚΑΙ ΑΠΟΚΑΤΑΣΤΑΣΗ

(VALIDATION OF POLAR RS800CX FOR MEASURING HEART RATE VARIABILITY DURING REST, EXERCISE AND RECOVERY)

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ABSTRACT

Research in the last decades indicated significant relation between autonomic nervous system and cardiovascular mortality resulting to sudden death and urging the need for heart rate measurement. A heart rate marker such as Heart Rate Variability (HRV) is considered a valid index. HRV analysis was interpreted through ECG signal by developing several devices and software. However, due to their high cost and difficult utilization, inexpensive and practical devices like Polar RS800CX heart rate meter were developed for HRV measurement.

The purpose of this study was to examine the validity of Polar RS800CX during rest, exercise and recovery. METHODS: Thirty-two healthy adults (32 males: age 23.96 years, BMI 24.52 kg/m^2 ± 4.10 SD) volunteered. On one day, participants completed HRV measurements through a Polar RS800CX (Polar Electro Oy, Kempele, Finland) and ECG (Welch Allyn, CardioPerfect) at laboratory. Data collected from 0-20, 20-40, and 40-60 minutes were used to derive HRV for different time points. The HRV indices studied were from the time-domain, the frequency-domain and indices from the non-linear section. RESULTS: Statistical significance ($P<0.05$) was observed through correlation at resting period, in contrast with the exercise and recovery period between Polar and ECG. The mean difference was statistical significant ($P<0.05$) in exercise and recovery periods, in contrast with the resting period. The 95% limits of agreement and the coefficient of variation were also measured for the three time phases. CONCLUSIONS: Polar RS800CX is valid for resting periods; however, it is an unreliable tool during exercise and recovery periods for measuring HRV.

ΠΕΡΙΛΗΨΗ

Μεγάλος αριθμός ερευνών ανέδειξε την σημαντική σχέση μεταξύ του αυτόνομου νευρικού συστήματος και της καρδιαγγειακής θνησιμότητας συντελώντας σε αιφνίδιο θάνατο. Η μεταβλητότητα του καρδιακού παλμού (ΜΚΠ) είναι ο πλέον συνιστώμενος δείκτης διάγνωσης καρδιακών προβλημάτων λόγω της ευχρηστίας και της οικονομίας που προσφέρει. Η ανάλυση του ΜΚΠ ερμηνεύεται μέσω ενός ηλεκτροκαρδιογραφικού σήματος από ποικίλους μηχανισμούς και υπολογιστικά προγράμματα. Μολαταύτα, εξαιτίας του υψηλού κόστους και της δυσχρηστίας τους, οικονομικοί και εύχρηστοι μετρητές καρδιακής συχνότητας όπως το Polar RS800CX αναπτύχθηκαν για την μέτρηση ΜΚΠ.

Ο σκοπός της συγκεκριμένης έρευνας ήταν να εξετάσει την αξιοπιστία του Polar RS800CX κατά την διάρκεια ηρεμίας, άσκησης και αποκατάστασης. ΜΕΘΟΔΟΙ: τριάντα-δύο υγιείς ενήλικες (32 άνδρες: ηλικίας 23.96 ετών, ΔΜΣ 24.52 kg/m^2 ± 4.10 Τ.Α.) συμμετείχαν. Οι εθελοντές ολοκλήρωσαν τις μετρήσεις της ΜΚΠ φορώντας ένα ρολόι Polar RS800CX (Polar Electro Oy, Kempele, Finland) και έναν φορητό ηλεκτροκαρδιογράφο ECG (Welch Allyn, CardioPerfect) με μία επίσκεψη στο εργαστήριο. Τα δεδομένα που συγκεντρώθηκαν από 0-20, 20-40, and 40-60 λεπτά, χρησιμοποιήθηκαν για την αξιολόγηση του ΜΚΠ για διαφορετικά χρονικά σημεία. Οι δείκτες ΜΚΠ που μελετήθηκαν ήταν από την κατηγορία του χρόνου, από την κατηγορία της συχνότητας και την μη-γραμμική κατηγορία. ΑΠΟΤΕΛΕΣΜΑΤΑ: Σημαντική στατιστική διαφορά ($P<0.05$) παρατηρήθηκε στην συσχέτιση κατά την περίοδο ηρεμίας μεταξύ του Polar και του ECG, αντιθέτως, με τις περιόδους άσκησης και αποκατάστασης. Επιπροσθέτως, η διαφορά του μέσου όρου ήταν στατιστικά

σημαντική (P<0.05) στην περίοδο άσκησης και αποκατάστασης ενώ στην περίοδο ηρεμίας δεν παρατηρήθηκε στατιστικά σημαντική διαφορά. Το 95% όριο συμφωνίας (95%ΟΣ) και ο ποσοστιαίος συντελεστής απόκλισης (%ΣΑ) υπολογίστηκαν και για τις τρεις χρονικές περιόδους. ΣΥΜΠΕΡΑΣΜΑΤΑ: Το Polar RS800CX είναι ένα έγκυρο εργαλείο κατά την περίοδο ηρεμίας. Αντίθετα, σε περιόδους άσκησης και αποκατάστασης η αξιοπιστία του περιορίζεται καταλυτικά., καθιστώντας το ανεπαρκές για τις συγκεκριμένες περιόδους.

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INTRODUCTION

Several studies acknowledged the important relation of autonomic nervous system and cardiovascular mortality resulting in sudden death, during the last two decades (Lown and Verrier 1976; Corr P.B. 1986; Schwartz P.J. 1990). It is evident through experimental research that there is a strong correlation between inclination to fatal arrhythmias and tracks of either raised sympathetic or decreased vagal activity which resulted in further researching for markers of autonomic nervous system function.

Heart Rate Variability (HRV) is recommended as one of the most prestigious markers due to its easy utilization and it's low-cost. Despite these advantages, the complexity of the many HRV measures leading to false conclusions and extravagant or unfounded extrapolations should be taken into consideration before using this marker. The variations of successive heart rate and RR intervals simultaneously are described as heart rate variability (HRV) becomes the conventionally accepted term to describe variations of both instantaneous heart rate and RR intervals.

In order to facilitate HRV analysis, a wide variety of equipment and software programs have been developed, such as Power Lab (AD Instruments, Australia) and the Reynolds Pathfinder program (Reynolds Medical Limited, United Kingdom) which measure HRV by means of an ECG signal. However, they present disadvantages such as difficulty of access and high cost. (Vanderlei, Silva et al. 2008). The Polar RS800 CX heart rate meter (Polar Electro, Finland) is a practical device that is less expensive than others and has been used to monitor the beat-to-beat HR for HRV analysis. This device captures RR intervals by means of electrodes attached to an elastic band placed around the thorax. Electronic signals are continuously transmitted and stored in a receiver via an electromagnetic field for later analysis and calculation of HRV values.

Purpose

The aim of this study was to examine the validity of Polar RS800 CX during rest, exercise and recovery.

Null Hypothesis

Polar RS800 CX will not have the same heart rate indices with ECG (WelchAllyn, CardioPerfect).

Alternative Hypothesis

Polar RS800 CX will have the same heart rate indices with ECG (WelchAllyn, CardioPerfect). Based on previous published data with older polar devices in humans (Vanderlei, Silva et al. 2008), it is anticipated that Polar RS800 CX will have the same indices with ECG (WelchAllyn, CardioPerfect).

LITERATURE REVIEW

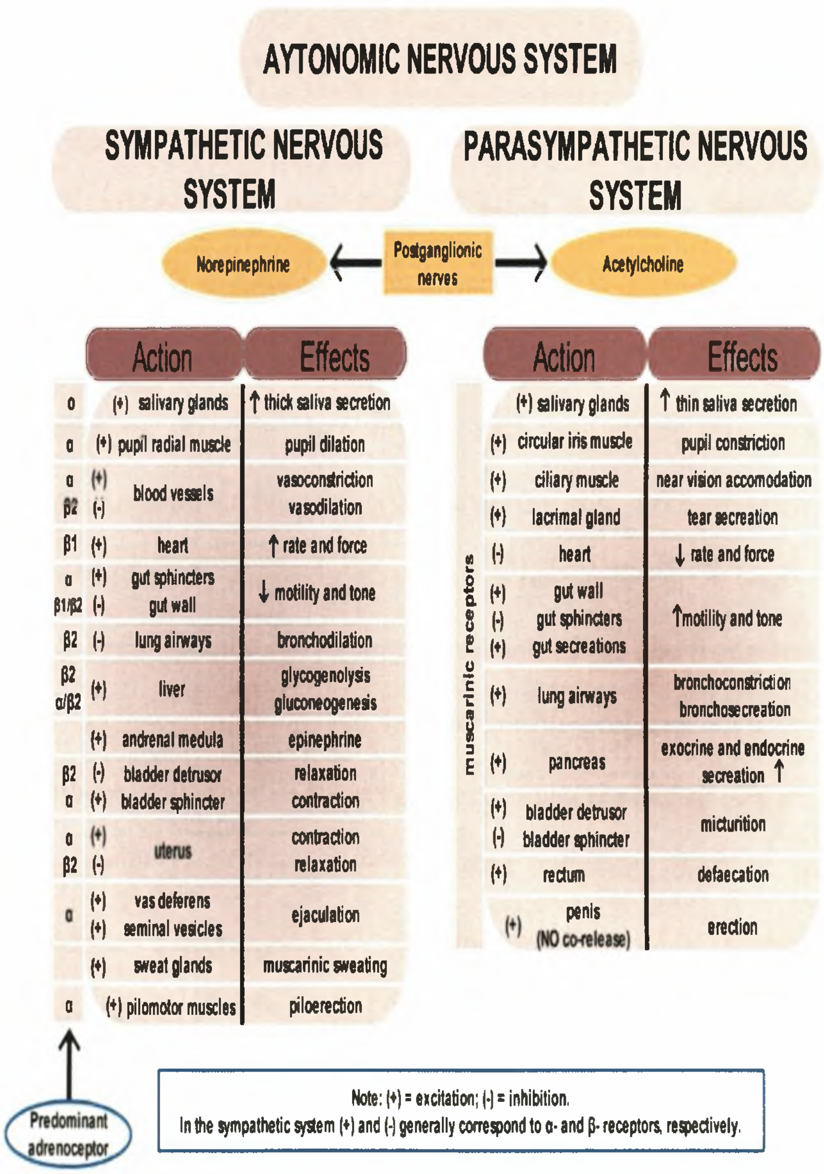
The purpose of this literature review is to examine previous physiological data regarding the validity of Polar RS800 CX on HRV indices. Furthermore, I summarize significant information on the various HRV indicators and their diagnostic significance. I hope that the information provided will be valuable not only to physicians, exercise physiologists and scientists, but also to those interested in personal or public health, politics, economics and sports. In order to achieve this, a thorough search in Pub Med was conducted using terms related to heart rate variability (HRV) and its ways of measurement both expensive and inexpensive, as well as, HRV testing on different devices.

Autonomic Nervous System

The differentiation of time between perpetual heart rate is a common prediction of HRV. (Anon 1996; Niskanen, Tarvainen et al. 2004). The autonomic nervous system (ANS) activation is based on this regulation mentioned above, affecting the motorized networking procedures of the neurons in several physiological functions of the human body (e.g., breathing stimuli, regulation of heart rate) by increasing or diminishing the neural stimuli (Kristal-Boneh, Raifel et al. 1995; Neal 2002; Niskanen, Tarvainen et al. 2004). The fluctuation of the ANS stimulation is regulated through the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) which constitute the two parts of ANS. The main regulation of sympathetic nervous system (SNS) is to increase the mechanization of certain body functions, for example the upsurge of heart pacemaker cells depolarization, in contrast, with parasympathetic nervous system (PNS) which cause hyperpolarization of cardiac pacemaker cells (Piot

O. 1997). This procedure is due to the action of epinephrine and norepinephrine secreted from the postganglionic neurons causing the effects of the sympathetic system activity and the action of acetylcholine causing the effects of the parasympathetic system activity. The actions of SNS and PNS stimulation on a variety of organs are summarized in Figure 1.

Figure 1 Autonomic nervous system and the actions of the sympathetic (SNS) and parasympathetic (PNS) sub systems stimulation on a variety of organs.



Heart Rate Variability (HRV)

HRV is considered a valid non-invasive method of electrocardiographic indication of the sympathetic and parasympathetic nervous system action in the heart. It presents the difference of the RR (NN) intervals (i.e., the time flowing between two consecutive R waves in the electrocardiogram) (Anon 1996; Niskanen, Tarvainen et al. 2004). In that way, in a healthy heart with a normal ANS, will have normal QRS variations presenting a physiological HRV. On the other hand, in a heart with a damaged myocardium, the different function of ANS will cause variable regulation resulting in a decreased HRV (van Ravenswaaij-Arts, Kollee et al. 1993). In Figure 1, it is illustrated that the SNS is a major regulator of the cardiovascular system in normal and pathological conditions and can result in higher heart rate (Sinski, Lewandowski et al. 2006). On the contrary, the action of PNS is to decrease heart rate (Neal 2002). As a result from this mechanism, SNS and PNS action is considered significant effector on the heart rate rhythm and the cardiac muscle contractive strength. At the activation of the two systems during rest, both of them should be comparable (Kristal-Boneh, Raifel et al. 1995; Acharya 2006). A huge number of major diseases are related with activation of SNS and PNS. The rising levels of SNS and the decreasing levels of PNS can lead to health problems like hypertension, diabetes, cardiovascular disease and psychological problems (Kristal-Boneh, Raifel et al. 1995; Anon 1996; Tsuji, Larson et al. 1996) indicating them as mechanisms deciphering relations of decreased HRV with increased mortality (Kleiger, Miller et al. 1987; Bigger, Fleiss et al. 1992; Tsuji, Larson et al. 1996). On the other hand, high level of physical activity, normal health state and young age are some of the results in increased PNS activation.

It is noticeable that HRV represents proof to heart problems and it is connected with cardiovascular mortality (Kleiger, Miller et al. 1987; Bigger, Fleiss et al. 1992; Anon 1996; Tsuji, Larson et al. 1996). Concerning to HRV adaptations at resting and aerobic exercise periods, it is evident that there are differences of the HRV in normal people and to people with cardiac problems (De la Cruz Torres B 2008 Sep). Further to this, general physical activity acts as a balance factor to obese people who have deteriorated levels of HRV (Felber Dietrich, Ackermann-Liebrich et al. 2008).

HRV demarcation led to the organized standards of measurement in 1996 by the Task Force of the European Society of Cardiology (ESC) and the North American Society of Pacing and Electrophysiology (NAPSE), thus, determining its clinical use and interpretation (Electrophysiology. 1996). The criteria used commonly nowadays for HRV measurement are time domain indices(Kleiger RE 1992; M. 1995), geometric measures (Cripps, Malik et al. 1991; Hnatkova, Copie et al. 1995), and frequency domain indices (Malliani, Pagani et al. 1991; Ori, Monir et al. 1992; Montano, Ruscone et al. 1994).

Indicators of HRV Analysis

The high possibility of post infarction mortality attached to low HRV levels, firstly, originated by Wolf et al. (Wolf, Varigos et al. 1978). Thus, in order to validate beat-to-beat cardiovascular control, a power spectral analysis of volatile heart rate was proposed (Akselrod, Gordon et al. 1981). The autonomic background of volatile RR interval in the heart rate record was strengthened with increased knowledge by the indicators that were discovered from these analyses (Pomeranz, Macaulay et al. 1985; Pagani, Lombardi et al. 1986). Up to date, either electrocardiography or heart rate monitors are used widespread to estimate HRV indices (Anon 1996; Gamelin, Berthoin et al. 2006; Gamelin, Baquet et al. 2008; Nunan, Jakovljevic et al. 2008; Vanderlei, Silva et al. 2008). A counting system based on an algorithm is being used to conduct HRV recording, which is linked with the autonomic nervous system stimulation separated by the SNS stimuli and the PNS stimuli. The HRV indicators are categorized between time-domain methods (measurement of time difference on successive RR intervals) and frequency-domain methods (the distribution of power (variance) as a function of frequency of the time difference between successive RR intervals).

Time-Domain Methods

Time-domain methods measure either the difference of heart rate over time or the intervals between successive normal heart circles and it is considered one of the most common form of HRV analysis (Kleiger, Stein et al. 1992; M. 1995; Electrophysiology. 1996). By utilizing a continuous ECG recording, each QRS complex is detected and the normal-to-normal (NN) intervals (i.e., intervals between adjacent QRS complexes resulting from sinus node depolarizations) or the instantaneous heart rate is determined. A number of HRV indices result from statistical or geometric analyses which are part of the time-domain methods.

Statistical Indices

Statistical time domain indices are divided either from the differences between successive NN intervals or on direct measurements of the NN intervals/instantaneous heart rate. The most frequently used statistical indices include:

1. Standard deviation of the average NN intervals [SDNN; in milliseconds (ms)] measured with a normative SDNN value of 141±39 ms over adjacent short-period recordings (Anon 1996; Niskanen, Tarvainen et al. 2004). The plain methodology used to calculate SDNN values is to separate 24-h recordings into short term 5-min monitoring periods, as SDNN is mostly influenced on the duration of monitoring period (Anon 1996). SDNN values, characterizes the PNS component of the autonomic function if all the cyclic components responsible for the variability in the period of recording are reflected and, if estimated based on 5-min recordings (Anon 1996; Karakaya, Barutcu et al. 2007).
2. SDANN, the standard deviation of the average NN intervals [SDANN; in milliseconds (ms)] estimated by short-period recordings (around 5 minutes on average) and it is driven by PNS activity (Anon 1996; Karakaya, Barutcu et al. 2007).
3. The root mean square of differences of successive NN intervals (RMSSD; in ms) with a normative value of 27±12 ms is driven primarily by PNS activation (Anon 1996; Niskanen, Tarvainen et al. 2004; Karakaya, Barutcu et al. 2007) .
4. Count number of pairs of NN intervals that differ more than 50 ms (NN50) indicating PNS activity (Anon 1996; Niskanen, Tarvainen et al. 2004).

5. The percentage value of pairs of NN intervals (pNN50%) that differ more than 50 ms characterizing the PNS component of autonomic function (Anon 1996; Niskanen, Tarvainen et al. 2004).

Geometric Methods

The geometric methods derive from the conversion of the time-domain sequences of NN intervals into a geometric pattern for example the sample density distribution of differences between adjacent NN intervals. As a consequence, geometric and/or graphic properties calculate the difference of the resulting pattern. HRV estimation is available through a variety of geometrical forms: the 24-hour histogram, the HRV triangular index and its modification, the method based on Lorentz or Poincare plots and the triangular interpolation histogram(Cripps, Malik et al. 1991; Hnatkova, Copie et al. 1995; M. 1995; Electrophysiology. 1996) Geometrical indices are a significant method which is influenced by the quality of the recorded data making accessible difficult obtainable statistical factors. As a requirement, though, the recording duration should last 30 minutes approximately, meaning that small duration recordings will not be calculated by geometric indices. The most widely used geometric indices include:

1. The integral of the sample density distribution of NN intervals divided by the maximum of the density distribution (NN triangular index) with a normative value of 37±15 ms (Anon 1996; Niskanen, Tarvainen et al. 2004). The triangular index involves all HRV indices calculated over 24 hours and indicating primarily SNS activity, however, it is also influenced by the PNS activity at a lesser extent (Anon 1996).

2. Baseline width of the minimum square difference triangular interpolation of the maximum of the sample density distribution of NN intervals. (TINN; in ms) This index involves primarily the SNS function with the affection of PNS function at a certain degree (Anon 1996).

Frequency-domain indicators

The frequency-domain analysis of HRV describes the distribution of power (variance) as a function of frequency of the time difference between adjacent NN intervals, also known as power spectral density. This analysis leads to further information about the relative intensity in the cardiac sinus rhythm derived from heart rate signal interpreted through differential frequencies and amplitudes (Malliani, Pagani et al. 1991; Ori, Monir et al. 1992; Montano, Ruscone et al. 1994; M. 1995; Electrophysiology. 1996; D.L. 1997). The methodologies of power spectral analysis can be separated in two ways: 1) a parametric method, the autoregressive model of calculation (Malliani, Pagani et al. 1991; Ori, Monir et al. 1992; Montano, Ruscone et al. 1994; M. 1995) and 2) a non-parametric method, involving distinct peaks for a variety of frequency components, the fast Fourier transformation (FFT), leading in a successive smooth spectrum of activity. The parametric method is complicated and requires verification of the suitability of the chosen model, in comparison with the FFT which is quick and plain method. The frequency-domain indices that are most widely used in a spectrum measured from short-term recordings of 2-5 minutes (Sayers 1973; Akselrod, Gordon et al. 1981; Hirsh 1981; Pagani, Lombardi et al. 1986; Malliani, Pagani et al. 1991) are:

1. Very Low Frequency (VLF) in the range of 0.0033 – 0.04 Hz. (Niskanen, Tarvainen et al. 2004; Haensel, Mills et al. 2008). The physiological

interpretation of VLF in relation to autonomic function needs further elucidation.

2. Low Frequency (LF) band in the range of 0.04—0.15 Hz is indicating mainly SNS function which is affected to a lesser extent by the PNS function (Anon 1996; Niskanen, Tarvainen et al. 2004; Felber Dietrich, Schwartz et al. 2007; Haensel, Mills et al. 2008).
3. High Frequency (HF) band in the range of 0.15—0.40 Hz is considered through respiration and seems to primarily activation of the PNS (Anon 1996; Niskanen, Tarvainen et al. 2004; Haensel, Mills et al. 2008).
4. The ratio of LF and HF frequency band powers (LF/HF), with normative values of 1.5-2.0 presenting the stability between SNs and PNS (Anon 1996; Niskanen, Tarvainen et al. 2004).
5. The total variance of all NN intervals, called total power, corresponds to the total of the overall spectral bands (i.e., 0.0—0.5 Hz) (Anon 1996; Niskanen, Tarvainen et al. 2004; Haensel, Mills et al. 2008).

It is worth mentioning that the frequency-domain methods can also be utilized to describe the sequence of NN intervals for long-time recordings (i.e. the entire 24-hour period). Results present the VLF, LF, HF parameters , in addition with, ultra-low frequency (ULF) components in values between 0 and 0.0033 Hz (Anon 1996).

Measuring HRV: Stability and Reproducibility

Several studies have presented results of rapid return to baseline after short-time measures of HRV during to the exposion of stimuli like low-intensity exercise. In contrast, more time was needed for control values during to manipulations like, high-intensity of exercise or high-duration drugs. On the other hand, it is important to note that there is lesser number of data from long-time HRV measures of 24-hour continuous monitoring. Furthermore, it is proposed that there is balance of HRV measures of 24-hour ambulatory monitoring due to the fewer data of long-term recordings, both in healthy subjects (Kleiger, Bigger et al. 1991; Van Hoogenhuyze, Weinstein et al. 1991) and in the post infarction (Kautzner, Hnatkova et al. 1995) and ventricular arrhythmia (Bigger, Fleiss et al. 1992) populations. Moreover, there is evidence proposing stability measuring HRV which may insist during months and years.

Recording Requirements

During ECG tracking of the fiducial point that introduces a QRS complex can be calculated on the determination of the maximum of an interpolating curve, on the maximum or baricentrum of the complex, or found by matching with a template or other event markers. To limit the fiducial point to a certain location, the ECG diagnostic equipment standards are good enough in cases like signal-to-noise ratio, common mode rejection, bandwidth, etc. (Bailey, Berson et al. 1990). There is a particular occasion leading to an error of the estimated RR intervals which is introduced through a jitter tracking down the QRS complex fiducial point. This jitter is created by an upper- band frequency cutoff of a lesser level than the suggested for diagnostic equipment (≈200 Hz). Moreover, there is an error in the HRV spectrum due to decrease which rises with frequency. As a result, more high-frequency components are influenced (Merri, Farden et al. 1990). It is possible to lower this error through an interpolation of the under sampled ECG signal, resulting to a suitable sampling rate even at 100-Hz, if the interpolation is correct (Bianchi, Mainardi et al. 1993). Data compression techniques must be examined thoroughly in terms of the quality of reconstruction methods and the effective sampling rate which can present amplitude and phase distortion with the utilization of solid-state storage recorders (Kennedy, Bavishi et al. 1992).

Editing of the RR Interval Sequence

The results of statistical time domain and all frequency domain indices are influenced significantly by the problems caused by the inaccurate NN interval sequence. It is still not recognized how accurate the editing should be to provide sufficient results from other methods. However, it is acceptable that simple editing of the RR interval is enough for measuring overall HRV by the geometric indices, at least. In this way, it is evident that editing RR data manually must be sequenced to a very high standard, when statistical time domain and/or frequency domain methods are utilized leading, eventually to ideal identification and classification of each QRS complex. Automatic "filters" which lead to the exclusion of a number of intervals from the first RR sequence, may not replace manual editing due to the fact that they function abnormally and to have disadvantageous effects resulting, possibly to wrong measurements (Malik, Cripps et al. 1989).

Suggestions for Standardization of Commercial Equipment

Standard measurement of HRV: Advertised HRV equipment constructed to describe short-time HRV may involve both parametric (favorable) and nonparametric spectral analysis. The analysis based on continuous sampling of the tachograms may be suggested in all situations, in order to diminish the chance of confusion derived from mentioning the components of the heart beat-based analysis in time frequency indices. Short-term recordings (5-minute recordings) can utilize 512 points with more favorable the 1024 points in nonparametric spectral analysis.

In cases of long-time recordings of HRV indices, the equipment should involve time domain methods with the four standard indices (SDNN, SDANN, RMSSD, and HRV triangular index). Furthermore, the frequency analysis should be measured in 5-minute parts by utilizing the same accuracy with short-term ECG recordings. The analysis should be measured with the same accuracy of periodogram sampling as proposed for the short-term analysis when spectral analysis of the whole nominal 24-hour measurement is executed to calculate the total range of HF, LF, VLF, and ULF indices (Electrophysiology. 1996).

Clinical use of HRV

In the past few years, the use of heart rate variability has been increased in several clinical chronic diseases, implementing diabetes (Malpas and Maling 1990), coronary artery disease (Kleiger, Miller et al. 1987; Bigger, Fleiss et al. 1992; Dekker, Crow et al. 2000), sudden cardiac death (Dougherty and Burr 1992), CHF (Ponikowski, Anker et al. 1997). Furthermore, it was used recently for monitoring patients with obstructive sleep apnea (Roche, Gaspoz et al. 1999). Moreover, further research was conducted on HRV and the effects of several pharmacological and non-pharmacological applications, including antiarrhythmic drugs (Rohde, Polanczyk et al. 1998), physical activity (Stein, Ehsani et al. 1999) and after radio-frequency ablation procedures (Dumaresq L. 1997). However, applicable instructions of HRV in clinical settings were recommended only to patients with diabetic neuropathy and myocardial infraction (Electrophysiology. 1996).

Prognostic value of HRV in CHF

Recently, it has become evident that the sympathetic nervous system is a fundamental factor in the development of heart failure (Packer 1992). The SNS may influence the cardiovascular system in different ways, implementing down-regulating b1-receptors, exposing to direct toxic effects on the myocardium and affecting myocardial remodeling and life-threatening arrhythmias. At this case, chronic heart failure patients (CHF) are a high-mortality group. HRV and ANS are correlated because of HRV dependence on ANS function and integrity resulting in influencing HRV in CHF patients. At the beginning of the disease, there is a noticeable increase in LF and a decrease in HF as a result of sympathetic stimulation and decreased vagal tone. The almost healthy sympathetic innervation in the first stages may cause sympathetic stimulation showing raised LF and leading to arrhythmogenesis and sudden death (Brunner-La Rocca, Esler et al. 2001). In further stages of chronic heart failure, it is important to note the loss of rhythmicity in the LF and HF bands. The huge reduction of LF power in advanced levels of heart failure comes second in comparison with irregular central autonomic activation and damaged sensitivity of β-adrenergic receptor (van de Borne, Montano et al. 1997; Cooley, Montano et al. 1998). In crucial stages of the disease, patients react like having cardiac denervation and loss of neural modulation of cardiac rate, similar to patients with newly transplanted hearts (Mortara, La Rovere et al. 1994). Heart rate variability may be used as an index for predicting mortality, resulting from successive LV dysfunction and sudden cardiac death, when it is used in CHF patients (Ponikowski, Anker et al. 1997; Nolan, Batin et al. 1998; Galinier, Pathak et al. 2000; Bilchick, Fetics et al. 2002; La Rovere, Pinna et al. 2003). Different studies show that an SDNN <70 ms was an independent index predicting mortality all-cause and of cardiac death (RR =2.8–3.7) (Nolan, Batin et al. 1998; Galinier, Pathak et al. 2000; Bilchick, Fetics et al. 2002). Moreover, values for LF <3.3 in ms2 (RR = 2.5) and <13 ms2 (RR = 3.7) have shown prediction for sudden cardiac death (Galinier, Pathak et al. 2000; La Rovere, Pinna et al. 2003).

HRV and Exercise Training

Exercise training may reduce the possibilities for cardiovascular mortality and sudden cardiac death (O'Connor, Buring et al. 1989). Furthermore, regular exercise is considered suitable for altering the autonomic nervous system balance (Arai, Saul et al. 1989; Furlan, Piazza et al. 1993). An experimental study planned to measure the effects of exercise training on indices of vagal activity offered new knowledge on modifications in heart electrical stability (Hull, Vanoli et al. 1994). In addition, exercise training can increase recovery of the physiological sympathovagal interaction (for example post-MI patients) (La Rovere, Mortara et al. 1992).

Heart Rate Monitors: Polar

Previous research suggests that heart monitors, such as older polar versions (e.g.S810i) which were used for measurement of heart rate indicate that polar device rate meter is able to provide consistent RR series that could be used for HRV analysis during rest and exercise (Vanderlei, Silva et al. 2008).

Literature Review Conclusions

All in all, the vast majority of published evidence suggests that measurement of HRV is a fundamental way of predicting the time between consecutive heart beats from exposion to training stimuli to clinical cases as a preventive factor of health. However, it is still considered a research method and not a clinical tool because: 1) the variability of the indices according to pharmacological interventions, chronic diseases, gender and age leading to insufficient methodology (not standardized) and resulting to restricted clinical application of HRV and 2) there is not an accepted opinion for the recommended HRV indices for clinical application, even though, it is evident the significant character of indices like SDNN and HRV. ECG stands as the gold standard way of precise prediction of HRV, even nowadays, however still expensive and inconvenient to purchase and utilize.

Recent research indicates that other heart monitors like the Polar heart rate monitor to be closely related to ECG in most heart rate indices, plus, being inexpensive and accessible to almost everyone. However, Polar models proved limited validity for some major heart rate indices, proving its lower quality in comparison with ECG. It is obvious, that, by the years accessible heart monitors like Polar will improve and achieve a more valid level. Future research should focus on new devices produced from Polar and other companies in order to validate in different conditions these new products and always in comparison with the gold standard like ECG. The same was attempted in this research for the new device of Polar RS800 CX.

METHODOLOGY

Participants

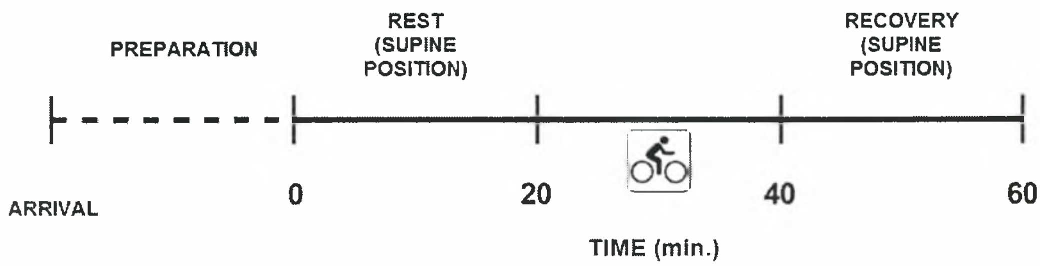
Thirty-two healthy adults (32 males: age 23.96 years, BMI 24.52 $kg/m^2 \pm 4.10$ SD) volunteered. Exclusion criteria included: smoking, women, training before the measurement evidence of cardiac or pulmonary disease, and previous disease and medications. The experimental protocol was approved by the ethical review board at the University of Thessaly.

Experimental Design

On one day, participants arrived at the laboratory (9.30 a.m.) to complete the experimental trial. They were welcomed by an investigator and were, firstly, subjected to height and weight measurements. Thereafter participants were asked to put on a Polar RS800 CX that is capable of measuring HRV indices. Furthermore, participants wore an ECG (Welch Allyn, CardioPerfect) by the investigator. The participants were asked to sit down and relax for 10 min. in order to lower their heart rate. Following this, the participants lied on a mattress on supine position for 20 min. which was the first part of the experiment. After the first part, participants were asked to perform aerobic exercise on a cycloergometer (Monark, Ergomedic) at 60% of maximal heart rate for 20 min. Maximal heart rate was calculated from Karvonnen equation [(220 – age) – rest heart rate] * 0.60 + rest heart rate. After the 20 min. of exercise, participants were asked to lie down on a mattress for another 20 min. at the recovery phase. Throughout their stay in the laboratory and to minimize influences on

HRV values, participants were instructed to remain silent and as calm as possible throughout data collection. When all participants arrived at the laboratory was instructed to refrain from strenuous physical activity and other excessive stressors. Furthermore, participants won't consume any food or caffeine before the measurement.

Figure 2: Experimental Protocol.



HRV Measurements

HRV measurements were taken using a Polar PS800CX (Polar Electro Oy, Kempele, Finland) and ECG (Welch Allyn, CardioPerfect) throughout the trials. Data collected from 0-20, 20-40, and 40-60 minutes (fig. 2) were used to derive HRV for different time points.

The heart rate monitor signal was transferred to the Polar Precision Performance Software (release 3.00; Polar Electro Oy), and R-R intervals were exported under ASCII format. Both frequency domain and time domain measures were analyzed using HRV analysis software version 1.1 (Finland: Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland 2002). The root mean square of differences of successive RR intervals (RMSSD) and the percentage value of pairs of RR intervals that differ more than 50 ms (pNN50) were studied for the time domain and the low (LF) and high (HF) frequency and their ratio (LF/HF) for the frequency domain.

Statistical Analysis

The data was analyzed, separated in three periods of (rest, exercise, recovery); the same way the experiment was conducted. The HRV indices studied were, also categorized into three sections: Time-domain indices, Frequency-domain indices and Non-linear indices. The time-domain indices studied were the mean of the RR intervals (Mean RR), the standard deviation of RR intervals (STD RR), the mean of the heart rate intervals (Mean HR), the standard deviation of the heart rate (STD HR), the root mean square of differences of successive RR intervals (RMSSD), the percentage value of pairs of RR intervals that differ more than 50 ms (pNN50) [Statistical Measures], the heart rate variability triangular index (HRV triangular index) and the (TINN) [Geometric Measures]. The frequency-domain indices that were studied were the low (LF) and the high (HF) frequency as well as the ratio of both of them (LF/HF) at the Power (n.u.). Finally, the non-linear indices studied were the SD1 and the SD2 at the Poincare plot, the mean line length (Lmean), the maximum line length (Lmax), the recurrence rate (REC), the determinism (DET), the shannon entropy (ShanEn) in the recurrence plot and the approximate entropy (ApEn), the sample entropy (SampEn), the detrended fluctuations (DFA): α1, the detrended fluctuations (DFA): α2 , the correlation dimension (D2) at the ''Other'' subsection. The statistical technique Kendall's Tau-b was used to show if the HRV indices from the ECG and the Polar RS 800CX correlate significantly in the three different periods of the experiment (rest, exercise and recovery). The Wilcoxon-signed rank test was used to assess mean differences in the HRV indices between the

ECG and the Polar RS 800CX in the three different periods of the experiment (rest, exercise and recovery). Furthermore, the 95% limits of agreement (95%LoA) and the percent coefficient of variation (CoV) were calculated for the rest, exercise and recovery periods. The statistical analysis was completed using SPSS 18.0 and the level of significance was set at $P<0.05$.

RESULTS

Rest period

During the resting period, it is presented that there is statistical significance ($p<0.05$) in most HRV indices from the correlation (Bivariate) between ECG and Polar RS 800CX (table 1), except the STDRR, the STDHR, the TINN, the SD2, the ApEn and the DFa_a2 indices. Furthermore, the mean difference (Wilcoxon signed-rank) indicates that there is not any statistical significance ($p<0.05$) between ECG and Polar RS 800CX (fig. 3). Moreover, the 95% limits of agreement (95%LoA) were -2.11±100.8 msec and the coefficient of variation (%CoV) was 52.5% for the NN index (table 2).

Table 1 Correlations (Kendall's Tau-b) between the ECG and the Polar RS 800CX for all assessed HRV indices during rest period.

	MeanRR	**RMSSD**	**TINN**	**SD1**	**REC**	**SamplEn**
Correlation	0.176*	0.238*	0.100	0.225*	0.183*	0.244*
	STDRR	**NN50**	**LF**	**SD2**	**DET**	**DFA a1**
Correlation	0.163*	0.296*	0.221*	0.060	0.178*	0.263*
	MeanHR	**pNN50**	**HF**	**Lmean**	**ShanEn**	**DFA a2**
Correlation	0.168*	0.284*	0.242*	0.168*	0.188*	0.048
	STDHR	**HRVtriagind**	**LFHF**	**Lmax**	**ApEn**	**D2**
Correlation	0.061	0.191*	0.248*	0.255*	0.158	0.193*

* = $p<0.05$

Fig. 3 HRV indices (Wilcoxon signed-rank) at rest period graph 1.

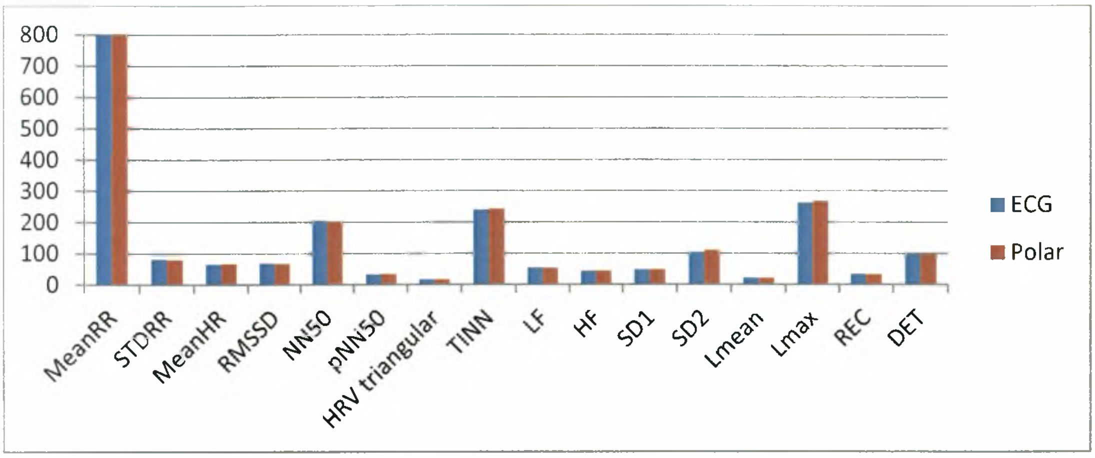


Fig. 4 HRV indices Wilcoxon signed-rank at rest period graph 2.

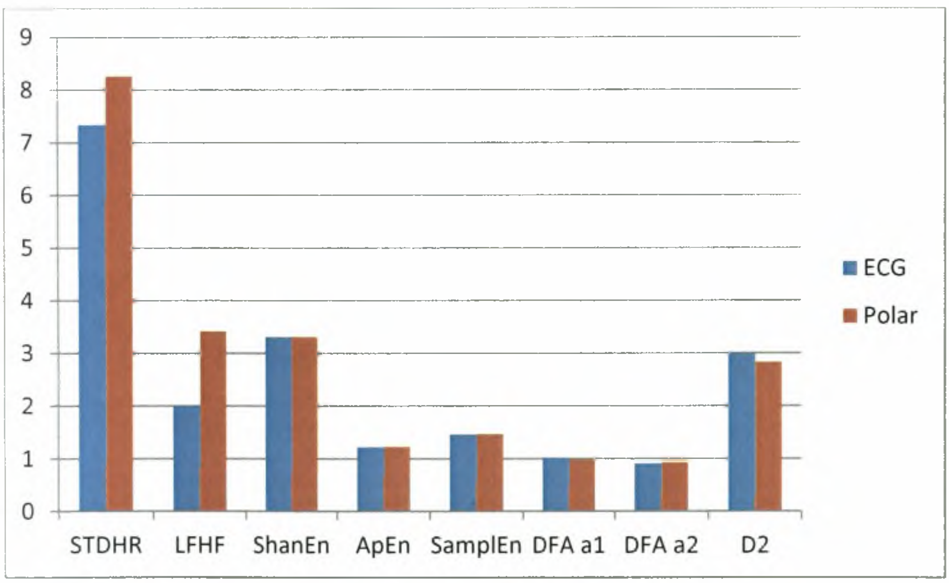


Table 2 95%LoA and CoV between the ECG and the Polar RS 800CX for all assessed HRV indices during rest period.

	MeanRR	STDRR	MeanHR	STDHR
95%LoA	-9.8± 287.9	2.5±69.6	-0.13± 27.2	-1.03± 18.5
CoV	23.3%	43.8%	20.1%	121.8%
	RMSSD	**pNN50**	**LF**	**HF**
95%LoA	2.1±88.3	-0.6±52	-0.2±44.4	1.53±4.82
CoV	66%	78.6 %	41.7 %	49.6%
	LFHF	**SamplEn**	**DFA a1**	**DFA a2**
95%LoA	-1.46± 25.2	-0.00± 0.7	0.0±0.6	-0.0±0.6
CoV	478.5%	25%	29.3%	33.3 %

Exercise Period

During the exercise period, it was observed that there was not statistical significance ($p<0.05$) in most of the HRV indices from the correlation (Bivariate) between ECG and Polar RS 800CX (table 3). In addition, the mean difference (Wilcoxon signed-rank) graph (fig. 4) illustrates that there is a statistical significance ($p<0.05$) in most of the HRV indices between ECG and Polar RS 800CX, except the STDHR, the LF, the HF, the LF/HF, the Lmean, the Lmax, the REC, the DET, the ShanEn, the ApEn and the SamplEn indices. Furthermore, the 95%LoA was -73.31±155 msec and the %CoV was 70.5% for the NN index (table 4).

Table 3 Correlations (Kendall's Tau-b) between the ECG and the Polar RS 800CX for all assessed HRV indices during exercise period.

	MeanRR	**RMSSD**	**TINN**	**SD1**	**REC**	**SamplEn**
Correlation	0.295*	0.033	0.065	0.031	0.071	0.014
	STDRR	**NN50**	**LF**	**SD2**	**DET**	**DFA a1**
Correlation	0.016	0.008	0.038	0.168	0.044	0.114
	MeanHR	**pNN50**	**HF**	**Lmean**	**ShanEn**	**DFA a2**
Correlation	0.288*	0.017	0.038	0.058	0.135	0.016
	STDHR	**HRVtriagind**	**LFHF**	**Lmax**	**ApEn**	**D2**
Correlation	0.011	0.359*	0.040	0.038	0.025	0.391*

* = $p<0.05$

Fig. 5 HRV indices (Wilcoxon signed-rank) at exercise period graph 1.

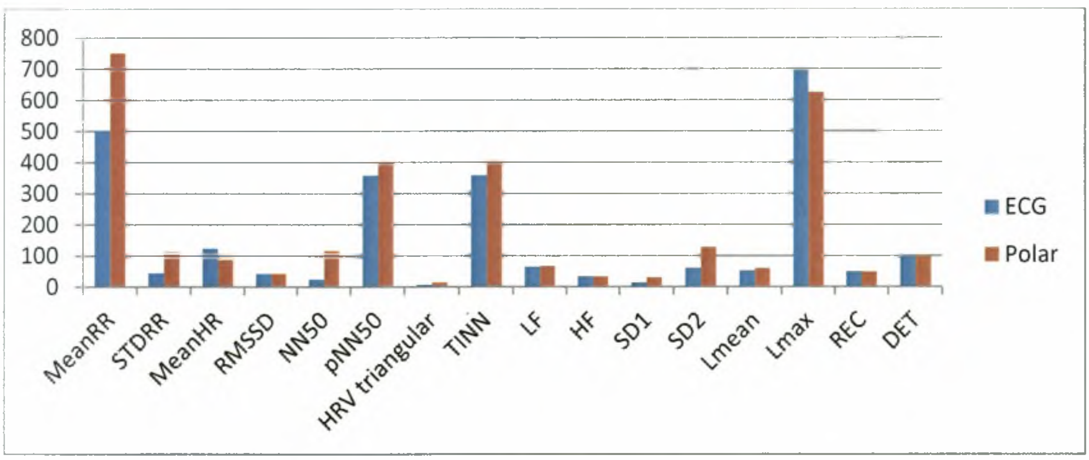


Fig. 6 HRV indices Wilcoxon signed-rank at exercise period graph 2.

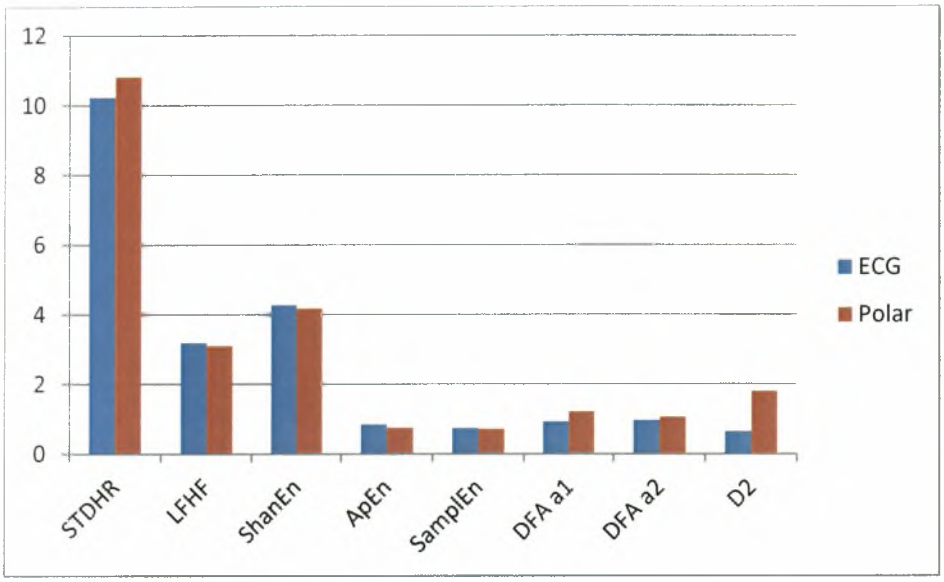


Table 4 95%LoA and CoV between the ECG and the Polar RS 800CX for all assessed HRV indices during exercise period.

	MeanRR	**STDRR**	**MeanHR**	**STDHR**
95%LoA	-251.3± 372.8	-63± 146.4	23.5± 85	-2.5± 15.9
CoV	56.7%	93.9%	51%	80.4%
	RMSSD	**pNN50**	**LF**	**HF**
95%LoA	-23.9± 67.3	-16± 37.2	-4.2±56	-1± 51.6
CoV	107.8%	184.5 %	42.9 %	78.5%
	LFHF	**SamplEn**	**DFA a1**	**DFA a2**
95%LoA	0.2± 6.9	-0.0± 1.42	-0.3±1	-0.0±0.7
CoV	112.8%	99.6%	48.3%	36.2 %

Recovery Period

In the recovery period, there was not any observed statistical significance ($p<0.05$) from the correlation (Bivariate) between ECG and Polar RS 800CX (table 5). Moreover, the mean difference (Wilcoxon signed-rank) graph (fig. 5) shows that there is a statistical significance ($p<0.05$) in most of the HRV indices between ECG and Polar RS 800CX, except, the STDRR, the STDHR, the TINN, the SD2 indices. Finally, the 95%LoA was 60.9±119.1 msec and the %CoV was 62.8 % for the NN index (table 6).

Table 5 Correlations (Kendall's Tau-b) between the ECG and the Polar RS 800CX for all assessed HRV indices during rest period.

	MeanRR	**RMSSD**	**TINN**	**SD1**	**REC**	**SamplEn**
Correlation	0.141	0.147	0.090	0.189	0.152	0.002
	STDRR	**NN50**	**LF**	**SD2**	**DET**	**DFA a1**
Correlation	0.057	0.209*	0.074	0.025	0.097	0.037
	MeanHR	**pNN50**	**HF**	**Lmean**	**ShanEn**	**DFA a2**
Correlation	0.119	0.227*	0.074	0.107	0.104	0.163*
	STDHR	**HRVtriagind**	**LFHF**	**Lmax**	**ApEn**	**D2**
Correlation	0.072	0.133	0.076	0.123	0.020	0.090

* = $p<0.05$

Fig. 7 HRV indices (Wilcoxon signed-rank) at recovery period graph 1.

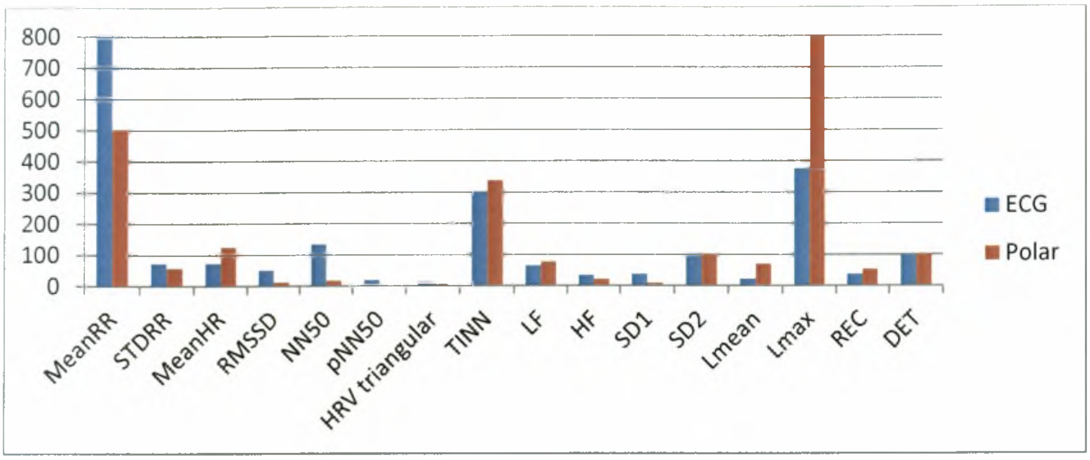


Fig. 8 HRV indices Wilcoxon signed-rank at recovery period graph 2.

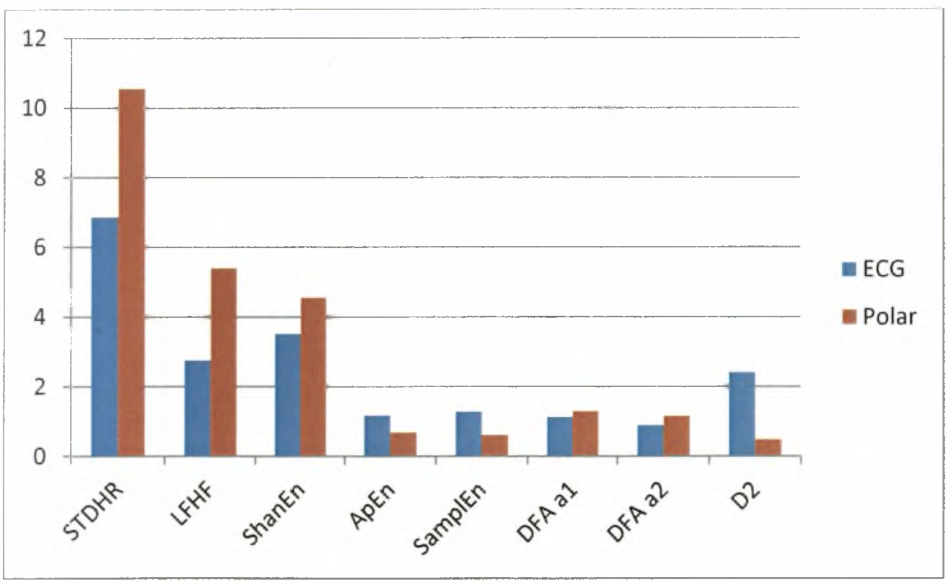


Table 6 95%LoA and CoV between the ECG and the Polar RS 800CX for all assessed HRV indices during recovery period.

	MeanRR	**STDRR**	**MeanHR**	**STDHR**
95%LoA	287.9± 297.1	13.6± 119.2	-54.1± 43.3	-3.7± 17.1
CoV	31.4%	92.2%	22%	105.7%
	RMSSD	**pNN50**	**LF**	**HF**
95%LoA	-38.6± 82.7	14.5± 35.4	-12.3±39	12.3± 39
CoV	130.2%	168.5 %	27.6 %	70.4%
	LFHF	**SamplEn**	**DFA a1**	**DFA a2**
95%LoA	-2.9± 8.9	-0.6± 1.17	-0.1±0.7	-0.2±0.46
CoV	108.1%	63.3%	28.8%	23 %

DISCUSSION

The purpose of this study was to examine the validity of Polar RS800 CX during rest, exercise and recovery. This experiment is the first to use exercise on humans during the measurement in order to examine also the validity of the Polar RS800 CX under the stress (exercise) stimulus, besides, the resting and the recovery periods. The results provide new knowledge, showing that the Polar RS800 CX during resting periods is a valid tool. However, during exercise and recovery periods, it seems that there are significant differences in several HRV indices between the ECG and the Polar RS800 CX, indicating that it is not ideal for utilization during exercise and recovery periods. Those findings represent that there is a contrast between the Polar RS800 CX and its previous models (i.e. S810i) because when older models were utilized, showed that they were valid and could measure HRV indices like other heart rate monitors (Vanderlei, Silva et al. 2008).

Further research, indicated that older versions of polar (Polar 810s) are in good terms with other gold standard heart rate monitors with a very small percentage of inaccuracy during exercise (at spectral analysis of RR interval data) (Kingsley, Lewis et al. 2005). Moreover, Polar 810s proved to be quantum of HRV measurement during rest periods, except from some short-time variability indices during measurement at standing position (Gamelin, Berthoin et al. 2006). In addition, other research suggest that Polar 810s is recommended as a valid and cost-effective tool for HRV analysis at resting periods in supine position for healthy people (Nunan, Jakovljevic et al. 2008), even for children (Gamelin, Baquet et al. 2008). However, even though, Polar S810 is suggested for measuring HRV at resting periods, some researchers argue that it should be only used for short-periods of time (Nunan, Donovan et al. 2009).

HRV analysis with Polar RS 800CX studied on dogs during normal heart rate periods, presented that Polar RS 800CX is a valid tool compared with the ECG (Essner, Sjostrom et al. 2013). However, when Polar RS 800CX was used on humans at rest, its accuracy was satisfactory for men and limited for women, especially of older age (60 yrs.) because of the tendency of Polar to falsely estimate higher HRV indices, compared to ECG (Quintana, Heathers et al. 2012; Wallen, Hasson et al. 2012). Furthermore, another study showed that Polar RS 800CX is associated with problems of technical nature and the most prevalent of them is its battery limitation, supplemented with discomfort and irritation problems (Dias, Fisterer et al. 2009).

It is important to note that the measurements were conducted only to men who mean that there could be different results in women as presented in previous studies (Quintana, Heathers et al. 2012; Wallen, Hasson et al. 2012). Furthermore, there is a possibility that the elastic band of the Polar RS800 CX with the ECG electrodes could cause interference like irritation and discomfort (Dias, Fisterer et al. 2009). Moreover, during exercise periods, when the subjects sweat, some electrode pads were sliding from the chest of the subject causing some problems during the measurement.

To conclude, the results represent data that Polar RS800 CX is a valid tool for resting periods; however, it is not considered a reliable and valid tool during exercise and recovery periods for measuring HRV.

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