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The Effect of Psychoemotional Load on Ventricular Repolarization Reflected in Integral Body Surface Potential Maps

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Summary

The aim of the present study was to investigate the reflection of psychoemotional stress in the body surface potential distribution as documented by isointegral maps of cardiac activation and recovery. In 72 young men (18.3 ± 7.3 y.) with no cardiovascular history body surface potential maps (BSPMs) at rest and during the test of mental arithmetic were recorded. The digitalized data for each point of the QRS, STT and QRST integral maps, for each subject in both situations, were processed and evaluated by methods of univariate as well as spatial mathematical and statistical modeling. The results showed during MA a significant decrease of repolarization integral values over the sternum and right precordium, which contributed to analogically localized decrements also in the QRST BSM. The decrease occurred in more than 2/3 of lead points. The most pronounced changes were observed in the right precordial area, where potentials decreased in more than in 70 % of subjects. In conclusion, the discriminative power of the difference STT and QRST integral maps was strong enough to distinguish the mental arithmetic induced changes in the superficial cardiac electric field. These adrenergic transient alterations in ventricular recovery may be of importance in subjects at risk for ventricular arrhythmias.

Key words
Electrocardiology • Depolarization • Repolarization • Body surface potential map • Mental arithmetic stress test

Introduction

Numerous experimental studies have demonstrated that minimal local changes of the myocardial action potential pattern can significantly alter the amplitude, duration and polarity of the T wave, with negligible, if any changes in the QRS complex (Surawicz 1972). T wave may be considered as "some kind of a special detector for differences in repolarization of the various parts of the ventricles" (Schaefer and Haas 1962). Excluding structural myocardial abnormalities as well as irregularities in myocardial perfusion, "primary"

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functional changes of ventricular repolarization may be produced in normal persons by a variety of physiological situations involving autonomic cardiovascular control. These transient alterations in ventricular recovery are of importance namely in subjects at risk for ventricular arrhythmias.

Electrophysiological parameters characterizing ventricular repolarization have repeatedly been shown to carry information on the direct effect of sympathetic activation on the ventricular myocardium (Ruttkay-Nedecký 2001) - in particular due to psychoemotional stress induced by mental arithmetic, active coping tasks to aversive stimuli, smoking, head-up tilting, prehypertension and hypertension, to adrenergic agonists, or to the opposite effect of beta-receptor antagonists (Andrásyová *et al.* 2001, 2002, Contrada *et al*. 1989, Dilaveris *et al.* 2000, 2001, Heslegrave *et al.* 1979, Kellerová *et al.* 1984, 1991, 1999, Kellerová and Regecová 2005, Rau 1991, Regecová *et al.* 2000, 2003, Ruttkay-Nedecký 1978a,b).

In the earlier studies the pattern of ventricular repolarization was evaluated by changes in T-wave shape and amplitude (Guazzi *et al.* 1978, Heslegrave *et al.* 1979). To enable the quantitative evaluation of the functional changes in repolarization, the maximal spatial T-vector was proposed as a convenient parameter (Rutkay-Nedecký 1978a).

In the last time increasing attention has been devoted to the study of the information content of the repolarization body surface potential maps (BSPM), in order to gain from different types of these maps more detailed information on the time and space related electrophysiological processes in the heart and on their physiological changes. Several papers offer basic data on ventricular recovery properties recorded in BSPM in normal subjects (Green *et al.* 1985, Kozmann *et al*. 1998, Montague *et al.* 1981*,* Ruttkay-Nedecký and Regecová 2002, Slavíček *et al*. 2001). However, only a few have dealt with the study of changing BSPM pattern of ventricular repolarization due to the variations in sympathetic drive of ventricles in subjects with no cardiovascular symptomatology (Pišvejcová *et al*. 2002, Ruttkay-Nedecký *et al.* 2002, Slavíček *et al.* 1998, Žďárská *et al.* 2006).

The aim of the present study was to investigate the reflection of psychoemotional stress in the body surface potential distribution as documented by isointegral maps of cardiac activation and recovery.

Methods

In the study participated 72 boys and men aged 18.3 ± 7.3 (SD) years, with no history of cardiovascular diseases and with normal ECG and VCG. The PC based electrocardiographic system CARDIAG 128.1 (METE, Prague, Czech Republic) was used to record and partly process the electrocardiographic parameters – standard 12 lead ECGs, Frank lead system VCGs and body surface potential maps (BSPM) related to the Wilson's central terminal potential. The 80 electrode sites for body surface mapping formed a regular grid of 5 rows and 16 columns, extending from jugulum to the lower border of thoracic cage. The application of electrodes in regard to the chest anatomy was following – the 1st column corresponded to the right midaxillary line, 5th column to the sternum, 9th to the left midaxillary line and the 13th to the spinal column.

Two recordings inclusive of blood pressure measurement were performed in sitting subjects – first at rest at the end of normal expiration, the second during the test of mental arithmetic (MA). The investigation conformed with the principles outlined in the Declaration of Helsinki and was approved by the Institutional Ethic Committee.

The digitalized data for each point of the QRS, STT and QRST integral maps, for each subject in both situations, as well as MA – rest difference maps (mean d) and maps of incidence of negative difference values (IN d %), were processed and evaluated by methods of univariate and spatial (multivariate) mathematical and statistical modeling (see Appendix).

Results

During the test of mental arithmetic, the BP increased in the average by 10±1.5 / 8±1 mm Hg, heart rate by 14±2 beats/min (shortening of R-R intervals by 102 ± 19 ms) and QTc interval was prolonged by 17 ± 4 ms (all significant at $p<0.001$).

The average isointegral QRS, STT and QRST maps at rest and their respective standard deviation maps are shown in Fig.1. The pattern of all integral maps is dipolar, with negative values over the right superior anterior torso and right shoulder and positivity over the left precordium. The highest within group standard deviations were found in the precordial region of positive potentials, whereby they dominated in repolarization maps, contributing to the variability of the QRST body surface map (BSM).

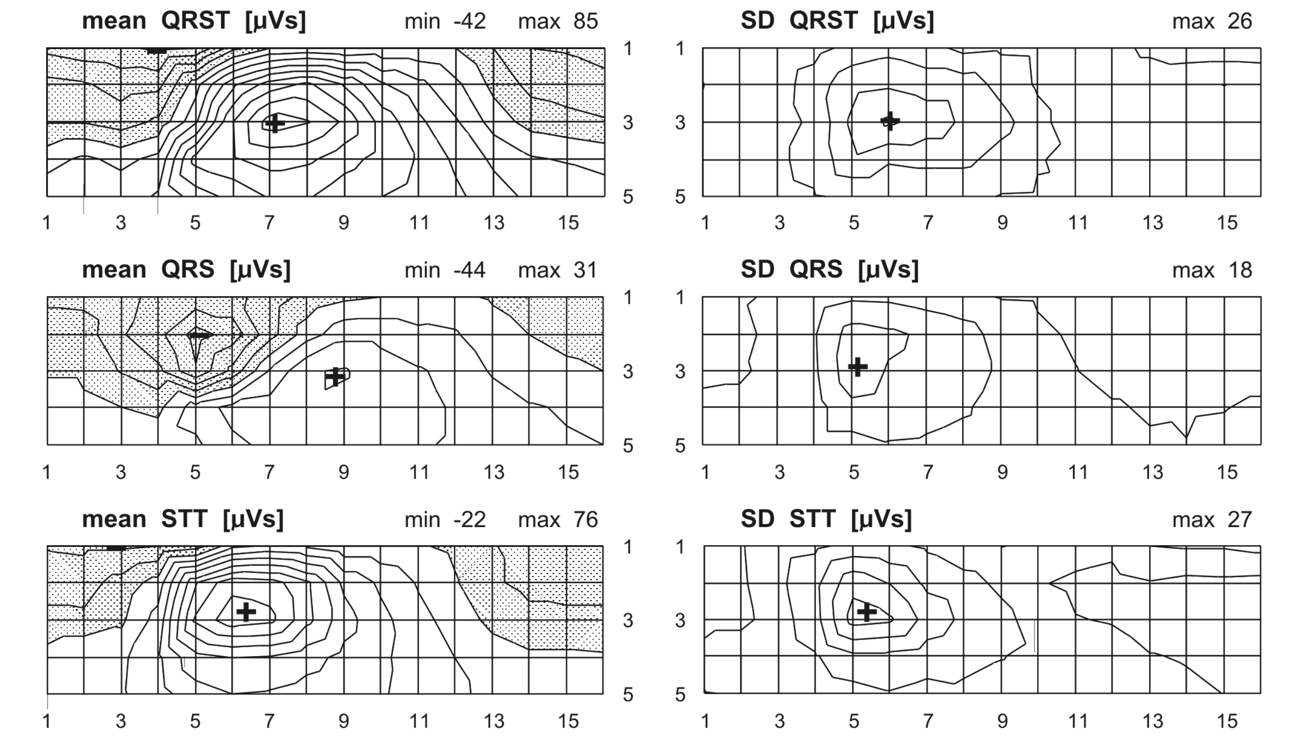

Fig. 1. Selected frames from isointegral mean QRST, QRS and STT maps compiled from all subjects at rest in sitting position and maps of their respective Windsorised standard deviations (SD). The left and right margins of the maps indicate the right midaxillary line. The 5th column represents the sternal region, the 9th the left midaxillary line and the 13th the spinal region. Contours are separated by 10µVs in the mean maps and by 5µVs in the SD maps. The dotted fields represent negative time-integral values, empty fields the positive ones. The sites of maxima / minima are indicated by + / -.

Basically, the character of the distributions on the respective integral maps remained analogical also during the test of MA, as illustrated by recordings taken from one representative subject (Fig. 2). However, as it is visible and quantified on the difference maps, there was a significant decrease of the integral values in all lead points of the QRST and STT maps and in 90 % points of the QRS BSM.

The average maps of differences affected by MA in respective integral values, in each lead point (Fig.3 A) show, that due to the stress-test, there was a highly significant decrease of repolarization integral values (mean d STT) over the sternum and right precordium, which contributed to analogically localized decrements also in the QRST BSM. The decrease occurred in more than 2/3 of lead points (IN maps – shaded areas), with prevailing incidence of negative d-values (Fig 3 B).

Discussion

This study intended to define in clinically normal sample of subjects, the range of integral BSMs of ventricular depolarization and repolarization and to provide their quantitative and statistical comparison in two physiological situations – at rest and during a mental arithmetic stress test. The central autonomic pattern of cardiovascular reactions to forced mental arithmetic test can be traced by the psychogenic heart rate, cardiac output and blood pressure increases (Brod *et al.* 1959) and an increased regional sympathetic discharge (Delius *et al.* 1971). Alterations of the ventricular repolarization during mental stimuli, concomitant with the enhancement in myocardial contractility, were suggested to be associated with, and possibly a consequence of the adrenergic activation (Guazzi *et al.* 1978). The finding that beta blockade prevented the task induced T-wave amplitude reduction, confirmed its beta-adrenergic origin (Rau 1991).

The significant increase of BP, shortening of R-R intervals and prolongation of QTc in the test situation documented that in our subjects the appropriate defense reaction was turned on.

In this study time integrals of body surface ECGs have been computed and isointegral contour maps constructed for the QRS, STT and QRST intervals, for each of the subjects in both experimental situations (rest, MA test). From the individual data corresponding mean BSMs (mean), isocontour maps of Windsorised standard

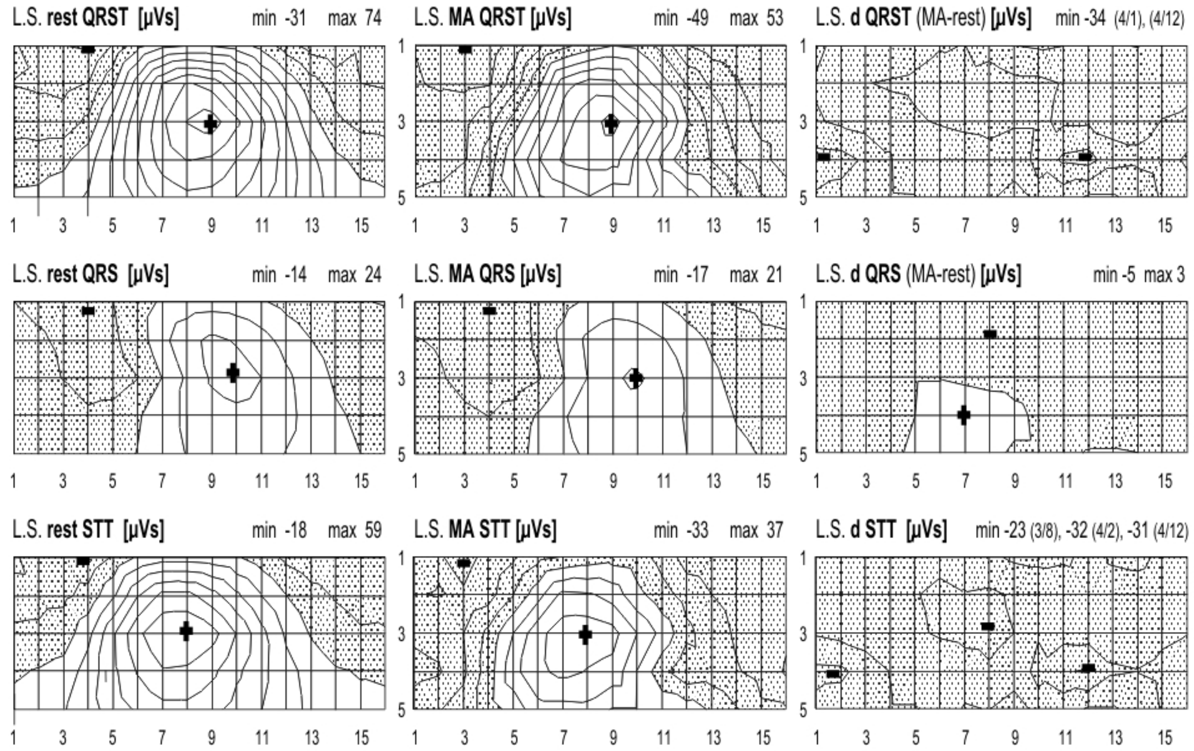

Fig. 2. Representative individual isointegral QRST, QRS, STT and difference (d) maps taken from the subject L.S. at rest and during MA. Contours are separated by 10μVs in all maps. The dotted fields represent negative time-integral values, empty fields the positive ones. The sites of maxima / minima are indicated by + / -.

deviations (SD), maps of the mean potential-time integral reactive changes at each lead point and of their significance (mean d) and maps of the incidence of the respective integral values fall or rise at each lead (IN d %) were constructed. For the evaluation of the size and torso location of surface areas of difference (MA test vs. rest) and of their significance, individual subtraction maps were used, i.e. each subject as his own control. This enabled quantitation of individual differences that deviate from the mean and for the future may be used for correlation with changes in other cardiovascular parameters.

The spatial and quantitative character of our depolarization and repolarization time-integral BSMs at rest is concordant with previous reports for clinically normal males (Montague *et al.* 1981, Kozmann *et al.* 1998, Slavíček *et al.* 2001)

The cardiovascular response to the forced MA was accompanied by a marked negativization of the integral BSM values in the whole ECG cycle, at more than 2/3 of the leads, mainly on the inferior torso and precordium – or even in all of them, as illustrated by the individual case. These changes in the time integral pattern during the mental-arithmetic test, were spatially and quantitatively most pronounced in the repolarization phase and contributed mainly to the changes of the QRST integrals, as indicated by the respective significances. This is in agreement with previous VCG studies documenting a significant diminution of the maximal spatial T-vector (Ruttkay-Nedecký 1978a,b) or a reduction in T-wave amplitude (Heslegrave *et al.* 1979, Rau 1991) during this active mental task in healthy subjects. This type of response was observed in 67 % of subjects of the present study. Analogical proportion was published also by Ruttkay-Nedecký (1978a).

We have not found any but one report using BSM to study the effect of mental stress on cardiac electric field parameters. As it referred the postinfarction patients, there was a remark supporting our results – a description of a small negative antero-superior area in the difference integral repolarization map, due to MA – test in healthy controls, only between the lines (Bosimini *et al*. 1991).

Analogical changes in some depolarization and repolarization BSM parameters, probably due to the augmented sympathetic nervous activity, were described in patients, with no cardiovascular diseases, but suffering from panic disorder (Pišvejcová *et al.* 2002), diabetes mellitus type-1 (Žďárská *et al.* 2006) or treated by antidepressant drugs (Slavíček *et al.* 1998).

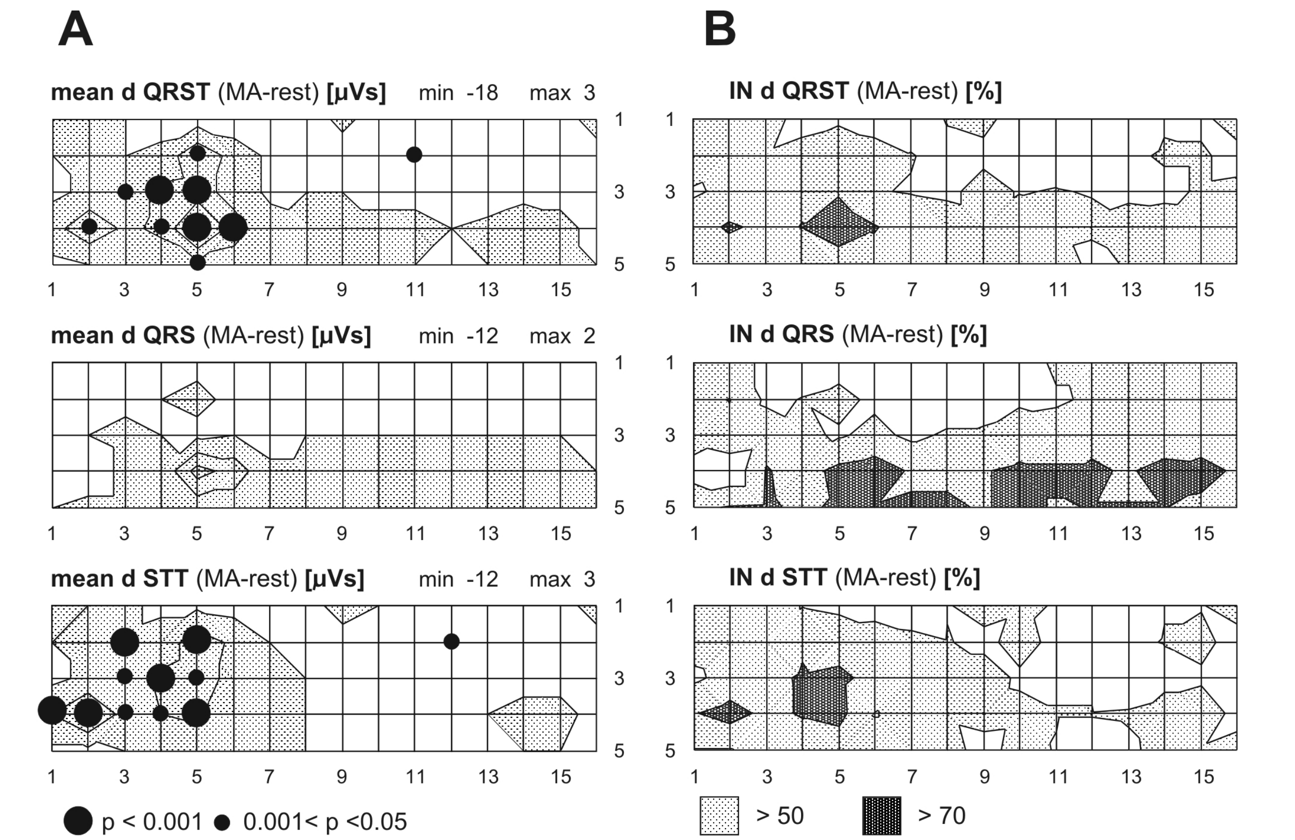

Fig. 3. Panel A - Maps of mean paired differences in integral QRST, QRS and STT values, during the test of MA vs. rest. Contours of differences are separated by 5 μVs. The level of significance of the reactive changes is indicated by differently sized black markers. Panel B - Maps of incidence of decreases in respective QRST, QRS and STT integral values due to mental arithmetic test. Dark areas indicate localities where integral values decreased in more than in 70 % of subjects. Textured fields indicate localities with decreases in more than 50 % up to 70 % of subjects.

In conclusion the discriminative power of the difference STT and QRST integral maps was strong enough to distinguish the mental arithmetic-induced changes in the superficial cardiac electric field, in spite of the large variability of the integral values at rest, found mainly in the precordial leads.

Multiple parameter correlative analysis of data is in preparation to elucidate factors affecting the interindividual variability responsible for differences that deviate the individual reactive changes in BSM pattern from the mean.

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Appendix

Methods of univariate and spatial (multivariate) mathematical and statistical modeling of chest surface isointegral cardiac maps were used. Maps ($\boldsymbol{M}_{i\bullet}$; $i = 1, 2, \ldots, n$; $\bullet$ = *QRST, QRS, STT*), where $(\boldsymbol{M}_{i\bullet})_{jk} = m_{i\bullet jk} = (x_{ijk}, y_{ijk}, z_{i\bullet jk})$ are points in R^3, $i = 1, 2, \ldots, n$, are statistical units, the coordinates (x_{ijk}, y_{ijk}) in R^2 signify fixed position of electrodes distributed regularly over the chest in *5* rows and *16* columns ($80 = 5 \times 16$, $j = 1, 2, \ldots, 5$, $k = 1, 2, \ldots, 16$). The coordinates z_{ijk} were recorded in the following physiological situations: seated position of person in mid respiration and mental arithmetic. In all statistical tests is $\alpha = 0.1$.

In the univariate part (separately for each z_{ijk} without relations with other points), we calculated univariate mean-map $\boldsymbol{M}_{\mu\bullet}$, *p*-quantile-maps $\boldsymbol{M}_{p\bullet}$, $p = \{0.05, 0.25, 0.5, 0.75, 0.95\}$, Winsorised covariance matrix $\boldsymbol{S}_{M\bullet}$ with *10 %* trimming (because of existence of both-side outliers). We paid special attention to the distribution of $min(z_i)$ and $max(z_i)$, $i = 1, 2, \ldots, n$, where $min(z_i)$ and $max(z_i)$ were *10%* trimmed minimum and maximum of z_{ijk} in each particular map $\boldsymbol{M}_{i\bullet}$ with trimmed means and Winsorised standard deviations $\mu_{z,min}$, $\mu_{z,max}$, $\sigma_{z,min}$ and $\sigma_{z,max}$.

In univariate part testing, we focused on 1) bootstrap Yuen-Welch (YW) test and bootstrap YW *(1 - α)%* confidence intervals (*CI*) for testing trimmed minimum and maximum mean difference ($\mu_{z,min,1}$ - $\mu_{z,min,2}$ and $\mu_{z,max,1}$ - $\mu_{z,max,2}$) between two physiological situations and 2) bootstrap Wilcox test of ratio of Winsorised standard deviations of maximum and minimum between two physiological situations $\sigma_{z,min,1}$ - $\sigma_{z,min,2}$ and $\sigma_{z,max,1}$ - $\sigma_{z,max,2}$ (Wilcox 2005).

In multivariate part testing, we focused on bootstrap YW test and bootstrap YW (*1 - α)%* CI for testing μ_{jk} difference in two physiological situations, e.g. seated position of person in mid respiration and mental arithmetic, where significance was calculated according to Benjamini and Hochberg (1995), where significance levels $\alpha_i = \alpha(i/80)$, where $i = 1, 2, ..., 80$, so if $p\text{-}value_{(i)} < \alpha_i$, than the particular hypothesis was rejected (where *(i)* means order of particular *p-value*).

In spatial modeling, spatial penalized nonparametric regression model built up on plastic splines on total variation penalty was used (Katina 2004, Katina and Mizera 2004, Koenker *et al.* 2004).

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