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ORIGINAL ARTICLE

Instantaneous changes in heart rate regulation due to mental load in simulated office work

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Abstract The cardiac regulation effects of a mental task added to regular office work are described. More insight into the time evolution during the different tasks is created by using time–frequency analysis (TFA). Continuous wavelet transformation was applied to create time series of instantaneous power and frequency in specified frequency bands (LF 0.04–0.15 Hz; HF 0.15–0.4 Hz), in addition to the traditional linear heart rate variability (HRV) parameters. In a laboratory environment, 43 subjects underwent a protocol with three active conditions: a clicking task with low mental load and a clicking task with high mental load (mental arithmetic) performed twice, each followed by a rest condition. The heart rate and measures related to vagal modulation could differentiate the active conditions from the rest condition, meaning that HRV is sensitive to any change in mental or physical state. Differences between physical and mental stress were observed and a higher load in the combined task was observed. Mental stress decreased HF power and caused a shift toward a higher instantaneous frequency in the HF band. TFA revealed habituation to the mental load within the task (after 3 min) and between the two tasks with mental load. In conclusion, the use of TFA in this type of analysis is important as it reveals extra information. The addition of a mental load to a physical task elicited further effect on HRV parameters related to autonomic cardiac modulation.

Keywords Heart rate variability (HRV) · Mental load · Physical load · Time–frequency analysis · Continuous wavelet transform

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Introduction

Job stress is a huge problem in today's society since 40–50% of all work-related absences are related to stress. This problem leads to losses of 0.5–2% of GNP per year. The problem has been noted by the European Commission (2004). Several studies have shown a link between the level of work stress and disease (Lundberg and Frankenhaeuser 1980; Johnson and Hall 1988; McEwen and Stellar 1993; Van Praag 2002; Kivimaki et al. 2002). Stress induces a number of physiological reactions, known as the fight or flight reactions (Taylor 2000), which are hormonal, neurological, cardiovascular, metabolic and muscular (Krantz et al. 2004). A chronic exposure to stressors can lead to an overload and consequently exhaustion of these physiological systems. This study focuses on changes in the cardiac regulation system induced by job stress in a simulated office environment.

When a person is exposed to a stressor, the sympathetic system of the autonomic nervous system (ANS) becomes more activated (Van Praag 2002). Once this stressor disappears, the vagal system decreases among others the heart

and breathing rate. Heart rate variability (HRV) refers to alterations in heart beat time intervals and provides quantitative markers of autonomic regulation (Akselrod et al. 1981; Task Force of the European Society 1996). HRV is therefore often used to examine the response of the ANS to mental and physical demands. Several studies have shown that physical tasks (Pagani et al. 1991; Perini et al. 2000; González-Camarena et al. 2000) influence HRV indices related to ANS. Mental stress in laboratory experiments (cognitive demands, mental arithmetic) has been associated with decreased HRV, indicating a disturbed ANS (Myrtek et al. 1996; Sloan et al. 1994; Mezzacappa et al. 2001). Many studies only focus on either physical or mental load, but only a few consider both (Garde et al. 2002; Hjortskov et al. 2004).

Time–frequency analysis (TFA) is a new trend in HRV analysis. The traditional frequency domain features (Task Force of the European Society 1996) are calculated in a predefined time window, hiding possible transients during this period, while TFA provides continuous time information in the response of several frequency HRV measures, enabling instantaneous information during mental tasks or transitions between several tasks.

In this study, the cardiac regulation effects of a mental task added to regular office work are described. The relative contribution of mental and physical stress on HRV is still not clear, but our hypothesis is that there is an additional effect of mental stress on a physical office task. To increase insight into the time evolution during the different tasks, time–frequency analysis is used, which is, to our knowledge, rarely used in this type of research. The combined physical and mental task was executed twice to investigate whether the potential effect remained the same even if one was already familiar with the mental stressor.

After describing the data and the HRV methods, results are given for every time and frequency HRV parameter separately next to the time–frequency analysis of the data. We then discuss these results by focusing on the differences in HRV characteristics between rest and activity (physical task and twice the physical task in combination with the mental task), as well as mutually between the active tasks to describe the influence of the mental load.

Methods

Participants

A total of 43 undergraduates, students and young people working at the Katholieke Universiteit Leuven participated in the study [21 men and 22 women, with a mean age of 20.25 (±1.78)]. Participants were individually invited to an experiment studying physiological effects of mental arithmetic. Upon arrival, the participants were informed on the course of the experiment and signed the informed consent. The experiment was approved by the Ethics Committees of the Department of Psychology and of the Faculty of Medical Science. The study was in accordance with the Declaration of Helsinki (2008).

Instrumentation

The participants were prepared for the measurements. The hair on the left chest was removed if appropriate and the skin was cleaned. Pre-gelled electrodes (Ag–AgCl, 10 mm diameter, Nikomed, Denmark) were placed on the body to measure the electrocardiogram (ECG) and the surface electromyogram (sEMG) on three parts of the M. trapezius (pars ascendens, pars traverses and pars descendens). The electrodes for the ECG were placed on the left chest on both sides of the heart and a reference electrode was positioned on the sternum. The sEMG electrodes were attached according to the surface electromyography for the non-invasive assessment of muscles (SENIAM) recommendations. sEMG signals were monitored for purposes which are beyond the scope of the text. The data were registered using sEMG amplifiers from Mega Electronics Ltd (Finland). These signals were amplified and low-pass filtered (450 Hz) and wired to an analog-to-digital converter with a cDAQ with module NI 9239 (National Instruments, Austin, TX, USA), sampled at 1,000 Hz and digitized (24 bits) before storage on a personal computer.

Protocol

In a laboratory environment, the participants were seated on an ergonomic office chair at a desk in front of a computer screen. The chair, the desk and the computer screen were individually adapted to physiology of the participant according to the ergonomic standards. The test subjects were instructed to perform three different tasks: rest (R), physical–mental task (MPT) and a physical task (PT). To be able to make a fair comparison of HRV features extracted during the different tasks, the tasks had a same duration of 6 min. One task was a rest phase. Rest involved watching a relaxing movie (‘The March of the Penguins’), exposing the participants to neutral stimuli and reducing boredom during this phase. Participants were ensured that no questions about the documentary would be asked later, so they could relax and enjoy the movie. Another phase was a mental and physical office task. The task consisted of continuous mental calculations of five operations with a two- or three digit number (e.g., 287 +24 a2 −43/3 +28), which had to be performed without verbal stimulation. Participants used the mouse cursor to indicate the correct answer while choosing between three alternatives. After

the decision, feedback of the answer was given. Participants were informed that at the end of the study, the five best performing participants would be rewarded with a movie ticket. The experimenter was seated next to the participant. MPT was considered to be stressful as task difficulty was high. Feedback, evaluation and rewards were given related to performance within time constraints and an observer was present (Gaillard and Wientjes 1994; Kelsey et al. 2000). The last task was a purely physical office task consisting of indicating the largest number of three alternatives using the mouse cursor. This task required the same motor movement as the MPT (indicating the correct answer with the cursor), but was not stressful: in contrast to the MPT, task difficulty was extremely low, no time constraints were applied and no task evaluation or reward for performance was given. The protocol consists of three active tasks: two times MPT and one time PT, each followed by a rest phase. The three active phases were fully randomized among the participants. The test started with a rest phase prior to the first active phase. The entire test lasts for 42 min.

Before the experiment started, the participants were explicitly instructed again not to speak, mumble or move their lips, to sit comfortably and not to change posture or move the body except for the dominant hand to move the mouse cursor.

Data preprocessing

The heart beats in the ECG signals were detected using the Pan Tompkins algorithm (Pan and Tompkins, 1985) that localizes the R peak in the QRS complex. This results in an RR interval time series, the tachogram. The data were preprocessed with a 20% filter to correct for erroneous detections and ectopic beats. This filter replaces every RR interval that differs more than 20% from the previous one by an interpolated value, defined via spline interpolation over the five previous and five next intervals (Kleiger et al. 1987). To overcome distortion in the HRV analysis due to non-stationarities in the tachogram, the RR time series needed to be detrended. The method based on smoothness priors to remove the trend in the data, described by Tarvainen et al. (2002), was used in this study.

Classical heart rate variability analysis

Linear HRV parameters were obtained in agreement with the standards of measurement, proposed by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996). Mean and standard deviation (SDNN) of the tachogram, the square root of the mean of squared differences between consecutive RR intervals (rMSSD) and the percentage of intervals that vary by more than 50 ms from the previous interval (pNN50) were calculated in the time domain.

For the frequency domain measures, an equally sampled time series is needed. After resampling the tachogram at 2 Hz, the power spectral density (PSD) was computed by using fast Fourier transformation. Low-frequency power (LF 0.04–0.15 Hz) and high-frequency power (HF 0.15–0.40 Hz), as well as the ratio of low- to high-frequency power (LF/HF), were calculated. In addition, the power can be expressed in absolute values (ms^2) or in normalized units (n.u.). LFnu and HFnu were calculated by dividing, respectively, LF and HF by the total power (TP 0–0.04 Hz) minus the very low-frequency power (VLF 0–0.04 Hz).

The measures described above were calculated for each condition (MPT1, MPT2, PT and R) of 6 min. The rest measures were represented as the mean value computed over the four rest periods in the protocol.

Time–frequency heart rate variability analysis

To overcome the possible non-stationarity in the data and to describe the quick changes in HRV spectra during transients, time–frequency representation (TFR) can be used. Short time Fourier transform (STFT) offers a solution by using time windows to select an epoch in the data from which the Fourier transform is calculated. By shifting the time window, a time–frequency representation is obtained. The main drawback of the STFT is the trade-off between time and frequency resolution, called the Heisenberg uncertainty principle. Therefore, this study applies the wavelet decomposition technique (Percival and Walden 2000; Kuklin et al. 2006) resulting in a good frequency resolution at the lowest frequencies and a good time resolution at the highest frequencies. A decomposition of a time signal $x(s)$ with wavelets starts from one mother wavelet, $\Psi_{t,a}(s)$, which can be shifted (time t) and dilated (scale a). The decomposition is given by the next formula, where TFR(t, a; Ψ) is the wavelet decomposition:

$$\mathrm{TFR}(t,a;\Psi) = \int_{-\infty}^{+\infty} x(s)\Psi_{t,a}(s)\,\mathrm{d}s$$

with $\Psi_{t,a}(s)$ defined as

$$\Psi_{t,a}(s) = |a|^{-1/2}\Psi\left(\frac{s-t}{a}\right)$$

$\Psi_{t,a}(s)$ is the mother wavelet and a the scales related to the frequencies 0–0.04 Hz. The Morlet wavelet is selected as the mother wavelet as literature shows that this is an appropriate function to study HRV (Clariá et al. 2008).

From this TFR, a time course of spectral parameters can be extracted. The spectral bands are chosen similarly to the task force description (1996) to enable a physiological

interpretation of the results: LF band (0.04–0.15 Hz) and HF band (0.15–0.40 Hz). The instantaneous frequency of a signal calculated as the derivative of the phase of its analytical signal often produces results that, in some ways, may seem paradoxical (Cohen 1995) and which, in any case, make their physical interpretation difficult. This drawback can be avoided by defining the instantaneous frequency as the mean frequency of the spectrum at each instant. The spectrum is obtained as a section of the time–frequency distribution at this instant:

$$f_s(t) = \frac{\sum_{n=n_b}^{n_e} f_n \, \mathrm{TFR}(t,f_n)}{\sum_{n=n_b}^{n_e} \mathrm{TFR}(t,f_n)}$$

with n_b, n_e, respectively, the beginning and end frequency of a selected frequency band and f_n the frequency representation of the scales a. The instantaneous frequency has no physiological meaning in the low-frequency band and is therefore only calculated in the high-frequency band (f_{HF}). Analogously, in the two frequency bands, the power (P_{LF}, P_{HF}) can be calculated by integrating the spectrogram, expressed in absolute values or normalized units.

$$P_s(t) = \sum_{n=n_e}^{n_b} \mathrm{TFR}^2(t,f_n)$$

Statistical analysis

Statistical analysis on the linear HRV parameters was executed using the nonparametric Friedman test adjusted for possible between-subject effects to test whether the different phases (R, PT, MPT1 and MPT2) affected the HRV parameters. Post hoc Tukey contrasts were used to explore further differences between two phases, taking into account multiple testing. $p < 0.05$ was considered statistically significant.

To statistically characterize the differences between the active phases in the time–frequency analysis, a minute-to-minute analysis was performed, analogously to Orini et al. (2010). At each time instant, the nonparametric Wilcoxon signed rank was used to find pairwise differences between two phases, resulting in a continuous estimation of the p value. The resulting time series allows assessing the time at which phases start to differ and for how long this difference is significant, as such insight into the additional effect of the mental load is revealed. $p < 0.05$ was considered to be statistically significant.

Results

Figure 1a shows a typical tachogram of an individual during execution of the protocol. The non-stationarity of the tachogram is clearly visible and the effect of detrending is shown in Fig. 1b. The different conditions, four rest conditions (indicated with R) and three active conditions, are indicated in the figure: one physical clicking task (PT) and two clicking tasks in combination with the mental arithmetic task. Visual inspection of the tachogram shows a clear transition between the active and the following rest condition. The time series also reveals a reduced variability

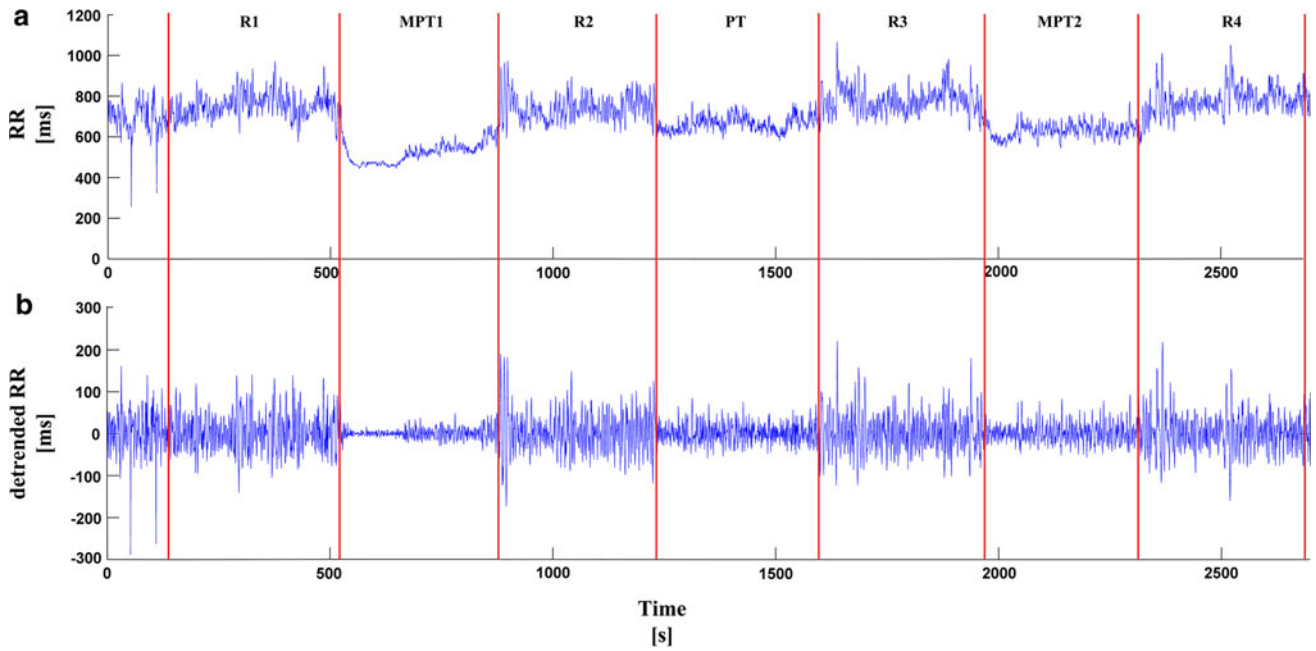


Fig. 1 Tachogram (**a**) and corresponding detrended time series (**b**) of a subject during the test. The *vertical lines* indicate the start and end of each experimental condition (*R* rest, *PT* physical task, *MPT* mental and physical task combined)

Table 1 Mean values (standard deviation) of different HRV parameters for the four conditions

Mean (SD)	R	PT	MPT1	MPT2
Mean NN (ms)	863.46 (147.98)	821.17 (141.18)[a]	755.44 (134.47)[a,b]	803.46 (147.98)[a,b,c]
SDNN (ms)	46.73 (19.48)	35.84 (15.26)[a]	35.40 (16.35)[a]	40.41 (18.74)[a,b,c]
rMSSD (ms)	28.74 (16.58)	22.83 (14.09)[a]	19.39 (13.77)[a]	22.94 (15.66)[a,c]
pNN50 (%)	31.83 (18.73)	27.68 (17.00)[a]	26.82 (16.10)[a,b]	28.68 (18.73)[a,c]
LF (ms^2)	868.42 (641.04)	522.10 (463.72)[a]	466.87 (460.20)[a]	645.06 (600.61)[b,c]
HF (ms^2)	1005.48 (782.59)	591.50 (550.31)[a]	552.46 (427.99)[a]	615.08 (569.34)[a]
LF/HF	1.15 (1.09)	1.08 (0.92)	1.10 (0.88)	1.17 (0.93)

[a] Significantly different from R ($p < 0.05$)

[b] Significantly different from PT

[c] Significantly different from MPT1

of the heart rate in the three active conditions compared to the preceding and following rest condition.

The Friedman statistics reveal that the phase has a statistically significant effect on mean NN, SDNN, rMSSD, pNN50, LF and HF (all $p < 0.0001$). Table 1 shows the post hoc contrasts. The mean values and standard deviation for the different HRV parameters are presented and the pairwise statistically significant differences between the conditions are indicated. The post hoc contrasts reveal that the changes between the rest condition and the three active conditions are statistically significant for all the HRV measures. SDNN, providing information about the total variability of heart rate control, was higher during rest compared to the active tasks. RMSSD, pNN50 and HF, all reflecting vagal modulation of ANS, showed similar behavior and reaction conforming to the literature, i.e., these values were significantly higher in the rest phase (R) compared to the activity phases PT, MPT1 and MPT2. The Friedmann test analysis did not reveal any statistically significant difference between the different conditions concerning the LF/HF ratio, which is also visible in Table 1.

More interesting are the differences between the three active phases. MPT1 has the lowest mean NN, followed by PT and MPT2. All these differences are statistically significant. The total variability (SDNN) is lower during PT and MPT1 compared to MPT2, while mutually there are no differences. The combined mental and physical task had lower vagal modulation than the physical task as expected: it was significant for pNN50, but not for RMSSD. More remarkable is that repetition has an effect on vagal modulation, as both HRV parameters are lower during MPT1 than during MPT2. Even more, there was no difference between MPT2 and PT, indicating that the additional effect of the mental load had decreased.

TFA analysis

Figure 2 shows the time evolution on group level of the power in the low-frequency (a) and high-frequency (b) bands (respectively, LF and HF) and the instantaneous frequency (c) in the high-frequency band (FH). The LF/HF is not presented here as the statistical analysis for the phase differences did not reveal a statistically significant difference. For visualization, the data are presented via the mean ± standard error in blocks of 1 min. The time series of p values are presented in Fig. 3.

The LF power (Figs. 2a, 3a–c), revealing information of both sympathetic and parasympathetic activity, is higher during the rest periods compared to the three active phases. The evolution of LF power within the phase is similar for PT and MPT2. The time series of the p values shows that although the evolution of MPT2 and PT is similar, the LF power is significantly higher in MPT2 compared to PT (Fig. 3b) for almost the complete duration of the test. The values during MPT2 tend more toward the values during the rest period compared to those of MPT1. Although MPT1 shows a linear increasing P_{LF} over time, statistics reveal that the differences between MPT1 and MPT2 (Fig. 3c) are only present during the first 2 min of the test. Although PT has a more or less constant evolution and MPT1 increases linearly, there are almost no statistical differences between the two periods (Fig. 3a), except at the end of the phase (min 5).

Information of the parasympathetic modulation on the heart rate is shown in the HF power band (Figs. 2b, 3d–f). The time evolution is similar to that of the LF power, but statistics reveal other differences. The statistical differences between the active phases are all present in the first 3 min of the phase. The effect of the mental task differs in time. During MPT1, P_{HF} differs from the period without mental load during the first 3 min (Fig. 3d), while the second phase with mental load is only significantly different during the second minute (Fig. 3e). This is also confirmed, as the difference between MPT1 and MPT2 is statistically not different during the second minute (Fig. 3f).

The instantaneous frequency in the high-frequency band shows an equal frequency during the four rest periods. The mean frequency increases during the active phases. Especially during MPT1, the f_{FH} is the highest, but only significant during the first 2 min (compared to MPT2, Fig. 3i) and during the second minute (compared to PT, Fig. 3g).

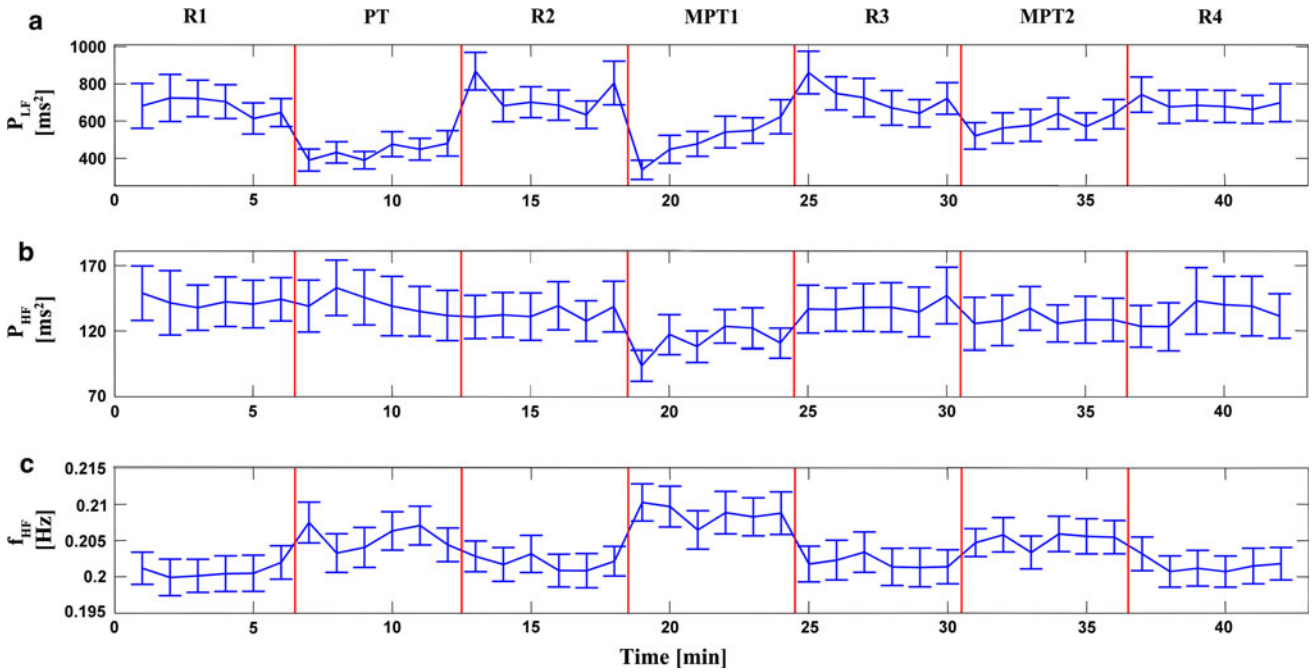


Fig. 2 Time evolution, indicated as mean ± standard error, of the power in the low-frequency (**a**) and high-frequency (**b**) band (respectively P_{LF} and P_{HF}) and the instantaneous frequency (**c**) in the high-frequency band (f_{HF})

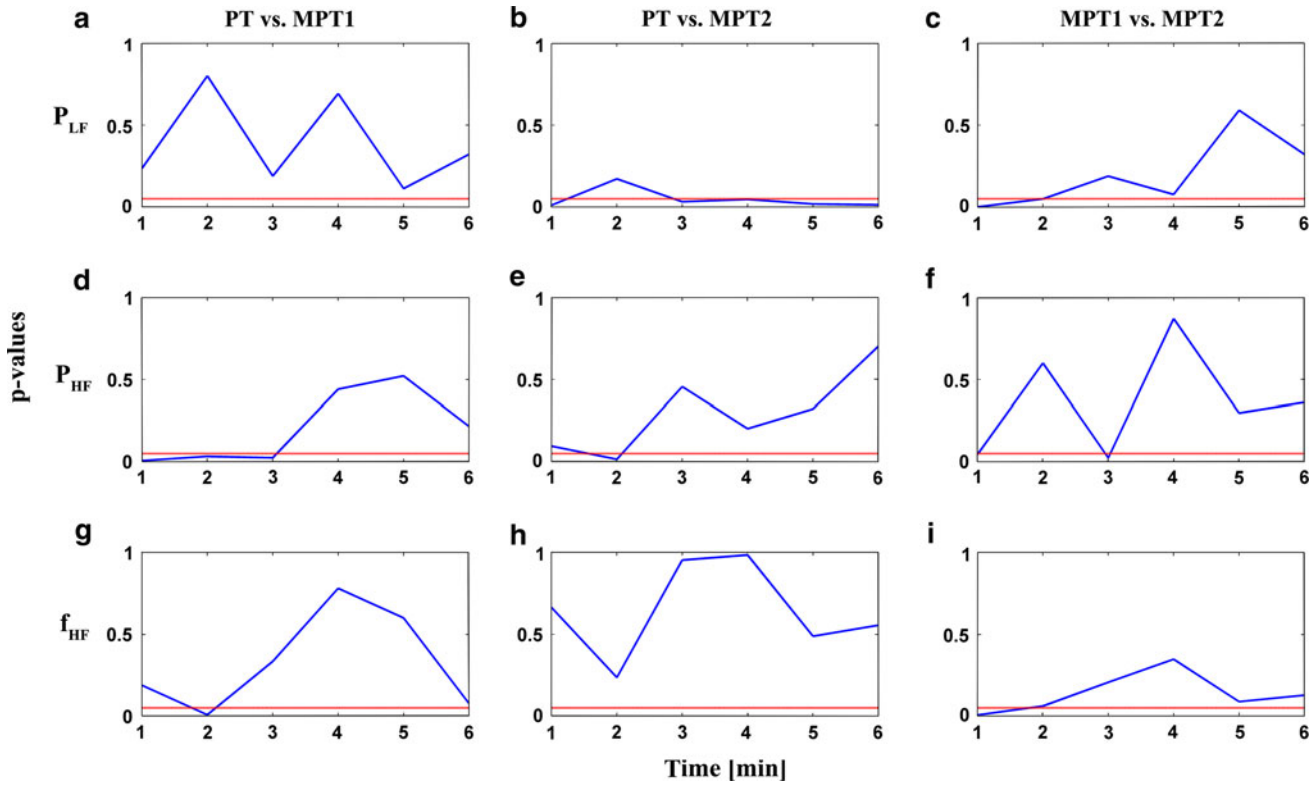


Fig. 3 The time series of *p* values. The *rows* depict from top to bottom the power in the LF (P_{LF}) band, the power in the HF band (P_{HF}) and the instantaneous HF frequency (f_{HF})

Discussion

HRV parameters were calculated in several conditions: rest, physical task and a combination of both tasks. The physical task consisted of computer mouse work, which is closely related to daily office work. This task was once combined with a low mental load, picking the highest number of three alternatives and will be referred to as a purely physical task (PT). The physical task was also combined twice with high mental load: complex arithmetic exercises (MPT1 and MPT2). For almost all described measures (mean NN, SDNN, rMSSD, pNN50, LF, HF), the active conditions can be distinguished from the rest condition, meaning that heart rate variability is sensitive to any change in mental or physical state despite a minimal physical load. This confirms the findings of previous work (Pagani et al. 1991; Perini et al. 2000; González-Camarena et al. 2000; Myrtek et al. 1996; Sloan et al. 1994; Mezzacappa et al. 2001; Garde et al. 2002; Hjortskov et al. 2004; Zhong et al. 2005) where evidence was found that physical and mental task influences HRV related to disturbances in the ANS.

A focus of this study was the additional effect on HRV parameters of a mental load to an office-related physical task. The combination of the physical and mental task (MPT1) was expected to result in a higher load compared to the physical task (PT) separately. Our hypothesis was confirmed by a significantly higher heart rate and a significantly lower vagal modulation (rMSSD, pNN50, HF) during MPT1. The effect of the single mental load (increased HR, decreased vagal modulation) is superposed to the cardiovascular effect of the physical load. This suggests an additional effect when multiple tasks are combined. Nevertheless, earlier studies found no effect of mental stress on physiological parameters (Wahlström et al. 2002). One study (Garde et al. 2002) reported that the addition of mental demands to a physical computer task does not elicit any further effect on HRV parameters related to autonomic modulation. Therefore, they suggested that the physical demands have a major influence on the observed ANS changes, whereas the influence of the mental load is insignificant. However, our study rejects their hypothesis. A mental load as such influences autonomic cardiac modulation, even in combination with a simultaneous physical task. In our previous study (Vandeput et al. 2009), we already described briefly the additional effect of mental load, albeit small in that case, on the physical load. During these measurements, the physical load was a 45° shoulder abduction, which was a much heavier physical load compared to the mental load in that study and to the physical load in the present study. The shift toward a slightly higher instantaneous HF frequency during MT can probably be related to a higher respiration frequency, as the main peak in the HF band is normally caused by respiration (Stevenson and Ripley 1952; Nilsen et al. 2007). An increased respiration frequency during a 1-h low-grade mental stress task in healthy subjects was already found in Nilsen et al. (2007). Vlemincx et al. (2011) also reported an increased breathing rate during mental stress, although Bernardi et al. (2000) in contrast observed a slowing down of respiration frequency. The results also reveal an additional effect of the mental load to the physical load as the respiration frequency was higher during MPT1 compared to PT.

The power in the low-frequency band is described in literature as the measure that reveals information of sympathetic and vagal modulation (Task force of the European Society of Cardiology 1996). The hypothesis for the study was an increased LF power during the active phases compared to the rest phases, as mental and physical load activates the sympathetic branch of the ANS (Delaney and Brodie 2000). In contrast, our results reveal a lower LF power confirming the findings in Hjortskov et al. (2004) where a withdrawal of vagal modulation during short-term stress was suggested (De Geus et al. 1990; Sloan et al. 1991). They also reported lower power in the LF band during tasks where mental stress was induced. Consequently, we can conclude that the clicking task does not activate the sympathetic branch of the ANS. This has implications on the LF/HF ratio, which is in accordance with the Task Force (Task force of the European Society of Cardiology 1996) measure for the sympathovagal balance. Our results, however, showed that the power in the LF band changed due to vagal modulation and the sympathetic branch did not influence this power. This is similar information as present in the power of the HF band and is, therefore, canceled out by calculating the LF/HF ratio. This study confirms the limitations of the LF/HF ratio, namely that this ratio is in some applications not a close enough approximation of the autonomic balance (Eckberg 1997; Zhong et al. 2006).

The time frequency analysis shows that the differences are not present during the complete phase. For example, the P_{HF} in Fig. 3 was only significantly different for the first 3 min between the task with the mental load (MPT1) and the task without the mental load (PT). There were clear differences for the HRV parameters during this short period, although the physical load was similar for both periods. The protocol was fully randomized for the active phases; so, we can conclude that these changes originated from the mental load and not from time. The differences caused by the additional mental load disappeared when repetition took place. This reveals that our ANS is able to cope with mental load. In literature, this has been discussed by McEwen and Stellar (1993) from the perspective of homeostasis and homeostatic load. They explained the

adaptability mechanism of the human body to unknown stress situations. Translated to this situation, the mental arithmetic is the stress situation and the HRV parameters change significantly at the beginning of the exposure to the task. After being exposed to this stress situation for several minutes, the body habituates and, at the end of this phase, the HRV parameters tend to those of PT. More evidence for homeostasis can be found by comparing the HRV parameters of MPT1 and MPT2. For almost all described parameters, there were significant differences between the first mental load and the second one, showing lower heart rate, more vagal modulation activity and lower instantaneous frequency in the HF band related to the breathing rate. Moreover, except for the mean heart rate and the power in the low-frequency band, no significant differences were observed between MPT2 and PT, revealing that the additional effect of the mental arithmetic is minimal during this second time. The participants knew what to expect and were familiar with the mental task. The steep increase in heart rate during the MPT1, as shown in Fig. 1 for one participant and in Fig. 2 with the time–frequency analysis, is less present explicitly. There was still a small effect as the time–frequency analysis of the power in the HF band revealed no statistically significant difference between MPT1 and MPT2 during the second minute, while the difference between PT and MPT2 was significant for this minute.

Studies conducted in a laboratory have the advantage that the experimental conditions are carefully controlled. However, it is also a limitation that the results and conclusions cannot necessarily be extrapolated to office settings, although we believe that the stressors and the physiological stress reactions in the present study may reflect the reactions during office work.

Conclusion

This study showed clearly that heart rate variability (HRV) was a very promising tool to observe the effect of mental stress. We were able to differentiate the HRV characteristics between rest, and physical and mental load. The addition of a mental load to a physical task did elicit further effect on HRV parameters related to autonomic cardiac modulation. Time–frequency analysis revealed that the mental stress level changes over time within one phase. The effect of the stressor used in this study was reduced after 3 min. This type of analysis is able to detect changes within the 6-min phase that were discarded by the standard HRV parameters across the 6-min phases. This clarifies the importance of using time–frequency analysis for this type of applications. In addition, calculation of HRV parameters is of low computational cost, making the findings of this study useful in daily life. This study supports the conclusion of Nolan et al. (2005) that HRV can be promising for use in a biofeedback system.

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Conflict of interest The authors declare that they have no conflict of interest.

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