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

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SUMMARY

The cardiac regulation effects of a mental task added on regular office work are described. More insight in 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 – 0.4Hz), in addition to the traditional linear heart rate variability (HRV) parameters. In a laboratory environment, 43 subjects underwent a protocol with 3 active conditions, being a clicking task with low mental load and twice a clicking task with high mental load, more specific mental arithmetic, each followed by a rest condition. The heart rate and measures related to the 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 towards a higher instantaneous frequency in HF band. TFA revealed habituation to the mental load within the task (after three minutes) and between the two tasks with mental load. In conclusion, the use of TFA to this type of analysis is important as it reveals extra information. The addition of a mental load to a physical task did elicit 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

Introduction

Job stress is a huge problem in today's society since forty to fifty percent of all work-related absences are related to stress. This problem leads to losses of 0.5 to 2% of GNP per year. The problem is noticed by the European Commission (2004). Several studies have shown a link between the level of work stress and disease (McEwen 1993; Van Praag 2002; Kivimaki 2002). Since the nineties, markers of stress and other psychosocial factors are associated with coronary disease (Lundberg 1980; Johnson 1988). Compared to other lifestyle risk factors, stress is different because no consensus exists with respect to either definition or measurement. Several definitions of stress exist, but here stress is defined as a mismatch between perceived demands and perceived capacities to meet those demands. Inevitably, stress is subjective and it can encompass several aspects, from external stressors such as adverse life events, financial problems or job stress to potential reactions such as depression, vital exhaustion, sleeping difficulties or anxiety. Stress induces a number of physiological reactions, known as the fight or flight reaction (Taylor 2000). This reaction is hormonal, neurological, cardiovascular, metabolic and muscular (Krantz 2004). Chronic stress can lead to an overload or exhaustion of these physiological systems. Frequently used biomarkers for detection are blood pressure, heart rate variability and catecholamine and cortisol secretion. 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 becomes more activated, resulting in the secretion of the hormones epinephrine and norepinephrine into the blood (Van Praag 2002). When the stressor disappears, the vagal system takes over to decrease among others sweating, heart rate and breathing rate. Several studies report that heart rate variability (HRV) refers to alternations in heart beat time-intervals and provides quantitative markers of autonomic regulation (Akselrod 1981; Task

Force of the European society 1996). Therefore, HRV is used to examine the responses to mental and physical demands on the autonomic nervous system (ANS). Several studies showed that physical tasks (Pagani 1991; Perini 2000; Gonzalez-Camarena 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 1996; Sloan 1994; Mezzacappa 2001). Many studies only focus on either physical or mental load, but only a few consider both (Garde 2002; Hjortskov 2004). In a previous study (Vandeput 2009), the difference in response in HRV between a mental stressor, a physical stressor and the combination of both stressors was explored. Statistically significant differences in HRV features were found between rest and the mental stressor. However, this study showed some limitations. The different conditions were not equal in length, disabling comparison between the full periods. Therefore, equal periods of two minutes were selected, leading to less reliable results as two minute blocks are small. Moreover, the physical task was a 45° shoulder abduction, which is not a regular physical office task and the physical load was high compared to the mental load. In the current study, these shortcomings are tackled by using equal lengths of the different tasks and the physical task has changed to a mouse clicking task, which is a normal office task.

In addition, time-frequency analysis (TFA) is used which is a new trend in HRV analysis. Regular frequency measures as described in the overview study of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996), are calculated in a predefined time window, hiding possible transients during this period. In contrast, 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 on 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 the physical office task. To increase insight in the time evolution during the different tasks, time-frequency analysis is used, which is to our knowledge hardly used in this type of research. The clicking task combined with the mental load was performed 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 in combination with the mental task) as well as mutually between the active tasks to describe the influence of the mental load.

Methods

Participants

Forty-three 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 is 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, 10mm diameter, Nikomed, Denmark) were placed on the body to measure the electrocardiogram (ECG) and the surface Electromyogram (sEMG) of the 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 SENIAM recommendations (Surface Electromyography for the Non-Invasive Assessment of Muscles). 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 (450Hz) and wired to an analog-to-digital converter with a cDAQ with module NI 9239 (National Instruments, Austin, TX, USA), sampled at 1000Hz and digitized (24bits) before storage on a personal computer.

Protocol

In a laboratory environment, the participants took place 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 3 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 have a same duration of 6 minutes. One task is a rest phase. Rest involved watching a relaxing movie ('The march of the Penguin') exposing the participants to neutral stimuli reducing boredom during this phase. Participants were ensured that no questions about the documentary would be asked later so they can relax and enjoy the movie. Another phase is a mental and physical office task. The task consists 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 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 was given, evaluation and rewards were given related to performance within time constraints and an observer was present (Gaillard 1994; Kelsey 2000). The last task was a pure 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, one time PT each followed by a rest phase. The three active phases were fully

randomized amongst the participants. The test started with a rest phase prior to the first active phase. The entire test lasts for 42 minutes.

Before the experiment started, the participants were explicitly instructed again not to speak, mumble or move the lips, to sit comfortably, not to change posture or to 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 1985) that localizes the R peak in the QRS complex. This results in an RR interval time series, the tachogram. The data was 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 5 previous and 5 next intervals (Kleiger 1987). To overcome distortion in the HRV analysis due to nonstationarities 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 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 minutes. The rest measures represent 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 tradeoff between time and frequency resolution, called the Heisenberg uncertainty principle. Therefore, this study applies the wavelet decomposition technique (Percival 2000; Kuklin 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, $\Psi_{t,a}(s)$, that can be shifted (time t) and dilated (scale a). The decomposition is given by next formula, where $TFR(t,a;\Psi)$ is the wavelet decomposition:

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

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

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

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

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

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.

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

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 in order 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 is performed, analogously to Orini et al (2010). At each time instant, the nonparametric Wilcoxon signed rank is used to find pairwise differences between two phases, resulting into 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 in the additional effect of the mental load is revealed. $P < 0.05$ was considered statistically significant.

Results

Figure 1a shows a typical tachogram of an individual during execution of the protocol. The nonstationarity of the tachogram is clearly visible and the effect of detrending is shown in figure 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 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 react conform to the literature, i.e. these values were significantly higher in rest phase (R) compared to the activity phases PT, MPT1 and MPT2.

More interesting are the differences between the three active phases. MPT1 has the lowest meanNN, 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 has lower vagal modulation than the physical task as expected, being 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 is no difference between MPT2 and PT, indicating that the additional effect of the mental load has decreased.

TFA analysis

Figure 2 shows the time evolution on group level of the power in the low frequency (a) and high frequency (b) band (respectively LF and HF) and the instantaneous frequency (c) in the high frequency band (FH). For visualization, the data are presented via the mean ± standard error in blocks of 1 minute. The time series of p-values are presented in figure 3.

The LF power (figure 2a and 3a,b,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 (figure 3b) for almost the complete duration of the test. The values during MPT2 are tending more towards 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 (figure 3c) are only present during the first two minutes of the test. Although PT has a more or less constant evolution and MPT1 is linearly increasing, there are almost no statistical differences between the two periods (figure 3a), except at the end of the phase (minute 5).

Information of the parasympathetic modulation on the heart rate is shown in the HF power band (figure 2b and 3d,e,f). The time evolution is similar as for the LF power, but statistics reveal other differences. The statistical differences between the active phases are all present in the first three minutes 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 three minutes (figure 3d), while the second phase with mental load is only significantly different during the second minute (figure 3e). This is also confirmed as the difference between MPT1 and MPT2 is statistically not different during the second minute (figure 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 two minutes (compared to MPT2, figure 3i) and during the second minute (compared to PT, figure 3g).

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 to highest number of three alternatives and will be referred to as a pure 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 (MeanNN, 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 in previous work [Pagani 1991; Perini 2000; Gonzalez-Camarena 2000; Myrtek 1996; Sloan 1994; Mezzacapp 2001; Garde 2002; Hjortskov 2004; Zhong 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 (Whalstrom 2002). One study (Garde 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, while 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 2009), we already described shortly 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 is a much heavier physical load compared to the mental load in that study and to the physical load in the present study. The shift towards 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 1952; Nilson 2007). An increased respiration frequency during a 1h low-grade mental stress task in healthy subjects was already found in Nilsen et al. (2007). Vlemincx et al. (2010) also reported an increased breathing rate during mental stress, although Bernardi et al. (2000) observed oppositely a slowing respiration frequency. The results here also reveal an additional effect of the mental load to the physical load as the respiration frequency is 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 2000). Contrarily, our results reveal a lower LF power confirming the findings in Hjortskov et al. (2004) were a withdrawal of vagal modulation during short-term stress was suggested (De Geus 1990; Sloan 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.

The time frequency analysis shows that the differences are not present during the complete phase. For example, the P_{HF} in Figure 3 was only significantly different for the first three minutes 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 are originated by the mental load and not by time. The differences caused by the additional mental load disappear when repetition took place. This reveals that our ANS is able to cope with mental load. In literature, this has been discussed by McEwen (1993) from the prospective of homeostasis and homeostatic load. He 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, 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 know what to expect and are used to the mental task. The steep increase in heart rate during the MPT1, as shown in Figure 1 for one participant and in Figure 2 with the time-frequency analysis, is less present explicitly. There is 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 is 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) is a very promising tool to see the effect of mental stress. We were able to differentiate the HRV characteristics between rest, 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 in time within one phase. The effect of the stressor used in this study was reduced after three minutes. This type of analysis is able to detect changes within the 6 minute phase that were discarded by the standard HRV parameters across the 6 minute phases. This clarifies the importance of using time-frequency for this type of applications. In addition, calculating HRV parameters is at low computational cost making the findings of this study useful in daily life. This study support the conclusion of Nolan et al (2005) that HRV can be promising to be used in a biofeedback system.

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Table 1: Mean values (standard deviation) of different HRV parameters for the four conditions. [a] indicates significantly different from R ($p<0.05$); [b] indicates significantly different from PT; [c] indicates significantly different from MPT1

Mean (SD)	R	PT	MPT1	MPT2
MeanNN [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]

Figure 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).

Figure 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})

Figure 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}).