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Mental Work Stimulates Cardiovascular Responses through a Reduction in Cardiac Parasympathetic Modulation in Men and Women

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Abstract

Mental Work (MW) stimulates Cardiovascular (CV) functions in healthy adults and a reduction in cardiac parasympathetic modulation could be one mechanism involved in such a response. The influence of sex on these CV responses remains ambiguous. The aim of the study was to evaluate CV impacts of MW in healthy individuals and whether sex influences CV responses induced by MW. The impact of a 45-min reading and writing session vs. a control condition, on Blood Pressure (BP), Heart Rate (HR), and Heart Rate Variability (HRV), was evaluated in 44 healthy adults with the use of a randomized crossover design. The influence of sex on those variables was then evaluated. Diastolic BP (74 ± 1 vs. 69 ± 1 mm Hg; $p < 0.05$) and mean arterial pressure (MAP; 87 ± 7 vs. 83 ± 8 mmHg; $p < 0.005$), HR (68 ± 1 vs. 62 ± 1 bpm; $p < 0.0001$) and low frequency/high frequency ratio (2.8 ± 0.1 vs. 2.0 ± 0.1; $p < 0.0001$) were higher, while global HRV (SDNN: 84 ± 3 vs.104 ± 3 ms; $p < 0.0001$) and cardiac parasympathetic activity were lower during MW ($p < 0.0001$) vs. the control condition in the whole sample. During both experimental conditions, HR was higher ($p < 0.0001$), while BP, rMSSD, pNN50 and low frequency component of HRV were lower in women compared to men (all $p < 0.05$). The intensity of the cognitive demand and its influence on CV variables were comparable between men and women. These results support that MW increases BP and HR through decrement in cardiac parasympathetic modulation in healthy subjects and suggest that sex does not influence CV responses induced by cognitive demand of similar intensity.

Keywords: Cardiovascular response; Mental work; Cardiac parasympathetic modulation; Blood pressure; Heart rate

Introduction

With the recent developments in communication and technologies, modernity has progressively promoted the reduction in physical activity participation in a labour environment and mental work has become the basis of innovation and productivity, particularly in a context of globalization [1-3]. In this regard, recent investigations clearly show that the cognitive effort imposed by mental work is not a trivial stimulus for the cardiovascular system. Indeed, many investigators have analyzed cardiovascular responses to mental work and have shown a common pattern characterized by increased heart rate and blood pressure [4-13].

The mechanisms underlying the stimulation of the cardiovascular response induced by mental work are not well understood. For instance, Muscle Sympathetic Nerve Activity (MSNA), known to represent sympathetic nervous activity [14], was found to increase [12] or decrease [15] in response to acute mental stress induced by mental arithmetic. In addition, a reduction in cardiac parasympathetic modulation may also be responsible for these hemodynamic responses observed during mental work, but the latter remains a matter of debate in healthy young individuals [16].

Sex is known to influence cardiovascular responses in several situations such as during isometric and aerobic exercise and postural changes [17-20]. Still, its influence on cardiovascular responses during mental work remains equivocal. In women, cardiovascular responses induced by mental stress may be driven by a cardiac parasympathetic modulation. Indeed, estrogen may contribute to activate the parasympathetic nervous system, while progesterone influences the sympathetic nervous system [20]. In men, cardiovascular responses induced by mental stress seem to be influenced to a greater extent by the sympathetic nervous system [21,22]. However, similar physiological and psychological responses to mental stress between men and women have also been reported [21]. The intensity of mental work could explain the different cardiovascular changes induced by mental work between sex. Indeed, women seem to perceive mental work (sustained attention to a spatial task) as more difficult than men, even for a similar mental task [23].

Accordingly, the aims of this intervention study were to evaluate cardiovascular responses, characterized by heart rate, blood pressure and Heart Rate Variability (HRV), induced by mental work in healthy individuals and whether sex influences these variables. We hypothesized that increases in heart rate and blood pressure would be associated with a reduction in cardiac parasympathetic modulation. We also hypothesized that the elevation in heart rate and blood pressure induced by mental work would be more important in women compared to men.

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Methods

Forty-four healthy young adults (22 women and 22 men), aged 24 ± 3 years, participated in this crossover study. The subjects had no history of smoking, hearing problems, cardiovascular diseases, and eating disorders, had a stable body weight since 6 months (± 2kg), had no metabolic problem and/or were not taking medication that could interfere with the objectives of the study, were familiar with the use of a computer, and were similarly practicing physical activity (< 30 minutes/day). Before each testing day, the subjects followed a standardized protocol including the following guidelines: 1) no caffeine and/or alcohol 24 hrs before the test, 2) no physical activity 24 hrs before the test, and 3) a standardized breakfast (women: 598 kcal, men: 714 kcal) 3 hrs before the test. Women were tested within 10 days following the start of their menses. The subjects were blinded in regard of the main hypothesis of the study. All subjects gave their written consent to participate in this study, which received the approval of the local ethics committee.

Study protocol

All participants were randomly assigned, using a computerized randomization scheme, to two experimental conditions lasting 45 min: (i) control condition, consisting in a resting period comfortably sitting in an arm chair, and (ii) a reading-writing condition, consisting in reading a 10-page text from a lay public magazine and summarizing the text, in no more than 350 words, using a word-processing software. The task had to be completed in 45 min and participants were aware of the time remaining before completion of the mental work. The participants were tested one at a time, on 2 different occasions, 1-4 weeks apart.

Measurements

Body mass index and waist circumference were measured according to international guidelines by a kinesiologist at study entry [24]. Body mass index was calculated as body weight (kg) divided by squared height (m^2). Waist circumference was measured in standing position midway between the lowest rib margin and the upper pole of the iliac crest with a measuring tape.

Blood pressure was measured three times (after 5, 20, and 40 min) over the 45-min period of each condition by a nurse with a manual sphygmomanometer and a stethoscope and then averaged. Mean arterial pressure was calculated as (systolic blood pressure/3) + [2 × (diastolic blood pressure)/3]. Heart rate and HRV were recorded by a Holter (Marquette Electronics Inc., Milwaukee, WI) during the two 45-min experimental conditions. In the frequency domain, power in the low frequency (0.04 to 0.15 Hz) and high frequency (0.15 to 0.4 Hz) ranges were calculated. The low frequency: high frequency ratio, considered to be a marker of the sympathovagal balance, was also determined [25]. Using time domain analysis, the Standard Deviation (SD) of the RR intervals (SDNN), the square root of the mean squared differences of successive RR intervals (rMSSD), and the SD of the average RR intervals were calculated over 5-min periods (SDANN). pNN50 is the proportion of interval differences of successive NN intervals >50 ms. rMSSD and pNN50 are indices of parasympathetic modulation [26]. NN intervals are the normal-to-normal intervals that include all intervals between adjacent QRS complexes resulting from sinus node depolarizations in the 45-min electrocardiogram recording. An experienced technician, using visual checks and manual corrections of individual RR intervals and QRS complex classifications, carefully edited the complete signal.

In order to assess the intensity of the cognitive demand for each subject, two techniques were used permitting its quantification and its qualification. First, the reaction time to a secondary task was used to objectively quantify the cognitive demand since it has been demonstrated to be a valid indicator of the intensity of the cognitive effort imposed by a primary task [27-29]. Briefly, the subjects had to vocally respond, as rapidly as possible, to an unpredictable auditory stimulus (secondary task), while performing a primary task (control or mental work). The reaction time was defined as the temporal interval between the presentation of the auditory stimulus and the onset of the verbal response. A long reaction time was interpreted as a high intensity perceived mental work [11,27,28]. The NASA Task-Load Index was used after each visit to assess the subject's perception of mental work. A high perception of the cognitive demand by the subject represented a high score [30]. In addition, anxiety level was assessed using the State-Trait Anxiety Inventory (STAI) [31] consisting of two anxiety scales composed of 20 questions evaluating how the subject feels generally (state scale) and at a specific moment (trait scale) to account for the influence of stress induced by the mental work. The anxiety-state scale was filled at the beginning (trait and state) and after each 45-min experimental condition (trait only). A high score represented a high anxiety level.

Statistical analyses

A two-way analysis of variance for repeated measures was performed on the means of all variables. A Tukey HSD post hoc test was then performed in order to contrast mean differences between the control and the mental work condition (multiple comparison with Bonferroni's correction). Low frequency and high frequency was log transformed since these parameters were not normally distributed. Pearson correlation analysis was used to evaluate the associations between the indices of mental work and changes in HRV parameters and other cardiovascular parameters. The statistical significance was set at a p value <0.05. All statistical analyses were performed using the JMP version 8.0.1 (SAS Institute, Cary, NC).

Results

Baseline characteristics of the 44 subjects as well as the subjects divided according to sex are presented in Table 1. Age, height, body weight and waist circumference were higher in men compared to women while body mass index was similar between sex.

Whole sample

There was a longer reaction time (0.76 ± 0.02 vs. 0.65 ± 0.02 s; $p < 0.0005$) and a higher NASA score (55.9 ± 1.5 vs. 19.3 ± 1.5; $p < 0.0001$) during mental work compared to the control situation, but no difference was observed in anxiety-state scale scores changes (1.0 ± 0.8 vs. -1.3 ± 0.8; p = 0.054). Diastolic blood pressure, mean arterial pressure, heart rate and low frequency/high frequency ratio were 7% (*p*

Variables	All (n=44)	Men (n=22)	Women (n=22)
Age (yrs)	24 ± 3	25 ± 3	23 ± 3*
Height (cm)	173 ± 9	180 ± 5	165 ± 6**
Body weight (kg)	69 ± 12	76 ± 9	61 ± 9**
BMI (kg/m^2)	23 ± 2	23 ± 2	22 ± 2
Waist circumference (cm)	79 ± 8	83 ± 6	74 ± 8*

Data are presented as means ± SD; BMI: body mass index; *p<0.05 between men and women;
**p<0.0001 between men and women.

Table 1: Baseline characteristics of the sample.

	Control			Mental work		
	All (n=44)	Men (n=22)	Women (n=22)	All (n=44)	Men (n=22)	Women (n=22)
Ratio LF/HF	2.0 ± 1.2	2.1 ± 1.1	1.9 ± 1.3	2.8 ± 1.4**	2.9 ± 1.5	2.7 ± 1.4
SDNN (ms)	104 ± 33	113 ± 38	93 ± 22	84 ± 27**	91 ± 29	75 ± 23
SDANN (ms)	34 ± 14	33 ± 15	36 ± 13	36 ± 18	34 ± 15	35 ± 20
LFln (ms^2)	7.3 ± 0.7	7.5 ± 0.6	7.1 ± 0.6†	7.0 ± 0.7*	7.3 ± 0.6	6.7 ± 0.6§
HR (bpm)	62 ± 8	58 ± 6	66 ± 9†	68 ± 9**	63 ± 6	75 ± 8§
SBP (mmHg)	110 ± 10	115 ± 9	105 ± 7†	112 ± 10	118 ± 9	106 ± 7§
DBP (mmHg)	69 ± 9	73 ± 8	66 ± 7†	74 ± 8*	77 ± 9	71 ± 5§
MAP (mmHg)	83 ± 8	87 ± 8	79 ± 6†	87 ± 7 *	91± 8	83 ± 4§

Data are presented as means ± standard deviation.
Heart Rate Variability (HRV) parameters in the time domain (calculation related to the time between two heart beats) and the frequency domain (quantification of the power spectrum of HRV signal) were measured and averaged over 45 minutes.

HRV: Low Frequency (LF), ratio Low Frequency/High Frequency (ratio LF/HF), the Standard Deviation of the RR intervals (SDNN), the SD of the average RR intervals were calculated over 5-minute periods (SDANN).
Hemodynamic parameters: Heart Rate (HR), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), and Mean Arterial Pressure (MAP)
*p<0.05 for n=44 between control and mental work; **p<0.0001 for n=44 between control and mental work; †p<0.05 between men and women for the control condition; §p<0.05 between men and women for the mental work condition.

Table 2: Cardiovascular responses to mental work.

< 0.05), 2% ($p < 0.005$), 10% ($p < 0.0001$) and 40% ($p < 0.0001$) higher, respectively, while global HRV (SDNN: $p < 0.0001$) was lowered by 19% during mental work compared to the control condition (Table 2). Cardiac parasympathetic activity was lowered during mental work (rMSSD: by 22%, PNN50: by 33 %, and HF_{ln}: by 9%; all $p < 0.0001$; Figure 1). Mental work did not influence any other variables. There were no correlations between indices of mental work and changes in HRV or the other cardiovascular parameters.

Influence of sex

During both experimental conditions, heart rate was higher ($p < 0.005$), while blood pressure, rMSSD, pNN50 and low frequency component of HRV were lower in women (all $p < 0.05$). The intensity (reaction time; 0.74 ± 0.04 vs. 0.79 ± 0.04 s; $p = 0.48$) and perception of mental work (NASA score; 56.8 ± 2.9 vs. 55.3 ± 3.0; $p = 0.72$) were similar between men and women. Sex did not influence any other variables. Changes in reaction time to a secondary task correlated with changes in diastolic blood pressure (r = 0.54; p = 0.02) in women only.

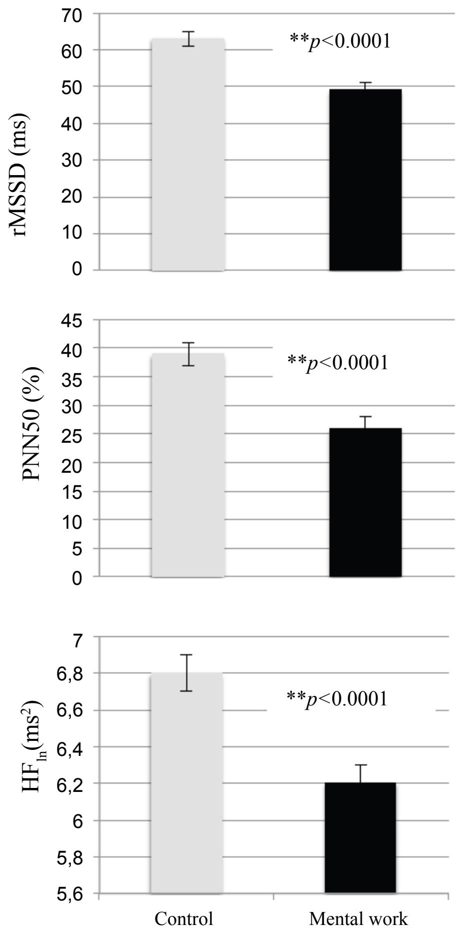

Figure 1: Effect of mental work on cardiac parasympathetic modulation Parasympathetic parameters of heart rate variability: high frequency (HF), the square root of the mean squared differences of successive RR intervals (rMSSD), and the proportion of interval differences of successive NN intervals >50 ms (pNN50)
**p<0.0001 for n=44 between control and mental work.

Discussion

These results suggest that an experimental mental work condition consisting of a 45-min period of reading and writing a summary, as other types of mental work (arithmetic) utilized in the laboratory, can modulate cardiovascular responses in healthy young adults through a reduction in cardiac parasympathetic activity. In addition, these results do not support an influence of sex on cardiovascular responses induced by the cognitive demand, at least when its intensity is comparable between sex.

In recent decades, the time spent in front of a computer or doing intellectual activities has increased relative to the time spent being physically active [32-34]. Our sample of full-time university students is well representative of the new workers' generation. Our study supports the impact of mental work on blood pressure. Indeed, diastolic blood pressure and mean arterial pressure were higher during mental work in comparison with the control condition. Systolic and diastolic blood pressures have been reported to increase with computer work and to remain significantly elevated during a resting period following mental work [10].

This hypertensive effect has also been demonstrated in a younger population, where children with a higher cardiovascular response to mental work presented a 7-mmHg increase in mean arterial pressure after one year [35]. Although the magnitude of the acute changes in blood pressure reported in our study may not be of concern for healthy individuals, such increase in blood pressure induced by mental work, over a prolonged period of time, could lead to the development of cardiovascular diseases [4,7,8,10,36]. Importantly, mild mental stress has been linked to long-term cardiac events [37]. These observations, including ours, could be of importance for borderline hypertensive individuals for example, who are more likely to express a pronounced cardiovascular response to mental work than normotensive individuals, which make them more susceptible to develop arterial hypertension [38]. However, adaptations might occur on a chronic basis and further research is needed to better understand the residual impact of mental work on cardiovascular reactivity in healthy individuals.

Durocher et al. [39] reported an increase in blood pressure and MSNA burst during mental stress when compared to a 5-min baseline period. It seems consistent in the literature that mental stress increases blood pressure, but sympathetic nervous activity, as characterized by MSNA, seems to react inconsistently between studies. Carter and Chester [12] observed different MSNA patterns in response to mental stress in a cohort of 82 healthy volunteers. Indeed, some subjects responded to mental stress by an increase in MSNA burst frequency while others did not. In all cases, blood pressure increased between baseline and mental stress [12]. Accordingly, the influence of mental work on sympathetic nervous activity remains equivocal and differences in the sympathetic baroreflex sensitivity to blood pressure elevation [39] or a greater effect of the perceived stress level than the mental stress itself [14] could explain these discrepancies.

Mental work is also known to elevate heart rate [6,9,10]. In our study, the 45-min reading-writing session increased heart rate by 10%. This finding is consistent with those of Martin et al. [9] who observed an increase of approximately 20% (+ 6.7 bpm) after a mental stress test in men and women and findings from Durocher et al. [39] who observed an increase of ~20 bpm compared to baseline with a single arithmetic task of 5-min duration. A reduction in cardiac parasympathetic modulation may be responsible for this observation during mental work [10], but the latter remains a matter of debate in healthy young individuals [16]. The observations derived from HRV in this study clearly suggest that a reduction in cardiac parasympathetic modulation is contributing to the elevation in heart rate during mental work. Few studies have investigated the influence of mental work on the parasympathetic branch of the baroreflex [5,10]. Taelman et al. [5] reported a decrease in high frequency power during a short-term mental stress task, suggesting a reduction in cardiac parasympathetic activity. Since both heart rate and blood pressure increased during mental work compared to the control condition in our study, a reset of the operating point of the baroreflex to a higher blood pressure induced by mental work, similarly to what has been observed during exercise [40], could be one mechanism explaining these CV changes. In addition, diminished baroreflex sensitivity induced by mental work could also be responsible for the reduction in cardiac parasympathetic modulation observed in this study. However, further research is needed to better understand the influence of mental work on both cardiac parasympathetic and sympathetic activities.

Differences in cardiovascular responses induced by mental work between sex remains equivocal. While some investigators have reported a gender effect in cardiovascular responses to mental stress [22,23,41], others did not [12,21]. In this study, we observed some differences in cardiovascular responses between sex in both conditions. Indeed, higher heart rate and reduced blood pressure and low frequency component of HRV were observed during mental work in women compared to men. However, these differences are most likely explained by the differences already present in the control condition, since changes in heart rate, blood pressure and low frequency component of HRV between the control and the mental work condition (deltas) were similar between men and women.

An important factor that could explain identical cardiovascular responses induced by mental work is the similar intensity of mental work in men and women. Indeed, Dittmar et al. [23] reported that for a similar mental work intensity, women perceived the workload to be more mentally challenging than men, and the latter is associated with a more important stimulation of the cardiovascular response in healthy subjects [14]. In our study, the intensity of mental work did not differ between men and women, as characterized by the NASA-Task Load Index score and the reaction time to a secondary task, which supports a recent study by Persson et al. [21], where they observed no difference in cortisol, adrenaline, noradrenaline, heart rate activation and perceived stress level between men and women with identical job tasks. However, the latter results are not consistent in the literature. Indeed, Ross et al. [6] demonstrated a number of differences between men and women in plasma adrenaline and noradrenaline and hematocrit responses to a mental arithmetic stress test, suggesting that women are less sympatho-reactive than men. Importantly, these authors did not provide any information characterizing mental load perception. In our study, we observed an association between the reaction time to a secondary task and the change in diastolic blood pressure induced by mental work in women only. A study by Carter et al. [12] reported that the perception of stress does not influence MSNA responses in men and women during mental arithmetic and emotional stress tests. However, Callister et al. [13] suggested that MSNA is highly variable and influenced by the perception of stress. The positive correlation between changes in reaction time to a secondary task and diastolic blood pressure observed in our study suggests that blood pressure response induced by mental work could be influenced by the perception of the mental workload in women.

Limitations

This study has limitations that need further discussion. One of the limitations is the homogeneity of the sample and the fact that they were all young university students, which might limit the generalization of the results to the whole population. We also acknowledge that the contribution of each determinant of the changes in blood pressure, heart rate and HRV with mental work may be different between young university students compared to older individuals [17,42]. The issue as to whether mental work per se or the related stress is responsible for such changes in blood pressure, heart rate and HRV cannot be solved with our results. However, the latter issue was outside the scope of the present study. The pilot nature of this contribution needs further research and should rather be perceived as a hypothesis generating study. However, since mental work acutely stimulates the cardiovascular function and the fact that the intensity of mental work has the potential to influence the magnitude of cardiovascular reactivity, our results imply that the stress-activating effect of mental work should be further studied in individuals susceptible to perform intellectually demanding activities on a daily basis to better understand its long term impact on the cardiovascular system. The menstrual cycle could also modulate cardiovascular responses to mental work. Indeed, there is a more important sympathetic nervous activity during the luteal phase and a greater parasympathetic nervous activity during the follicular phase [20,22]. Accordingly, women tested in this study were evaluated within day 0 and 10 of their menses in order to minimize the influence of women's reproductive hormones. Finally, the mental work condition that we used in the present study is different to what has been used in the literature. Up to now, mental stress has been experimentally represented by arithmetic-stress session or cognitive tests such as the Stroop color word test [43]. With our experimental session, we tried to reproduce real-life conditions with a mental task mimicking computer-job tasks like reading and summarizing a text and we consider that the latter represents a strength of this study.

Conclusion

These results support that mental work increases blood pressure and heart rate through decreased cardiac parasympathetic modulation in healthy subjects and suggest that sex does not influence cardiovascular responses induced by mental work when the objective and subjective intensity is similar in both men and women. Future studies should put efforts in determining the long-term effects of these findings.

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Ethical Standards

All subjects gave their written consent to participate in this study, which received the approval of the local Ethics Committee in accordance with the declaration of Helsinki.

Disclosures

The authors declare that they have no conflict of interest.

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