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Differences in autonomic heart rate modulation during rest and after a supramaximal anaerobic test in relation to gender and the menstrual cycle in women

Razlike u autonomnoj modulaciji srčanog ritma u stanju mirovanja i nakon supramaksimalnog anaerobnog testa u odnosu na pol i menstrualni ciklus žena

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Abstract

Background/Aim. Heart rate variability (HRV) and heart rate recovery (HRR) show differences between genders, and dissimilarities were also reported in women in various menstrual cycle (MC) phases. The aim of this research was to analyze cardiac autonomic indices during rest and in recovery after the Wingate test between genders in the young, sedentary population and to investigate whether a MC phase in women can influence these indices. **Methods.** Twenty-five females (20.5 ± 0.7 years) and sixteen males (20.4 ± 0.7 years) performed the Wingate anaerobic test on a cycle ergometer while their HRR and resting and recovery HRV indices were obtained. In females, data were collected during three distinctive MC phases. **Results**. The natural logarithm of low-frequency (lnLF) HRV marker and the natural logarithm of high-frequency (lnHF) HRV marker were higher in males during rest compared to women in all MC phases, except in the late follicular phase, where no differences in lnHF between genders were observed. Markedly higher lnLF and lnHF were recorded in males after the Wingate test. There were no differences in HRV between women in various MC phases during rest. Surprisingly, parasympathetic time-domain marker (the square root of the mean squared differences of successive NN intervals, RMSSD) and lnLF were both higher in the early follicular phase in comparison to the luteal phase of MC during recovery. HRR was faster in men in comparison to women in all MC phases. **Conclusion.** Males show greater HRR and total variability during rest and recovery, but it appears that resting parasympathetic activity is similar when females are in the late follicular phase of MC. Intra-female resting autonomic variability is not affected by the sex hormonal cycle. Post-exercise HRV in the early follicular phase reflects a significantly favourable autonomic profile in comparison to the luteal phase of MC.

Key words:
heart rate; autonomic nervous system; exercise test.

Apstrakt

Uvod/Cilj. Razlike u varijabilnosti srčane frekvencije (VSF) i oporavku srčanog ritma (OSR) postoje kako između polova, tako i među ženama u različitim fazama menstrualnog ciklusa (MC). Cilj istraživanja bio je da se ispitaju autonomni indeksi u stanju mirovanja i tokom oporavka nakon Vingejtovog testa između polova u mladoj, sedentarnoj populaciji i da li faza MC kod žena može imati uticaj na ove indekse. **Metode.** Dvadeset i pet ispitanica (20,5 ± 0,7 godina) i šesnaest ispitanika (20,4 ± 0,7 godina) izvodili su Vingejtov anaerobni test na bicikl ergometru pri čemu su im registrovani OSR i VSF u stanju mirovanja i tokom oporavka. Kod ispitanica, podaci su prikupljani tokom tri faze MC. **Rezultati.** brži OSR i veću ukupnu varijabilnost u stanju mirovanja i Prirodni logaritam markera niskih frekvencija (lnLF) VSF i prirodni logaritam markera visokih frekvencija (lnHF) VSF bili su veći kod muškog pola u stanju mirovanja u odnosu na žene u različitim fazama MC, osim u slučaju kasne folikularne faze gde nije bilo razlike u lnHF među polovima. Značajno veći lnLF i lnHF uočeni su kod muškaraca tokom oporavka od Vingejtovog testa. Nije bilo razlike u parametrima VSF u stanju mirovanja među ženama u različitim fazama MC. Iznenađujuće, parasimpatički marker vremenskog domena – kvadratni koren srednje vrednosti sume kvadrata razlika između sukcesivnih NN intervala (RMSSD) i lnLF bili su veći u ranoj folikularnoj fazi u odnosu na lutealnu fazu MC tokom oporavka. OSR je bio brži kod muškaraca u odnosu na žene u svim fazama MC. **Zaključak.** Muškarci pokazuju tokom oporavka, ali čini se da je parasimpatička ak-

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tivnost u stanju mirovanja slična između polova kada su žene u kasnoj folikularnoj fazi. Hormonski ciklus kod žena nema uticaj na autonomnu varijabilnost u stanju mirovanja. Rana folikularna faza pokazuje poželjniji autonomni profil tokom oporavka u poređenju sa lutealnom fazom MC.

Ključne reči:
srce, frekvencija; nervni sistem, autonomni; vežbanje, testovi.

Introduction

Besides autonomic regulation, the rhythmicity of cardiac beats is finely directed by humoral factors, hence the influence of hormonal fluctuations on heart rate variability (HRV) throughout the menstrual cycle (MC) [1, 2]. The female monthly sexual cycle is dominantly regulated through the influences of the hypothalamic releasing hormone – gonadotropin-releasing hormone (GnRH), anterior pituitary sex hormones – follicle-stimulating hormone (FSH) and luteinizing hormone (LH), and the ovarian hormones – estrogen (mainly in the form of ß-estradiol) and progestogens (almost exceptionally progesterone). At the very beginning of the proliferative phase, there is a rise in FSH and LH levels, where FSH increases estrogen production in primary follicles leading to a peak secretion just before the ovulation. Two days prior to ovulation, the LH surge happens, rising by 6–10 fold, with the about 2–3-fold increase in FSH production at the same time. After ovulation, concentrations of progesterone and estrogen start to increase until the late luteal phase when involution of corpus luteum and cessation of progesterone and estrogen secretion removes the feedback inhibition, and levels of FSH and LH start to rise again [3]. The influence of the MC phases on HRV is not yet clear. Higher sympathetic activity in the luteal phase has been reported proposing the effect of progesterone increase on parasympathetic withdrawal [4–7]. At the same time, others have reported the opposite or did not find any significant phase differences [8, 9]. On the other side, estrogen, the leading hormone of the follicular phase, has a positive relationship with vagal activity [9]. It acts on presynaptic alpha-2 adrenoceptors leading to a decrease in norepinephrine secretion and is also associated with an increase in acetylcholine production [10], thus, it may be that the rise in FSH, LH, and progesterone levels accounts for the inhibition of estrogen-related vagal control [9]. Some studies show marked sympathetic tone in male athletes, while the parasympathetic nervous system dominates in female athletes [11, 12]. Research conducted on non-athletes showed diminished parasympathetic influence in younger and middle-aged women [13]. In another study, parasympathetic influence prevailed among adolescent female non-athletes, as opposed to their age-matched male counterparts [14]. Women have a faster vagal post-exercise recovery after a maximal aerobic capacity test [15], but the supra-maximal anaerobic test has a greater impact on autonomic reactivation in women [16, 17]. Women are, in general, underrepresented in exercise studies, and the majority of those that include them do not hold MC phases into account.

The aim of this paper was to investigate the influence of different MC phases (especially the early and late follicular phase) on resting and post-exercise autonomic modulation between genders, as well as in females solely. It was postulated that females would have higher parasympathetic indices when in the early and/or late follicular phase in comparison to males and intra-subject relations. Secondly, we wanted to examine how MC phases possibly influence the results of a supra-maximal (Wingate) test in females.

Methods

Participants

Forty-one participants (16 males and 25 females), aged 18 to 24 years (age 20.4 ± 0.7 years and 20.5 ± 0.7; height 184 ± 5 cm and 168 ± 5 cm; body weight 79.38 ± 9.42 kg and 60.96 ± 6.93 kg; body mass index 23.53 ± 2.83 and 21.57 ± 2.23, for males and females, respectively) entered the study voluntarily. All participants were regularly enrolled in the studies of medicine at the Faculty of Medicine, University of Novi Sad. Subjects were in self-reported good health, without the use of medications, and with no medical history of cardiovascular and neuromuscular diseases, including neuro-vegetative dystonia. The inclusion criterion for female participants was a regular MC. Additional criteria implied that leisure-time physical activity in the past six months did not exceed an hour of sports activity per day for no more than three days a week.

The research was approved by the Ethics Committee of the University of Novi Sad, Faculty of Medicine, and it was conducted according to the Declaration of Helsinki. Participants were thoroughly introduced to the study procedure and its goal, and they all gave written informed consent.

All measurements were conducted at the Laboratory for Functional Diagnostics of the Department of Physiology, between 10 and 12 am, at room temperature around 22–24ºC. Participants were strongly advised to restrain from intensive training and from consuming caffeinated and alcoholic beverages, including stimulant substances, 24 h before the test. Female subjects were required to come at three phases of their MC. MC phase calculation was performed via recommendations provided by Stricker et al. [18], where the 14th day of the cycle was marked as day zero. The measurements were taken during the phase of menstrual bleeding (from day -15 until -6) – the early follicular phase, when levels of both estrogen and progesterone are low; in the middle of late follicular phase (from day -5 until -1), when estrogen reaches its peak; in mid-luteal phase (from day +5 until +9), when progesterone peak is expected.

Study protocol and data acquisition

The protocol consisted of two modes of heart rate acquisition – at rest and during recovery, using a telemetric pulsometer (Polar RS800CX, Finland). Firstly, participants were required to sit quietly and breathe spontaneously for 5 minutes on a cycle ergometer (Wattbike, Wattbike Ltd, Nottingham, UK), with their feet placed on a platform in front of the pedals, knees flexed at a 90-degree angle, and arms resting on thighs while heart rate recordings were obtained. The Wingate anaerobic test was preceded by a 3-minute warm-up where resistance was set at 50 W. Throughout this period, they performed 2–3 bouts of sprint in order to get adjusted to the level of speed and exertion they had to engage for the test. After the warm-up period, subjects were instructed to pedal at full speed in a standing position against the constant breaking force (7.5% of body weight). Upon cessation of the exercise test, heart rate recording was started again for 5 minutes. During the first minute of the recovery period, participants continued pedalling without any resistance, and afterwards, they were required to stay in the same body position as before the exercise for additional 4 minutes.

Data analysis

Ergometric parameters

Peak power (PP) was a value of the highest power achieved at any 5-second stage. Mean power (MP) was defined as an average of all obtained power values.

Heart rate variability

A sampling rate of 1000 Hz was chosen, and data from the pulsometer were transferred to a laptop computer via a USB interface, where they were analyzed in Polar ProTrainer 5 TM (Polar, Finland) software. Ectopic beats and artefacts were identified with visual inspection and removed. They were deleted with the post extra systolic beat and replaced automatically with interpolated adjacent R-R interval values. HRV indices (the square root of the mean squared differences of successive NN intervals (RMSSD), low-frequency (LF) spectral power (0.04–0.15 Hz), and high-frequency (HF) spectral power (0.15–0.40 Hz) were calculated for all 5 minutes of resting period and for the 3-minute recovery period (minutes 3–5). In order to ensure the stability of the data and reduce bias arising from non-uniformity of error, natural log-transformations (ln) of spectral HRV indices were performed.

Heart rate recovery (HRR)

HRR was assessed via indices which were extracted from the 5-minute recovery recordings. HRR60 represents the absolute difference between heart rate values at 60 seconds after exercise termination (HR60) and peak heart rate values registered immediately after termination of the test (HRmax). Resting heart rate (HRrest) was presented as a mean heart rate value acquired from the pre-exercise 5-minute recordings. Heart rate readings at the end of the post-exercise period (HRend) were also obtained. T30 was a time constant of the rapid heart rate decay during the first 30 seconds of recovery and it represented the negative reciprocity of regression line slope. T was the time constant decay obtained by fitting the 5-minute post-exercise HRR into the first-order exponential curve [16, 19, 20], where heart rates were modelled with an iterative technique using MatLab software (The Math Works Inc, Natick, MA, USA) to fit the following equation:

$$HR = HR_o + HR\Delta e(-t+T)$$

Where: HR = heart rate, HR_o = stabilized heart rate following exercise, HRΔ = maximal heart rate – HR_o, t = time (s), T = time constant of exponential heart rate decay.

Statistical analysis

The normality of the distribution was assessed with the Lilliefors normality test. Microsoft Excel data analysis tool was used for statistical inspection. The F-test was performed to assess the equality of variances between groups, after which we did the two-sample *t*-test. The data are presented as means ± standard deviation (SD) with respect to 95% confidence interval (95% CI). Statistical significance was indicated at $p < 0.05$.

Results

There were significant differences in mean values of PP comparing the results in men with the results in women in early follicular ($p = 0.0000117$), late follicular ($p = 0.000016$), and luteal phase ($p = 0.0000157$). There were also significant differences in mean values for MP comparing the results in men with the ones in women in early follicular ($p = 0.000000213$), late follicular ($p = 0.00000871$), and luteal phase ($p = 0.000000209$) (Figure 1). There was no statistical significance in these parameters among menstrual cycle phases in women.

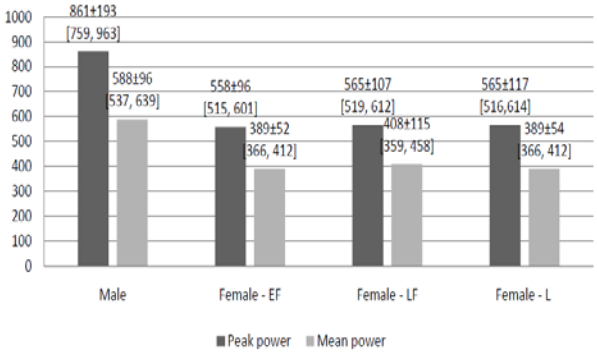

Fig. 1 – Wingate anaerobic test peak and mean power in men and women in different menstrual cycle phase [mean ± standard deviation (95% confidence interval)] EF – early follicular phase; LF – late follicular phase; L – luteal phase

Table 1

Resting heart rate variability indices in men and women in the early follicular menstrual cycle phase

Indices	Men	Women in the early follicular phase	*p*-value
RMSSD	27.25 ± 8.27 (22.84–31.66)	29.25 ± 15.82 (22.24–36.27)	> 0.05
lnLF	7.49 ± 0.51 (7.21–7.76)	6.62 ± 0.85 (6.24–6.99)	0.000376
lnHF	6.32 ± 0.58 (2.82–3.81)	5.73 ± 0.83 (5.36–6.09)	0.019372

***Note*: Results are given as mean ± standard deviation (95% confidence interval).**
RMSSD – root mean square of the successive differences; lnLF – natural log-transformations of low-frequency (LF) spectral power; lnHF – natural log-transformations of high-frequency (HF) spectral power.

Table 2

Resting heart rate variability indices in men and women in the late follicular menstrual cycle phase

Indices	Men	Women in the late follicular phase	*p*-value
RMSSD	27.25 ± 8.27 (22.84–31.66)	31.87 ± 14.92 (25.41–38.32)	> 0.05
lnLF	7.49 ± 0.51 (7.21–7.76)	6.61 ± 0.75 (6.29–6.93)	0.000248
lnHF	6.32 ± 0.58 (2.82–3.81)	5.93 ± 1.10 (5.45–6.40)	> 0.05

***Note*: Results are given as mean ± standard deviation (95% confidence interval).**
RMSSD – root mean square of the successive differences; lnLF – natural log-transformations of low-frequency (LF) spectral power; lnHF – natural log-transformations of high-frequency (HF) spectral power.

Table 3

Resting heart rate variability indices in men and women in the luteal menstrual cycle phase

Indices	Men	Women in the luteal phase	*p*-value
RMSSD	27.25 ± 8.27 (22.84–31.66)	28.66 ± 12.92 (23.20–34.11)	> 0.05
lnLF	7.49 ± 0.51 (7.21–7.76)	6.47 ± 0.82 (6.12–6.81)	0.0000232
lnHF	6.32 ± 0.58 (2.82–3.81)	5.67 ± 0.89 (5.29–6.05)	8.79E-10

***Note*: Results are given as mean ± standard deviation (95% confidence interval).**
RMSSD – root mean square of the successive differences; lnLF – natural log-transformations of low-frequency (LF) spectral power; lnHF – natural log-transformations of high-frequency (HF) spectral power.

By analyzing HRV indices during rest in relation to gender, RMSSD did not show valuable differences, lnLF was significantly higher in men in comparison to women throughout all three MC phases, and lnHF was significantly higher in men in contrast to women in the early follicular and luteal phase of MC (Tables 1–3).

After analyzing the HRV recovery parameters, it was noticed that RMSSD did not show statistical significance when compared to any of the female cycle phases with males. On the other side, lnLF and lnHF values markedly differed between men and women in all MC phases (Figure 2).

When comparing females during rest in various MC phases, no differences were observed in HRV. However, during the recovery from the Wingate anaerobic test, RMSSD was noticeably higher while females were in the early follicular phase vs. luteal phase of MC (6.29 ± 1.06, 5.20 ± 0.83; $p = 0.011415$). Moreover, in the early follicular phase, female participants had greater values of lnLF in

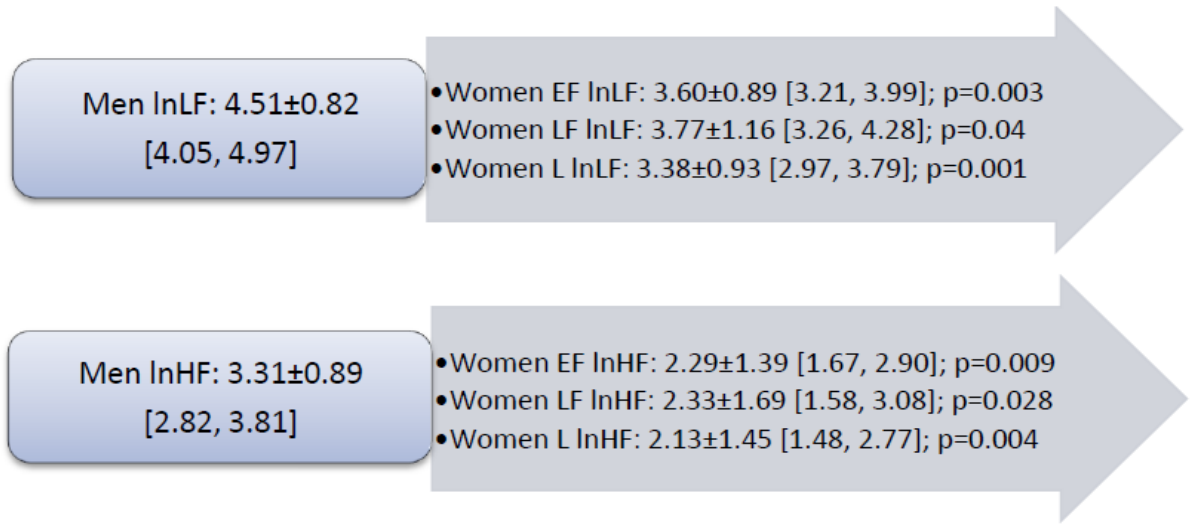

Fig. 2 – Recovery lnLF and ln HF values in men and women in different menstrual cycle phases [mean ± standard deviation (95% confidence interval)].
lnLF - natural log-transformations of low-frequency (LF) spectral power; lnHF - natural log-transformations of high-frequency (HF) spectral power; EF – early follicular phase; LF – late follicular phase; L – luteal phase.

comparison to the luteal phase of MC (3.62 ± 0.20, 3.39 ± 0.21; $p = 0.008511$).

Mean values of HRrest, HRmax, HR60, HRR60, HRend, and T did not significantly differ between men and women in the examined MC phases ($p > 0.05$), but heart rate recovery perceived through T30 was faster in men in comparison to women in all MC phases (Table 4). Not one parameter showed differences in various phases among the females ($p > 0.05$).

Discussion

As opposed to what we have expected, males had a more favourable autonomic profile than females. Our study showed that males had greater resting and post-exercise overall HRV, as well as faster HRR no matter in which phase of the menstrual cycle the women were in. Contrary to the findings of some authors [21, 22], we did not find intra-subject HRV differences regarding the cycle phase during rest. Sur-

Table 4

Resting heart rate and heart rate recovery indices after a Wingate anaerobic test in men and women in different menstrual cycle phases

Indices	Men	Women – early follicular phase	Women – late follicular phase	Women – luteal phase
HRrest	89 ± 11 (84–95)	89 ± 12 (70–95)	87 ± 14 (81–93)	90 ± 13 (84–95)
HRmax	188 ± 9 (183–193)	186 ± 7 (182–189)	185 ± 9 (181–189)	186 ± 10 (182–191)
HR60	158 ± 13 (151–166)	155 ± 8 (151–159)	156 ± 13 (150–161)	154 ± 13 (148–160)
HRR60	30 ± 9 (25–34)	30 ± 7 (27–33)	29 ± 9 (25–33)	32 ± 11 (27–37)
HRend	116 ± 6 (112–119)	113 ± 13 (107–119)	110 ± 15 (104–117)	115 ± 16 (108–122)
T30	262.1 ± 91.8 (213–311)	621.4 ± 161.1* (548–695)	607.04 ± 150.6† (538–675)	661.34 ± 206.9‡ (570–753)
T	135.7 ± 53.1 (107–164)	134.2 ± 47.1 (112–156)	123.7 ± 44.2 (102–145)	117.8 ± 43.4 (98–138)

***Note*: Results are given as mean ± SD (95% confidence interval).**
***p* = 6.88E-10; †*p* = 4.72E-10; ‡*p* = 4.56E-09.**
HRrest – resting heart rate; HRmax – peak heart rate values registered immediately after termination of the test; HR60 – the absolute difference between heart rate values at 60 seconds after exercise termination; HRR60 – the absolutwe difference between heart rate values at 60 seconds after exercise termination (HR60) and peak heart rate values registered immediately after termination of the test (HRmax); HRend – heart rate values at the end of the post-exercise period; T30 – time constant of the rapid heart rate decay during the first 30 seconds of recovery; T – time constant decay obtained by fitting the 5-minute post-exercise heart rate recovery into a first-order exponential curve.

prisingly, both RMSSD and lnLF were augmented in the early follicular in comparison to the luteal phase of MC.

The anaerobic capacity results (PP, MP) after the Wingate test were in accordance with the existing literature [16, 23, 24]. Muscle hypertrophy and variations in muscle fibre type are, allegedly, the main causes for higher values of PP and MP in men. There is a prevalence of slow twitching fibres in skeletal muscle sections in women [25, 26]. Furthermore, some authors suspect that differences in sarcomeral metabolism might influence the divergence in muscle power between sexes [27]. Similar to the recently published results [28, 29], the difference in anaerobic power parameters in women concerning MC phases was not observed in our study.

In the general population, sympathetic nervous system activity is higher in men and parasympathetic one in premenopausal women [12, 14, 30–32]. Time and frequency domain differences between genders gradually fade out with age. In fact, they fade more progressively after the third decade [33]. Numerous papers point out that the differences disappear after 50 years of age [12, 34], which is addressed to postmenopause and a lowered protective effect of endogenous sex hormones in women. In our study, resting values of lnLF were higher in men, which is in agreement with the above mentioned if we consider LF as a marker of solely sympathetic activity. However, LF portrays joined actions of both autonomic branches with a slight predominance in sympathetic activity, especially after a workout [35]. LF also represents oscillations in the baroreceptors system [36, 37], and baroreflex sensitivity (BRS) is said to be higher in men while at rest [38]. Our participants had their HRV registered in a sitting position, which provokes the sympathetic response, but we saw no change in lnLF while comparing females in different phases, although the baroreflex response of a sympathetic component in women is found to be more pronounced in the menstrual and/or luteal phase [21]. In fact, a significant number of papers imply that the sympathetic nervous system is more active during the luteal phase [5, 7, 10]. However, there are also papers where no differences between phases were observed [6, 9]. On the other hand, our results also showed that parasympathetic influence (lnHF) during rest was more prominent in the male sex in comparison to women in the early follicular and luteal MC phase. The lack of differences between genders when females were in the late follicular phase might express the evolving vagal tone while approaching peak levels of estrogen. Despite a much greater number of opposing results [39–41] that did not take MC into account, it appears that working in shifts can indeed influence female HRV depending on the MC phase [8]. In this case, the follicular phase shows a fall in vagal and an increase in sympathetic activity. The results we got might have an explanation for stress and lack of sleep that medical students deal with, which may have heightened sympathetic tone in the male and lessened parasympathetic tone in female participants. On the other side, our study lacks information on physical activity levels. Greater participation in recreational sport could explain prevailed vagal indices in men.

Markedly higher lnLF and lnHF values were obtained in males after the Wingate test in comparison to women in all menstrual cycle phases. These findings contrast the ones found by authors who reported higher values of HF in women during recovery from the test for maximal oxygen consumption and concluded that women have faster vagal post-exercise reactivation [15]. In general, HRR is faster after the Wingate test, and recovery after an incremental VO2max test sometimes takes several days [42, 43], but supramaximal exercise has a greater impact on autonomic modulation in women. Significantly decreased HF power after the Wingate test in females in contrast to males was reported in one study with the upright sitting position where only vagal indices were analyzed [16], and a significant increase in LF power was reported in another study where recovery took place in a supine position [17]. Despite that, men have accentuated resting baroreflex sensitivity (BRS), and women might possess a higher diapason of its effect during post-exercise recovery. This was supported by a persistent reduction in heart rate in women while seated, but not in men [38]. Contrary to this, another study found that seated position provokes less favourable recovery than supine [19]. In our study, women had a slower HRR and a lesser lnLF after exercise. Although stress can be addressed for suppressed BRS [44], our participants were subjected to the same levels. Maybe poor engagement in sport in our female participants can be held responsible for such results, but we do not have evidence to support that.

Intra-subject differences in HRV during recovery were observed in females. A marker of vagal activity, RMSSD, was higher in the early follicular phase in comparison to the luteal one. Among eumenorrheic women, even in those who report premenstrual symptoms, resting RMSSD is mostly higher in the follicular in comparison to the luteal phase [10, 45]. However, some authors consider the follicular phase as the one that follows the menstrual phase, starting on day 8 or 9 of MC, which is by our classification addressed as the late follicular phase. We also found that post-exercise lnLF was higher in the early follicular phase in relation to the luteal phase. Whether dysmenorrhoea can be the cause of disrupted autonomic modulation was a matter of subject in various studies [46, 47], which stated that a slight increase in LF/HF can exist during menstruation pointing out to a fall in parasympathetic activity. However, in our female population vagal index – RMSSD, was marked in the early follicular phase. It is possible that BRS during post-exercise recovery is more pronounced in the early follicular phase in comparison to other phases, or that the parasympathetic component of the low-frequency domain is augmented.

Resting heart rate did not differ between the sexes in our study. Literature shows favourably lower resting heart rates in men [16, 48, 49]. The lack of this difference in our results might be because of the small sample size but also because of the specificity of the medical student population. There is proof that stress and working in shifts can significantly lower the HRV indices (SDNN, TP, HF) among the male health workers without greater interfering with these indices in females [39–41]. The similar stressful life milieu of our participants could have influenced diminished differences in genders. Maximally achieved heart frequencies did not stand in

contrast between men and women in our study, which is consistent with previous results [15, 17, 23].

In accordance with the previous findings [16], our results showed faster vagal reactivation in males, perceived by T30, which is an immediate post-exercise index of vagally mediated cardiac rate decay [50, 51]. HRR was found to be in a strong correlation with the level of physical activity [52]. It was also found to negatively correlate with resting supine parasympathetic markers of HRV when in a standing position during the first minute of recovery, but the higher the indices of combined autonomic modulation (LF, lnLF), the greater the HRR in the third and fifth-minute post-exercise [53–55]. The existing data report no correlation of estradiol levels with the initial HRR dynamics [38]. Similar to a study by Pestana et al. [29], we did not find statistical differences in HRR among the MC phases.

Conclusion

Men have greater total variability and a more favourable autonomic profile during rest and in a seated recovery after the Wingate test. Our study supports the notion that supra-maximal exercises present a heavier load to the female autonomic nervous system. Products of anaerobic metabolism and muscle metaboreflexes, in a way, may be responsible for this. We would also like to instigate more research towards understanding HRV dynamics concerning the early and late follicular phases. We guess that in a resting state, vagal influence could be expected in the late follicular phase coinciding with the peak levels of estrogen. On the other hand, in a recovery state, vagal reactivation might preferably be recorded in the early follicular phase before the preovulatory FSH and LH surge happen.

R E F E R E N C E S

1. *Brar TK, Singh KD, Kumar A.* Effect of different phases of menstrual cycle on heart rate variability (HRV). J Clin Diagnostic Res 2015; 9(10): CC01-4.
2. *Neufeld IW, Kiselev AR, Karavaev AS, Prokhorov MD, Gridnev VI, Ponomarenko VI,* et al. Autonomic control of cardiovascular system in pre- and postmenopausal women: a cross-sectional study. J Turk Ger Gynecol Assoc 2015; 16(1): 11–20.
3. *Hall JE.* Gyton and Hall textbook of medical physiology. 12th ed. Philadelphia (PA): Saunders; 2011.
4. *McKinley PS, King AR, Shapiro PA, Slavov I, Fang Y, Chen IS,* et al. The impact of menstrual cycle phase on cardiac autonomic regulation. Psychophysiology 2009; 46(4): 904–11.
5. *Bai X, Li J, Zhou L, Li X.* Influence of the menstrual cycle on nonlinear properties of heart rate variability in young women. Am J Physiol Heart Circ Physiol 2009; 297(2): H765–74.
6. *Yazar S, Yazici M.* Impact of menstrual cycle on cardiac autonomic function assessed by heart rate variability and heart rate recovery. Med Princ Pract 2016; 25(4): 374–7.
7. *Tenan MS, Brothers RM, Tweedell AJ, Hackney AC, Griffin L.* Changes in resting heart rate variability across the menstrual cycle. Psychophysiology 2014; 51(10): 996–1004.
8. *Chung MH, Yang CCH.* Heart rate variability across the menstrual cycle in shift work nurses. J Exp Clin Med 2011; 3(3): 121–5.
9. *Leicht AS, Hirning DA, Allen GD.* Heart rate variability and endogenous sex hormones during the menstrual cycle in young women. Exp Physiol 2003; 88(3): 441–6.
10. *Grrishma B, Gaur GS, Velkumary S, Subramanian SK, Gurunandan U.* Assessment of cardiovascular autonomic functions and baroreceptor reactivity in women with premenstrual syndrome. Indian J Physiol Pharmacol 2015; 59(2): 148–54.
11. *Schafer D, Gjerdalen GF, Solberg EE, Khokhlova M, Badtieva V, Herzig D,* et al. Sex differences in heart rate variability: a longitudinal study in international elite cross-country skiers. Eur J Appl Physiol 2015; 115(10): 2107–14.
12. *Dutra SG, Pereira AP, Tezini GC, Mazon JH, Martins-Pinge MC, Souza HC.* Cardiac autonomic modulation is determined by gender and is independent of aerobic physical capacity in healthy subjects. PLoS One 2013; 8(10): e77092.
13. *Zhao R, Li D, Zuo P, Bai R, Zhou Q, Fan J,* et al. Influences of age, gender, and circadian rhythm on deceleration capacity in subjects without evident heart diseases. Ann Noninvasive Electrocardiol 2015; 20(2): 158–66.
14. *Sharma VK, Subramanian SK, Arunachalam V, Rajendran R.* Heart rate variability in adolescents – normative data stratified by sex and physical activity. J Clin Diagnostic Res 2015; 9(10): CC08-CC13.
15. *Kappus RM, Ranadive SM, Yan H, Lane-Cordova AD, Cook MD, Sun P,* et al. Sex differences in autonomic function following maximal exercise. Biol Sex Differ 2015; 6: 28.
16. *Barak O, Klasnja A, Gacesa-Popadic J, Ovicn Z, Grujic N.* Gender differences in parasympathetic reactivation during recovery from Wingate anaerobic test. Period Biol 2014; 116(1): 53–8.
17. *Mendonca GV, Heffernan KS, Rossow L, Guerra M, Pereira FD, Fernhall B,* et al. Sex differences in linear and nonlinear heart rate variability during early recovery from supramaximal exercise. Appl Physiol Nutr Metab 2010; 35 (4): 439–46.
18. *Stricker R, Eberhart R, Chevailler MC, Quinn FA, Bischof P, Stricker R.* Establishment of detailed reference values for luteinizing hormone, follicle stimulating hormone, estradiol, and progesterone during different phases of the menstrual cycle on the Abbott ARCHITECT® analyzer. Clin Chem Lab Med 2006; 44(7): 883–7.
19. *Barak OF, Jakovljevic DG, Popadic Gacesa JZ, Ovcin ZB, Brodie DA, Grujic NG.* Heart rate variability before and after cycle exercise in relation to different body positions. J Sports Sci Med 2010; 9(2): 176–82.
20. *Buchheit M, Laursen PB, Ahmaidi S.* Parasympathetic reactivation after repeated sprint exercise. Am J Physiol Heart Circ Physiol 2007; 293(1): H133–41.
21. *Saeki Y, Atogami F, Takahashi K, Yoshizawa T.* Reflex control of autonomic function induced by posture change during the menstrual cycle. J Auton Nerv Syst 1997; 66(1–2): 69–74.
22. *Yildirir A, Kabakci G, Akgul E, Tokgozoglu L, Oto A.* Effects of menstrual cycle on cardiac autonomic innervation as assessed by heart rate variability. Ann Noninvasive Electrocardiol 2002; 7(1): 60–3.
23. *Astorino TA, Allen RP, Roberson DW, Jurancich M, Lewis R, McCarthy K,* et al. Adaptations to high-intensity training are independent of gender. Eur J Appl Physiol 2011; 111(7): 1279–86.
24. *Hazir T, Kosar N.* Assessment of gender differences in maximal anaerobic power by ratio scaling and allometric scaling. Isokinet Exerc Sci 2007; 15: 253–61.
25. *Driss T, Vandewalle H.* The measurement of maximal (anaerobic) power output on a cycle ergometer: a critical review. Biomed Res Int 2013: 2013: 589361.
26. *Perez-Gomez J, Rodriguez GV, Ara I, Olmedillas H, Chavarren J, Gonzalez-Henriquez JJ,* et al. Role of muscle mass on sprint performance: gender differences? Eur J Appl Physiol 2008; 102(6): 685–94.

27. *Fuentes T, Guerra B, Ponce-Gonzalez JG, Morales-Alamo D, Guadalupe-Grau A, Olmedillas H,* et al. Skeletal muscle signaling response to sprint exercise in men and women. Eur J Appl Physiol 2012; 112(5): 1917–27.
28. *Wiecek M, Szymura J, Maciejczyk M, Cempla J, Szygula Z.* Effect of sex and menstrual cycle in women on starting speed, anaerobic endurance and muscle power. Acta Physiol Hung 2016; 103(1): 127–32.
29. *Pestana ER, Salvador EP, Pereira GB, Mostarda CT, Leite RD, Silva CR,* et al. Influence of the mid-follicular and late luteal phases on anaerobic power in university students. Sport Sci Health 2017; 13(2): 281–6.
30. *Da Silva VP, De Oliveira NA, Silveira H, Mello RGT, Deslandes AC.* Heart rate variability indexes as a marker of chronic adaptation in athletes: a systematic review. Ann Noninvasive Electrocardiol 2015; 20(2): 108–18.
31. *Yang SG, Mlcek M, Kittnar O.* Estrogen can modulate menopausal women's heart rate variability. Physiol Res 2013; 62 Suppl 1: S165–71.
32. *Sookan T, McKune AJ.* Heart rate variability in physically active individuals: reliability and gender characteristics. Cardiovasc J Afr 2012; 23(2): 67–72.
33. *Antelmi I, De Paula RS, Shinzato AR, Peres CA, Mansur AJ, Grupi CJ.* Influence of age, gender, body mass index, and functional capacity on heart rate variability in a cohort of subjects without heart disease. Am J Cardiol 2004; 93(3): 381–5.
34. *Voss A, Schroeder R, Heitmann A, Peters A, Perz S.* Short-term heart rate variability-influence of gender and age in healthy subjects. PLoS One 2015; 10(3): e0118308.
35. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 1996; (93): 1043–65.
36. *da Silva E, Rebelo ACS, Tamburus NY, Salviati MR, Santos MCS, Zuttin RS.* Spectral analysis of heart rate variability in women. In: Salih S, editor. Fourier Transform Applications. London, UK: Intech Open; 2012. p. 169–80.
37. *Roach D, Sheldon R.* Origins of the power of the low frequency heart rate variability bandwidth. J Electrocardiol 2018; 51(3): 422–7.
38. *Beltrame T, Catai AM, Rebelo AC, Tamburus NY, Zuttin RS, Takahashi ACM,* et al. Associations between heart rate recovery dynamics with estradiol levels in 20 to 60 year-old sedentary women. Front Physiol. 2018; 9: 533.
39. *Lin YH, Chen CY, Lin SH, Liu CH, Weng WH, Kuo TBJ,* et al. Gender differences in cardiac autonomic modulation during medical internship. Psychophysiology 2013; 50(6): 521–7.
40. *Hulsegge G, Gupta N, Proper KI, van Lobenstein N, IJzelenberg W, Hallman DM,* et al. Shift work is associated with reduced heart rate variability among men but not women. Int J Cardiol 2018; (258): 109–14.
41. *Kikuchi Y, Ishii N, Kodama H.* Effects of night-time on-call work on heart rate variability before bed and sleep quality in visiting nurses. Int Arch Occup Environ Health 2018; 91(6): 695–704.
42. *Goulopoulou S, Heffernan KS, Fernhall B, Yates G, Baxter-Jones ADG, Unnithan VB.* Heart rate variability during recovery from a Wingate test in adolescent males. Med Sci Sports Exerc 2006; 38(5): 875–81.
43. *Daniłowicz-Szymanowicz L, Raczak G, Szwoch M, Ratkowski W, Torunski A.* The effect of anaerobic and aerobic tests on autonomic nervous system activity in healthy young athletes. Biol Sport 2010; 27(1): 65–9.
44. *Teixeira AL, Ritti-Dias R, Antonino D, Bottaro M, Millar PJ, Vianna LC.* Sex differences in cardiac baroreflex sensitivity after isometric handgrip exercise. Med Sci Sports Exerc 2018; 50(4): 770–7.
45. *Vallejo M, Marquez MF, Borja-Aburto VH, Cárdenas M, Hermosillo AG.* Age, body mass index, and menstrual cycle influence young women's heart rate variability: a multivariable analysis. Clin Auton Res 2005; 15(4): 292–8.
46. *Wang YJ, Wang YZ, Yeh ML.* A prospective comparison study of heart rate variability during menses in young women with dysmenorrhea. Biol Res Nurs 2016; 18(4): 365–72.
47. *Singh K, Srivastava D, Archana, Misra R, Tyagi M.* Cardiac autonomic activity in young females with primary dysmenorrhea. Indian J Physiol Pharmacol 2013; 57(3): 246–54.
48. *Golosheykin S, Grant JD, Novak OV, Heath AC, Anokhin AP.* Genetic influences on heart rate variability. Int J Psychophysiol 2017; 115: 65–73.
49. *Dantas EM, Kemp AH, Andreao RV, da Silva VJD, Brunoni AR, Hoshi RA,* et al. Reference values for short-term resting-state heart rate variability in healthy adults: results from the Brazilian longitudinal study of adult health-ELSA-Brasil study. Psychophysiology 2018; 55(6): e13052.
50. *Imai K, Sato H, Hori M, Kusuoka H, Ozaki H, Yokoyama H,* et al. Vagally mediated heart rate recovery after exercise is accelerated in athletes but blunted in patients with chronic heart failure. J Am Coll Cardiol 1994; 24(6): 1529–35.
51. *Otsuki T, Maeda S, Iemitsu M, Saito Y, Tanimura Y, Sugawara J,* et al. Postexercise heart rate recovery accelerates in strength-trained athletes. Med Sci Sports Exerc 2007; 39(2): 365–70.
52. *Guerra ZF, Pecanha T, Moreira DN, Silva LP, Laterza MC, Nakamura FY,* et al. Effects of load and type of physical training on resting and postexercise cardiac autonomic control. Clin Physiol Funct Imaging 2014; 34(2): 114–20.
53. *Molina GE, Fontana KE, Porto LGG, Junqueira LF.* Post-exercise heart-rate recovery correlates to resting heart-rate variability in healthy men. Clin Auton Res 2016; 26(6): 415–21.
54. *Esco MR, Flatt AA.* Ultra-short-term heart rate variability indexes at rest and post-exercise in athletes: evaluating the agreement with accepted recommendations. J Sport Sci Med 2014; 13(3): 535–41.
55. *Nakamura FY, Flatt AA, Pereira LA, Ramirez-Campillo R, Loturco I, Esco MR.* Ultra-short-term heart rate variability is sensitive to training effects in team sports players. J Sports Sci Med 2015; 14(3): 602–5.

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