Changes of Cardiopulmonary and Metabolic Functions during Jogging with and without Breast Supports: a randomized controlled trial

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Research article

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Abstract

Background:To shed light on the physiologic reasons behind exercise intolerance in active females, we investigated the physiological changes of cardiopulmonary and metabolic functions during jogging with and without breast supports.

Methods/Design:Thirteen healthy females participated in three randomized jogging trials of no bra (NB, served as control), and two breast supports of casual bra (CB), and jogging bra (JB). Immediate effects of bras on static and dynamic lung functions were identified by using the standard pulmonary function test. Metabolic changes and cardiovascular functions were continuously determined at rest, during jogging and recovery.

Results:Results showed the only immediate effect of donning jogging bra on temporary reductions in resting respiratory flow rates (forced expiratory volume in 1 second and maximum voluntary ventilation) ($P<0.05$) compared with pre-bras values, while static lung function remained unchanged. Theabove immediate effects of breast support on respiratory flow reductions regained during exercise. All cardiorespiratory and metabolic variables were similar among conditions ($P>0.05$) of either at rest, during or after jogging. Only casual bra showed significant late recovery in tidal volume, oxygen consumption and energy expenditure compared with resting values.

Conclusions: Any types of breast support exhibit no limitation on cardiorespiratory and metabolic functions during jogging. Jogging with breast support is recommended during exercise for health promotion and wellbeing in adolescent girls and women.

Trial registration: The current study was retrospectively registered. Clinicaltrials.in.th TCTR20200311002. Registered 11 March 2020.

Background:

Jogging is one among popular health promotion tools worldwide for all ages and genders [1, 2]. For some reasons, numbers of females participating in physical activity are lower than males for all age groups [3, 4]. In which repeated breast displacements during workout, either vertical or horizontal directions, adversely affect women's abilities, for example discomfort, pain, and chronic soft tissue injury, especially in active females with large breasts [5–7]. A review from cohort studies likely reported physical activity and risks of breast cancer in this specific population [8].

Breast supports, in term of common fashion bras, are typically produced for commercial purposes [6, 9]. This, in turn, fails to minimize repeated breast motions during exercise [9, 10]. Other types of breast support, encapsulation or compression bras [10], have been specifically designed to minimize excessive breast motion during physical activity [5, 6]. Despite the fact that breast supports, of either low or high quality, could promote willingness to exercise [11], only 13% of adolescent females [12] and 41% of women are reported to use breast supports (jogging bras) during physical activity [13] for the belief that this will induce skin furrows from shoulder straps, discomfort, and dyspnea [13, 14]. Results obtained from previous studies demonstrated that elastic thoracic band may cause restriction, which limits chest wall expansion and lung function [15, 16] and may deviate respiratory pattern towards rapid and shallow breathing [17]. Controversially, a study showed that wearing a jogging bra exerted no significant effects on the respiratory function of healthy active females [14]. Most of the previous studies focused on subjective outcomes and respiratory functions [1, 2, 5, 9, 14, 17]. We believed that female’s breast support may interfere with cardiorespiratory and metabolic functions. Up-to-date, there is no available evidence on the effects of different breast supports on cardiorespiratory and metabolic changes. Therefore, the primary aim of this study is to investigate the effects of jogging with and without two types of breast supports on dynamic alterations of cardiopulmonary and metabolic function at rest, and during exercise and recovery.

Methods:

Participants

Sample size (n = 15) was estimated based on the previous study [14] using G-Power program at a significant level of α = 0.05, power of 80%. Eligibility criteria included young participants with age ranges 20–25 years, had active lifestyle with B and C breast cup sizes (determined by an expert), free from any cardiorespiratory and musculoskeletal disorders, had regular menstrual cycle, not using hormone replacement therapy, non-pregnant, non-smoking, non-alcoholic, had no experience wearing any jogging bras within the last 6 months prior to testing and abled to complete all three trials within three months of the study. Objectives, experimental procedures, potential benefits, and possible risks were explained to subjects before completing the informed consent forms. A week prior to the test, participants’ bra sizes were identified according to the previous report [12]. Instructions were provided to the participants to maintain their regular diet, avoid coffee, tea, tobacco and alcohol, to avoid vigorous or unfamiliar strenuous physical activity and to sleep more than 8 hours on the day prior to the test. All participants completed the informed consent forms authorized by the committees.

Participating institutions

College of Sports Science and Technology, Mahidol University in Thailand designed and developed this study with supported from experts from R&D Division of Thai Wacoal Public Co., Ltd.

Experimental procedures

This study was a 3-month crossover designed. All participants visited the laboratory (College of Sports Science and Technology, Mahidol University) to complete three jogging exercises in a randomized order of no bra (NB, control), casual bra (CB, individual’s daily worn bra), and jogging bra (JB). To minimize hormonal fluctuations and carry over effect, subjects were asked to visit the laboratory at the same phase of the menstrual cycle during three months period. After a 5-minute callisthenic warm up, participants then exercised continuously on a motor-driven treadmill at a constant speed of 4 mph up to 80% of their age-predicted maximum heart rates (MHR). Series of data were presented at rest, 60%, 70%, and 80% of MHR, and during the 5-minute recovery period. Telemetry gas analyzer (Oxycon Mobile, Germany) was used to determine oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), and energy expenditure (EE). Cardiovascular function and hemodynamic responses, including heart rate (HR), stroke volume (SV), cardiac output (CO), end-diastolic volume (EDV), ejection fraction (EF), systemic vascular resistance (SVR) etc., were also continuously monitored using a non-invasive technique (Physioflow, Manatec, France). The above variables and subjective evaluations, including ratings of perceived exertion (RPE), discomfort and dyspnea scales were also collected prior to, during and after exercise. Resting pulmonary functions (MicroLab Digital Spirometer, USA) were performed before and immediately after wearing CB and JB to determine static and dynamic lung functions, including tidal volume (V_T), vital capacity (VC), inspiratory capacity (IC), inspiratory reserve volume (IRV), expiratory reserve volume (ERV), respiratory rate (RR), minute ventilation ($\dot{V}_E$), forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), percentage of forced expiratory volume in 1 second and forced vital capacity (%FEV_1), peak expiratory flow (PEF), and maximal voluntary ventilation (MVV).

Statistical analysis

A two-factor [condition (NB, CB, JB) x time (rest, exercise, recovery)] general linear model, two-way ANOVA with repeated measures, was used to evaluate differences of cardiorespiratory and metabolism between conditions as the primary outcomes. Significant main effects and interactions were compared using Tukey's *post hoc* test. A paired-*t* test was used to analyze the differences of pulmonary functions between the pre- and post-bra (CB and JB) data as the secondary outcomes. Level of significance was accepted at $P < 0.05$. All data are presented as mean ± standard error of mean (SEM).

Results:

Subjects' ages and heights were 22.88 ± 2.42 yrs and 1.61 ± 0.06 m respectively. Body mass index (BMI) for NB, CB, and JB conditions were 21.70 ± 1.77, 21.78 ± 1.68 and 21.70 ± 1.64 kg/m^2 respectively. At a constant jogging speed of 4 mph, no significant differences in jogging durations between the three conditions were found. Exercise durations at 60%, 70% and 80% MHR were 7.06 ± 1.66 min, 12 ± 2.82 and 14.88 ± 1.95 min (NB), 8.94 ± 2.10, 15.07 ± 3.95 and 24.60 ± 3.54 min (CB), and 8.13 ± 1.98, 12.42 ± 2.59, and 20.78 ± 3.70 min (JB) respectively. Number of subjects whose exercise terminated at 60%, 70% and 80% MHR were 1, 3, and 9 (during NB trial), 1, 3, and 9 (during CB trial), and 2, 2, and 9 (during JB trial), respectively.

Immediate effects of donning a breast support on resting lung volumes and capacities

Immediate effects of breast support on resting lung volumes and capacities could only be done in resting CB and JB conditions (Table 1). Data were compared for both within- and between-groups. There were no significant changes in VC, IC, V_T, IRV, ERV, RR, $\dot{V}_E$, FVC, %FEV_1, or PEF variables from donning either the

CB or JB (all $P > 0.05$). However, significantly lower FEV_1 (L) and MVV ($P < 0.05$, Table 1) were found only between the pre- and post-donning JB.

Lung volumes and flows during and after exercise

Participants reported no evidence of dyspnea during exercise or recovery in any conditions. Only V_T, RR, and $\dot{V}_E$ were compared at 60, 70, and 80% MHR, during jogging and recovery period (Fig. 1). These respiratory variables significantly increased with exercise duration ($P < 0.05$), with a peak in RR and $\dot{V}_E$ observed at the highest workload of 80% MHR in all groups, whereas V_T reached plateaus since 60%MHR. During the exercise period, there were no significant differences between these variables among breast supports conditions ($P > 0.05$).

After exercise cessation, V_T and RR (Fig. 1A, B) showed immediate recovery compared to resting values for all groups. Only $\dot{V}_E$ of NB condition showed an immediate recovery after exercise, whereas JB returned to its resting value after 3 min. In CB condition, $\dot{V}_E$ did not recover even at 5 min post-exercise (Fig. 1C).

Metabolic profiles during and after exercise

Compared to resting values, there were abrupt increased in $\dot{V}O_2$, $\dot{V}CO_2$, and EE with the gradually increased of RER during exercise in all conditions (Fig. 2). There were no significant differences in $\dot{V}O_2$, $\dot{V}CO_2$, RER, and EE among conditions at rest, during exercise, and recovery ($P > 0.05$). During exercise, NB and JB conditions exhibited higher RER with respect to their resting values, but was not in CB trial (Fig. 2C).

During recovery, RER further increased with no significant differences observed among conditions ($P > 0.05$). NB condition showed that most of the metabolic variables immediately returned to their resting levels during recovery, with the exception of RER at 2 min. In the CB trial, $\dot{V}O_2$, $\dot{V}CO_2$, and EE showed recovery at 4, 4, and 4 min respectively, with an immediate recovery of RER. In the JB condition, $\dot{V}O_2$, $\dot{V}CO_2$ and EE showed recovery at 4 min with no recovery of RER throughout 5 min period.

Cardiovascular profiles during and after exercise

With the exception of the reductions of SVR, most cardiovascular variables (HR, SV, CO, CI, EF and EDV) significantly increased, from resting values, during exercise in all conditions ($P < 0.05$) (Fig. 3). However, comparisons among the three conditions showed no significant differences in cardiovascular variables at rest, during exercise, and the recovery period ($P > 0.05$). During exercise, EF in CB and JB conditions significantly increased from resting values ($P < 0.05$) but EF remained unchanged in NB trial (Fig. 3E).

During recovery, SV and EDV (Fig. 3B, F) remained unchanged from resting values in each condition. HR, CO, CI were all significantly elevated (Fig. 3A, C, and D). In the NB condition, the recovery of SVR and EF occurred at 2 and 3 min after exercise, respectively (Fig. 3E, G). SVR and EF in CB were observed at 4 and 2 min whereas SVR and EF in JB were at 3 and 4 min after exercise, respectively.

Discussion:

This study demonstrates the absence of limitations in either cardiorespiratory or metabolic variables during jogging regardless of types of breast support used. The slightly diminished respiratory flow rates after immediate donning the JB can be compensated during jogging. In addition, JB shows an earlier recovery of some metabolic and cardiorespiratory variables ($\dot{V}O_2$, EE, $\dot{V}_E$, and SVR) in comparison with CB. As jogging without breast support causes the risks of repeated motions of soft tissues around the chest [18], we recommend active females to jog with bras to enhance cardiorespiratory recovery during training.

Results from this study show that elastic compression of bras, from either CB or JB, will not cause any difficulties in cardiorespiratory and metabolic functions during jogging. Thus, intensity-dependent characteristics likely dominate most of the cardiorespiratory and metabolic responses, not the compressive force from bra elastic properties. It was reported that the difficulty of breathing in association with uncomfortable feeling will only from the tight chest wall restriction [17]. Indeed, it has been shown that high chest wall compressive pressures of over 75 mmHg (101 cm H_2O) [19] or up to -20% of chest circumference [20] can cause deteriorations in lung function with reductions in VC and expiratory flow rates. According to previous finding [21], we observed minimal skin furrows from chest straps, which indicate minimal pressure generated from either CB or JB. However, this minimal pressure is possibly the cause of immediate unfamiliar feelings [22] which lower some respiratory variables. In addition, women subjects with statures of 160 cm and 60 kg body weight have small chest wall area compared to the whole body surface area [23] which approximately corresponds to about 0.3 m^2 [24]. Thus, the bra types used in this study cover minimal chest surface area and would not induce high chest wall restriction.

Ventilatory responses to exercise in the present study confirm the intensity dependent characteristics. This exercise-induced ventilation was observed immediately after the exercise activity was started, of which ventilatory changes were similar regardless types of breast support. An immediate ventilatory response is initially derived from neural drives and later from blood-borne mediators from exercising muscles [25]. Thus, exercise-induced ventilation via neural and chemical drives could overcome any pressure-induced respiratory limitations from breast supports. Neural and chemical components were the main ventilatory drives [26], we believe that the diminutions, as well as the fluctuations, of these components after exercise explain the differences of cardiorespiratory patterns during recovery. During exercise, plateaus in V_T appeared earlier where RR gradually increased across all conditions. This suggests that further increases in $\dot{V}_E$ at higher intensities were mainly a result of the increase in RR.

Similar to other Asian women, Thai female adolescents determine the smaller bra sizes with various styles [27]. It was notified that wearing an inappropriate breast support for many hours a day is possibly associated with increased risk of breast cancer [28]. In the present study, there were variations in CB sizes and cup types (B and C), however, JB participants had correct sizes and cups fitting by the professional staffs. Even if minimal, both bras may induce some compression from the elastic recoil of garments. Consequently, the self-determined breast support causes higher $\dot{V}_E$ during recovery.

Metabolism during exercise showed intensity-dependent patterns in all conditions. It appears that the effects of exercise intervention seem likely to override effects of breast supports. A previous study reported that high external chest wall restriction resulted in minimal reductions in maximum oxygen uptake (41.9 ± 1.3 to 39.4 ± 1.3 ml/kg/min) [29]. In the present study, we observed no changes in oxygen consumption in all conditions. Thus, this indicates that there are no limitations in metabolism despite NB or breast support types during exercise.

An immediate metabolic recovery was primarily observed only in the NB condition. In fact, full recovery appears within 3–4 min post-exercise, which is a common characteristic. Metabolism remained slightly elevated across all conditions during recovery, indicating that despite the exercise cessation, biochemical processes remain active [30]. This was documented by the elevated rate of high glucose uptake in working muscles during recovery [31]. This may have occurred in all conditions during recovery. However, we believe that breast support pressures, even slight, possibly reflect higher metabolic processes during recovery.

The RER values during exercise indicated that all conditions utilized glycolytic processes as the main energy substrate. During recovery, we found significant differences in $\dot{V}O_2$, $\dot{V}CO_2$, RER, and EE compared with resting values only in two breast support conditions. With minimum pressure, we believe that this will additionally induce higher rates of excess post-exercise oxygen consumption and even higher carbon dioxide production [32] because biochemical activation remains [31]. We also observed the remaining high RER, > 1.00, in all conditions condition during recovery. This may hypothetically indicate the interference of anaerobic processes. However, as we did not measure any blood chemistry (e.g. lactate), this will be our concern for the next investigation. Looking back at respiratory rate (RR), values across all conditions at 80% MHR (Fig. 1B) approached the nearest maximum respiratory rate of 45–50 bpm which adults can attain during exercise [33]. As RR becomes limited, this will predict involvement of anaerobic processes thereafter. Unlike other studies [34], the 5-min recovery period in the present study is not appropriate for exercise at moderate to high intensities, i.e., > 80% MHR.

Likewise, the similar changes in cardiovascular variables across all conditions confirm that the effects of exercise intensity overcome the effects of breast support upon wearing. The present study and previous report [35] confirm that physical activity induces higher ventricular contraction, which in turn results in increasing stroke volume and cardiac output. This will occur with the reduction in total peripheral vascular resistance *via* vasodilation mechanism [36]. This is due to changes in intrathoracic pressure. These cardiac compensatory conditions may be impaired only when chest wall restriction is extremely high [35].

We also explored the evidence of compressive forces related to the bras' shoulder straps and found that the JB induced only 6 g/cm^2 (data from manufacturer side). This minimal external pressure may not affect the hemodynamics within the thorax [20]. Since body surface area is constant, increasing CI is mainly due to increases in CO. This suggests that cardiac compensation during exercise can sufficiently provide hemodynamics to all body parts [37].

The increases in SV and CO during exercise are most likely due to higher RR, HR and venous return (VR) from changes in intrathoracic pressure. The volume of blood being ejected or remaining in the heart are unique parts of our investigation. Since the EDV mainly depends on end-diastolic duration and VR, thus the longer the end-diastolic duration at sub-maximum workload, the higher blood volume will be filled in the heart chamber [38]. Accordingly, heart rates across all exercise intensities were in the same ranges among conditions, thus presumably resulting in similar EDV. Ejection fraction (EF) normally ranges from 55 to 70% and may rise up to approximately 80% during maximum exercise to adapt to the higher physical workload [39]. In healthy individuals during exercise, higher EF would represent an increase in ventricular function, whereas a decrease in EF would represent impairment of ventricular function [38]. The above has been used as a clinical indicator [38], in which it is generally known that sympathetic activation during exercise will stimulate greater cardiac contraction in parallel with a faster cardiac rhythm. Moreover, the reductions in vascular resistance are due to exercise-induced vasodilation *via* an increased secretion of nitric oxide, a local vasodilator, and other agonists, which are involved in endothelium-dependent pathways [40].

Conclusion:

In conclusion, breast supports exerted no limitation on cardiorespiratory and metabolic functions of either at rest, during or after exercise. Minor limitations in some resting flows from immediate donning of jogging bra disappeared during exercise. This study indicates that despite the absence of limitations of two breast supports on metabolic and cardiovascular profiles during constant speed running, jogging bra enhances slightly earlier recovery from it resting values. From the results in this study, we suggest that breast supports should be worn without worry or difficulty for females participating in daily jogging activity. Further investigation should be focused on effects of long-term jogging without and with breast support on exercise adaptations.

Abbreviations:

NB no bra

CB casual bra

JB jogging bra

MHR age-predicted maximum heart rates

$\dot{V}O_2$ oxygen consumption

$\dot{V}CO_2$ carbon dioxide production

RER respiratory exchange ratio

EE energy expenditure

HR heart rate

SV stroke volume

CO cardiac output

EDV end-diastolic volume

EF ejection fraction

SVR systemic vascular resistance

RPE perceived exertion

V_T tidal volume

VC vital capacity

IC inspiratory capacity

IRV inspiratory reserve volume

ERV expiratory reserve volume

RR respiratory rate

$\dot{V}_E$ minute ventilation

FEV_1 forced expiratory volume in 1 second

FVC forced vital capacity

$\%FEV_1$ percentage of forced expiratory volume in 1 second and forced vital capacity

PEF peak expiratory flow

MVV maximal voluntary ventilation

SEM standard error of mean

BMI body mass index

VR venous return

Declarations:

Ethics approval and consent to participate

This study was approved by the Human Research Ethics Committee of Mahidol University, Thailand (MU-IRB2013/159.1112). All participants completed the informed consent forms authorized by the committees.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Both of RC and KM designed the study, and collected, analyzed and interpreted the data including contributing in the manuscript writing. All authors have read and approved the final manuscript.

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Tables

Table 1. Immediate effects of Casual and Jogging bras (CB and JB) on resting static and dynamic pulmonary function. It is noted that $FEV_{1.0}$ (L) and MVV diminished only at post-JB condition.

Variables	CB		JB	
	Pre-Bra	Post-Bra	Pre-Bra	Post-Bra
VC (L)	2.84 ± 0.12	2.87 ± 0.12	2.91 ± 0.12	2.85 ± 0.13
IC (L)	1.81 ± 0.06	1.84 ± 0.06	1.83 ± 0.06	1.78 ± 0.06
V_T (L)	0.88 ± 0.04	0.86 ± 0.04	0.88 ± 0.04	0.93 ± 0.03
IRV (L)	0.93 ± 0.06	0.98 ± 0.06	0.93 ± 0.05	0.86 ± 0.07
ERV (L)	1.02 ± 0.10	1.02 ± 0.10	1.09 ± 0.09	1.07 ± 0.09
RR (breaths/min)	12.38 ±0.56	12.69 ± 0.61	13.38 ± 0.45	12.85 ± 0.46
V_E (L/min)	10.93 ± 0.74	11.07 ± 0.67	11.81 ± 0.62	11.95 ± 0.63
$FEV_{1.0}$ (L)	2.72 ± 0.11	2.71 ± 0.10	2.77 ± 0.10	2.71 ± 0.10**
FVC (L)	3.01 ± 0.12	3.01 ± 0.11	3.10 ± 0.10	3.05 ± 0.10
%FEV_1	90.23 ± 0.48	89.77 ± 0.48	89.15 ± 0.54	88.85 ± 0.65
PEF (L/s)	6.27 ± 0.35	6.19 ± 0.34	6.45 ± 0.33	6.27 ± 0.24
MVV (L/min)	103.42 ± 4.27	103.94 ± 4.02	107.12 ± 3.53	104.49 ± 3.56**

*Values are mean ± SEM. VC, vital capacity; IC, inspiratory capacity; V_T, tidal volume; IRV, inspiratory reserve volume; ERV, expiratory reserve volume; RR, respiratory rate; V_E, minute ventilation; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; %FEV_1, percentage of FEV_1 and FVC; PEF, peak expiratory flow; MVV, maximum voluntary ventilation. ** represents significant differences between pre-post JB condition at P<0.05.*

Figures

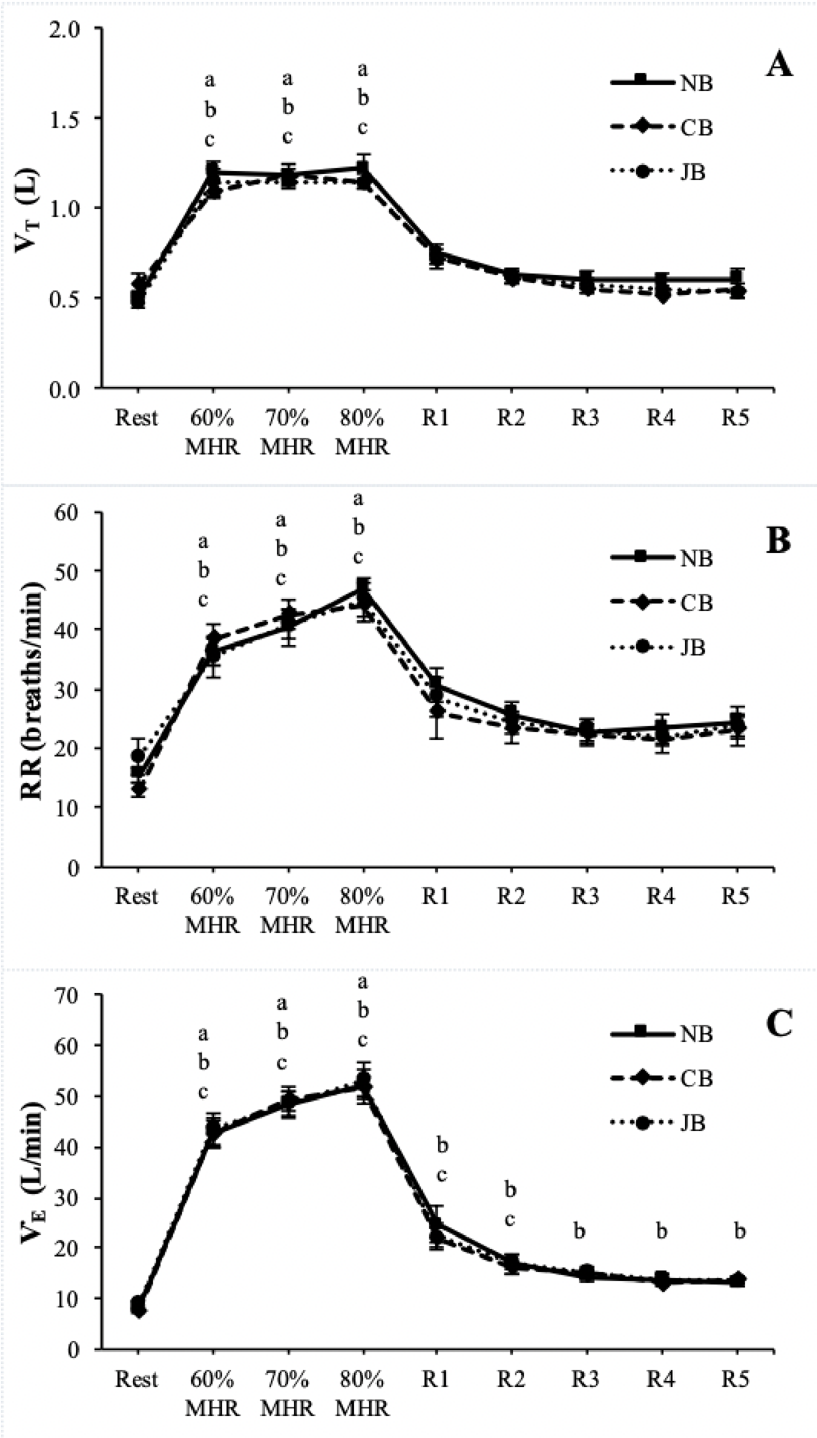

Figure 1

Changes in tidal volume (VT, in A), respiratory rate (RR, in B), and minute ventilation (V̇E, in C) at rest and during jogging with no bra (NB), casual bra (CB) and jogging bra (JB) at 60, 70 and 80% MHR and the 5-minute recovery (R1-R5). Abbreviations a, b and c represent significant difference from resting values of NB, CB and JB respectively.

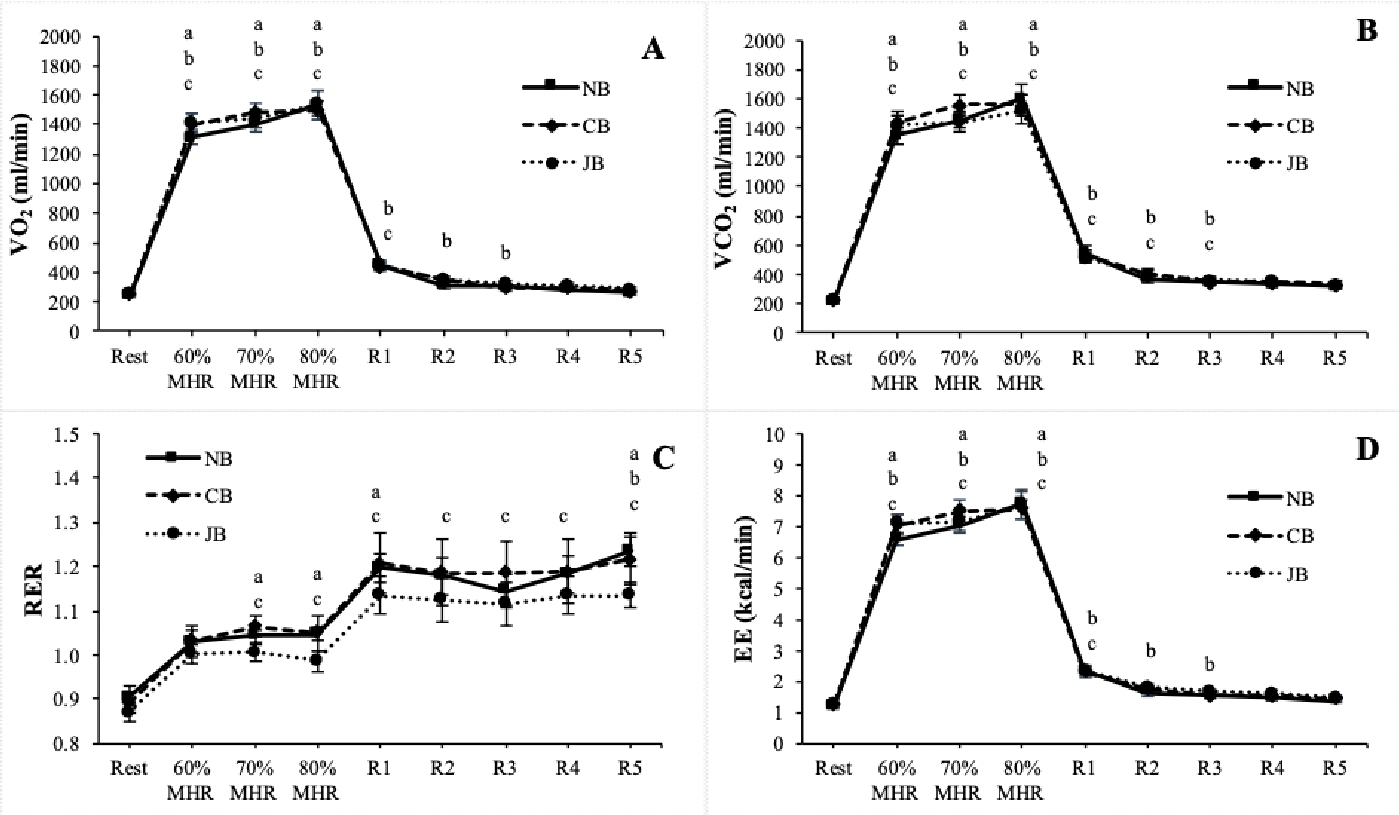

Figure 2

Oxygen consumption (V̇O2 in absolute unit, A), carbon dioxide production (V̇CO2 in absolute unit, B), respiratory exchange ratio (RER, C), and energy expenditure (EE, D) at rest and during jogging with no bra (NB), casual bra (CB), and jogging bra (JB) at 60, 70 and 80% MHR and 5-minute recovery (R1-R5). It was noted that RER increased in all groups during the recovery period. Abbreviations a, b and c represent significant difference from resting values in NB, CB and JB respectively.

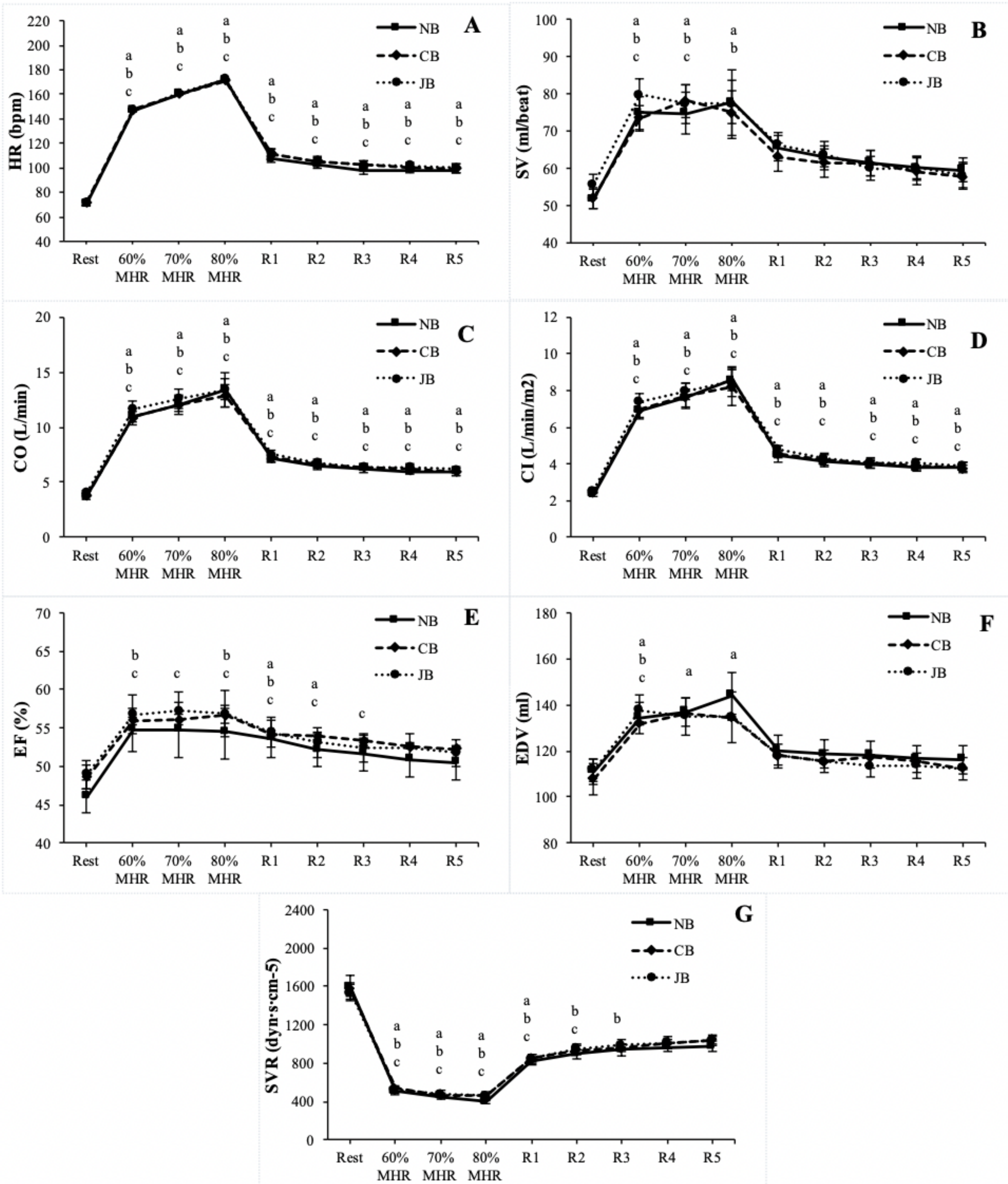

Figure 3

Changes in cardiovascular variables including heart rate (HR, A), stroke volume (SV, B), cardiac output (CO, C), cardiac index (CI, D), ejection fraction (EF, E), end diastolic volume (EDV, F), and systemic vascular resistance (SVR, G) during jogging with no bra (NB), casual bra (CB), and jogging bra (JB) at 60, 70 and 80% MHR and 5-minute recovery (R1-R5). It is noted that SVR decreased during and after recovery.

Abbreviations a, b and c represent significant difference from resting values of NB, CB and JB respectively.

Supplementary Files

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- CONSORT2010ChecklistJoggingbras.pdf