Heart rate and exercise intensity during training: observations from the DREW Study

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Abstract

Objective: Cardiovascular drift (CVdrift) is characterised by a continuous, gradual increase in heart rate (HR) after ~10 min of moderate-intensity aerobic exercise, despite maintenance of a constant work rate. This has important implications for trials that employ HR to monitor exercise intensity, as reducing work rate in order to keep HR constant could result in participants exercising below the intended intensity. Utilising the Dose Response to Exercise in Women (DREW) database, we sought to determine if increases in HR during exercise (CVdrift) resulted in clinically significant reductions in exercise work rate in order to keep HR within a target range.

Design: Randomised, prospective study.

Setting: DREW clinical exercise trail, The Cooper Institute, Dallas, Texas.

Participants: Overweight (body mass index 25–43 kg/m²), previously sedentary postmenopausal women (n = 326).

Intervention: Treadmill and cycling exercise (30–90 min, three to five times per week) at a HR corresponding to 50% of peak oxygen uptake (Vo₂peak).

Main outcome measure: Changes in exercise intensity (metabolic equivalents (METS)) during exercise in response to CVdrift.

Results: We observed small increases in HR (1–4 beats per minute, p<0.001) combined with small increases in intensity (0.01–0.03 METS, p<0.03) during the combined 12 963 exercise training sessions. Further, we identified only 101 (0.78%) sessions in which intensity was reduced during the course of the exercise session, potentially in response to CVdrift.

Conclusions: We conclude that CVdrift did not contribute to significant reductions in exercise intensity in the DREW study.

National and international public health organisations have long recognised the health benefits associated with regular exercise. Though the American College of Sports Medicine and Centers for Disease Control and Prevention recommend at least 30 min of physical activity most days of the week, the optimal dose and intensity of exercise required to elicit specific health benefits, particularly in high-risk populations, remains an active area of investigation. Controlled exercise intervention trials that investigate these matters are dependent on stringent standardisation of the dose (time or caloric expenditure) and intensity of exercise in order to ensure that participants exercise at the target intensity, for the required amount of time or achieve the intended level of caloric expenditure.

Dose may be regulated by establishing time limits for exercise duration or utilising caloric expenditure goals. The ease and low-cost of monitoring heart rate (HR) has led to the widespread use of HR as a gauge of relative exercise intensity. It is well-established that there is linear relationship between HR and exercise intensity, and HR is generally accepted as an accurate means of assessing and monitoring relative exercise intensity. Nonetheless, there is some concern regarding the use of HR to monitor exercise intensity because of a phenomenon known as cardiovascular drift (CVdrift).

CVdrift is characterised by a steady increase in HR during prolonged (>10 min) moderate-intensity exercise, despite maintenance of exercise intensity. The mechanisms responsible for CVdrift remain a subject of investigation, but declines in stroke volume resulting from hypovolemia, high metabolic demand, thermal stress or increased cutaneous blood flow have all been suggested to play a role in increasing motor unit recruitment and alterations in sympathetic activation.

CVdrift has the potential to undermine study results from controlled exercise dose trials for the reason that investigators often adjust workload during exercise in order to keep HR within a target range. If CVdrift does occur, this may have the undesired affect of “undertraining”, or reducing the intensity of exercise, potentially compromising the precision of the delivery of the exercise intervention.

Recent reports suggest that significant reductions in exercise intensity were necessary to hold HR constant in men cycling at 60% Vo₂max in a warm (35ºC) environment. On the other hand, other studies suggest that little CVdrift occurs in men exercising in cooler environments (24ºC) or at lower intensities (40% Vo₂max). Little work has been done to examine the effects of holding HR constant on exercise intensity in large clinical trials, and to the best of our knowledge, the effects of doing so in postmenopausal women has never been examined. The aim of the current investigation was to examine data from the Dose Response to Exercise in Women (DREW) study, a large tightly controlled exercise trial in which HR was used to monitor exercise intensity, to determine if reductions in exercise intensity were necessary to keep HR within a target range. Having a better understanding of the prevalence of CVdrift in large exercise training trials composed of sedentary individuals can help shape future exercise intervention protocols.

Methods

Participants and purpose

The study design and methods for DREW have been presented elsewhere. Briefly, the DREW study was...
designed to examine the effect of different exercise doses on cardiorespiratory fitness and cardiovascular disease risk factors in postmenopausal women, 45–75 years old with a body mass index of 25–43 kg/m² and systolic blood pressure (SBP) of 130–159 mm Hg. This research was approved by the Institutional Review Board at The Cooper Institute in Dallas, Texas, and all participants provided written informed consent prior to participation.

Experimental design
Four hundred and sixty-four women were recruited and assigned to a no-exercise control group (n = 102) or one of three exercise groups: (A) 4 kilocalories per kilogram body weight per week (KKW; n = 155), (B) 8 KKW (n = 104) or 12 KKW (n = 103).

Exercise intervention
Participants in the exercising groups met their respective caloric expenditure requirements by exercising three to five times per week at a HR (+5 beats per minute (bpm)) associated with 50% \( V_{\text{O2peak}} \). Participants alternated treadmill and cycle ergometer exercise sessions. The exercise intervention was 6 months in duration. To minimise the risk of injury, participants in all three groups began exercising with a goal of expending 4 KKW throughout the first week of the intervention. Beginning the second week, the 8 and 12 KKW groups increased their energy expenditure by 1 KKW until they reached their target energy expenditure levels, while the 4 KKW group continued to exercise at 4 KKW. Trained staff supervised all exercise sessions in exercise training facilities on the North Dallas and Oak Cliff campuses of The Cooper Institute. The ambient temperature of the fitness centres was kept between 18° and 22°C. Participants were allowed to read, watch television, utilise the fans and had ad libitum access to water during exercise. HR monitors (Polar Vantage XL and NV, Port Washington, New York, USA) were worn during all sessions, and HR was continually monitored and recorded every 6 min, as were speed and grade on the treadmill and Watts on the cycle ergometer.

Data collection
An electronic data capture system (Clinaero, Bellevue, Washington, USA) was used to track HR and workload during exercise sessions. Following randomisation, participant data, including participant identifiers, group assignment and prescribed HR range were entered into the system. Each week, participants were weighed, and the data was entered and used to calculate energy expenditure (EE) requirements for that week. During exercise, HR and intensity were input every 6 min. The data capture system was programmed to alert the exercise intervention staff when a HR outside a given participant’s range was entered, and the staff was prompted to immediately alter the intensity of exercise (ie, adjust workload) until HR returned to the desired range.

The software was also capable of calculating the duration of exercise necessary to achieve EE goals for each participant at a given workload. Because the software immediately adjusted for changes in minute-to-minute EE resulting from alterations in workload, real-time corrections to the target exercise duration were achieved, thus ensuring that participants met their EE requirements for each session.

Data abstraction and analysis
Data from all exercise sessions completed in the DREW study were obtained. Speed and grade data from treadmill exercise sessions and wattage values from cycle ergometer exercise were converted to metabolic equivalents (METS) for comparison and analysis. Data from exercise sessions <24 min in group A, <42 min in group B and <60 min in group C were removed, as the use of data from shorter sessions within each group would result in non-random distribution of missing values, namely, in the latter stages of the exercise sessions, potentially skewing the results of analysis. This also effectively removed all sessions completed during the ramping period and sessions cut short because of illness or other impediments. This resulted in the removal of 904 (~6.5%) of the sessions in the database and left a total of 12 963 sessions from groups A (n = 6584), B (n = 3659) and C (n = 2940) available for analysis. Of these sessions, 6392 were performed on the treadmill and 6571 were performed on the cycle ergometer.

We also quantified the number of sessions in which METS were reduced during exercise, presumably to keep HR within the desired range. A number of factors, aside from CVdrift, have the potential to contribute to elevations in resting and exercise HR, such as sympathetic nervous system activation resulting from caffeine ingestion, increased core temperature, or stress,31–33 and such factors would likely influence HR early during exercise. Furthermore, because CVdrift does not occur until >10 min beyond the onset of exercise, we also assumed that CVdrift sufficient to drive HR beyond the desired range would not occur between minute 10 and minute 12 of exercise, and therefore, in cases of CVdrift, METS would remain unchanged prior to minute 12 of exercise. Consequently, we quantified only those sessions in which METS were stable between minute 6 and minute 12 of exercise, but in which METS were reduced at any point after minute 12 as sessions in which CVdrift may have occurred.

Differences in demographic and anthropometric parameters, and the prevalence of reductions in exercise intensity across groups, were analysed using Pearson’s \( \chi^2 \) test. Results of \( \chi^2 \) analysis are reported as means (SD). A mixed linear model (proc mixed; SAS, Cary, North Carolina) was used to assess changes in HR and METS within and across groups and exercise modalities (mode). Data from mixed linear analysis are expressed as means (SE). Pearson’s correlation coefficients were used to estimate the association between the change in METS and change in HR over time across groups.

RESULTS
Participants
Mean (SD) age was 57 (7) years, body mass was 83.8 (11.6) kg and peak oxygen uptake (\( V_{\text{O2peak}} \)) was 15.4 (2.8) ml/kg/min. Of the 326 women included in this analysis, 65% were Caucasian, 30% were African-American, and 7% belonged to other ethnic groups. There were no differences in age, body mass, baseline fitness or ethnic distribution among the randomised groups (table 1).

Treadmill exercise
We observed small but significant increases in HR during treadmill exercise for all groups and for METS in groups A and B (all, p<0.001; fig 1). Within group A, HR increased from 108 (1 bpm) at minute 6 to 109 (1 bpm) at minute 24 (p<0.001). In group B, HR at minute 6 was 109 (1 bpm) and increased to 111 (1 bpm) by minute 42 (p<0.001), and mean HR in group C at minute 6 was 106 (1 bpm) and increased to 108 (1 bpm) at minute 60 (p<0.001). METS increased from 2.99 (0.04) to 3.01 (0.04) in group A from minute 6 to minute 24, (p<0.001). In group B, METS at 6 min were 3.11 (0.05) and increased to 3.13
At minute 6, METS were 3.21 (0.06) and remained at 3.21 (0.06) at minute 60 in group C (NS).

Cycle ergometry exercise
Differing only modestly from treadmill exercise, we observed significant increases in HR and METS at all time points relative to minute 6 (all, p<0.001; fig 2). HR increased from 112 (1 bpm) at minute 6 to 115 (1 bpm) at minute 24 in group A (p<0.001). In group B, HR was 111 (1 bpm) at minute 6 and increased to 115 (1 bpm) by minute 42 (p<0.001). At minute 6, HR was 109 (1 bpm) in group C and increased to 112 (1 bpm) at minute 60 (p<0.001). METS increased significantly during cycle

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Baseline characteristics</th>
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<tr>
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<td>All (n = 326)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>57 (7)</td>
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<tr>
<td>Body mass (kg)</td>
<td>83.8 (11.6)</td>
</tr>
<tr>
<td>V̇O₂peak (mL/kg/min)</td>
<td>15.4 (2.8)</td>
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<tr>
<td>Ethnic distribution (%)</td>
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</tr>
<tr>
<td>Caucasian</td>
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</tr>
<tr>
<td>African-American</td>
<td>30</td>
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<tr>
<td>Other</td>
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KKW, kilocalories per kilogram body weight per week.
Values are mean (SD).

Figure 1 | Heart rate (HR) and intensity during prolonged, moderate-intensity treadmill exercise in previously sedentary postmenopausal women (n = 326). (A) HR (in bpm) by group ((A) 4 kilocalories per kilogram body weight per week (KKW), open circles; (B) 8 KKW, open triangles; and (C) 12 KKW, open squares). HR at all time points was significantly greater than at minute 6 in all groups (p<0.001). (B) Mean (SE) initial (minute 6, white bars) and final (minute 24 for group A, minute 42 for group B and T60 for group C, black bars) HR during treadmill exercise by group. Final HR was significantly greater than initial HR across all groups (p<0.001). (C) Intensity by group. In group A, intensity was significantly higher across all time points relative to minute 6 (p<0.02). In group B, intensity increased significantly by minute 24 (p<0.05) and remained elevated through minute 42 (p<0.05). Intensity was significantly higher at minute 30 (p<0.03) and remained higher throughout minute 42 (p<0.05) but returned to initial levels by minute 48 and remained there until minute 60 in group C. (D) Mean (SE) initial and final METS by group. Final METS were significantly higher than initial METS across groups A and B (p<0.001 and p<0.03, respectively). In group C, final METS were not different from initial METS.
ergometry exercise in all groups (p<0.001). In group A, METS were 3.72 (0.02) at minute 6 and increased to 3.73 (0.02) at minute 24 (p<0.007). METS began at 3.74 (0.03) at minute 6 in group B and rose to 3.76 (0.03) at minute 42 (p<0.001).

Similarly, in group C, at minute 6, METS averaged 3.82 (0.04) and progressed to 3.84 (0.04) at minute 60 (p<0.001).

Correlation analysis
Changes in HR observed during exercise were correlated with changes in METS for groups A (r = 0.41, p<0.001), B (r = 0.36, p<0.001) and C (r = 0.36, p<0.001).

Prevalence of cardiovascular drift
Of the 12 963 sessions examined in this analysis, 101 (0.78%) were identified as sessions in which CVdrift may have resulted in compensatory reductions in exercise intensity (METS stable between minute 6 and minute 12, with a reduction in METS thereafter). There were no differences in the number of sessions identified across groups. Of the treadmill sessions identified, 21 were from group A, 29 were from B and 29 were from C. On the cycle ergometer, 6, 8 and 8 sessions were identified for groups A, B and C, respectively (table 2).

**Table 2** Prevalence of sessions in which exercise intensity was reduced

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>4 KKW</th>
<th>8 KKW</th>
<th>12 KKW</th>
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<tr>
<td>Total sessions, n</td>
<td>12963</td>
<td>6384</td>
<td>3639</td>
<td>2940</td>
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<tr>
<td>Sessions in which exercise intensity was reduced</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Treadmill sessions, n</td>
<td>79</td>
<td>21</td>
<td>29</td>
<td>29</td>
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<tr>
<td>Bike sessions, n</td>
<td>22</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Bike and treadmill sessions combined, n (%)</td>
<td>101 (0.78%)</td>
<td>27 (0.21%)</td>
<td>37 (0.29%)</td>
<td>37 (0.29%)</td>
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</table>

Sessions were identified if METS were reduced following 12 min of exercise but were stable between 6 and 12 min. Percentages are expressed as a percentage of all sessions (n = 12 963). KKW, kilocalories per kilogram body weight per week.

Figure 2 Heart rate (HR) and intensity during prolonged, moderate-intensity cycle ergometry exercise in previously sedentary postmenopausal women (n = 326). (A) HR (in bpm) by group. HR at all time points was significantly greater than at minute 6 in all groups (p<0.001). (B) Mean (SE) initial and final HR by group. Final HR was significantly greater than initial HR across all groups (p<0.001). (C) Intensity by group. In group A, intensity increased significantly by minute 18 (p<0.02) and remained significantly higher than minute 6 at minute 24 (p<0.007). Intensity increased significantly in group B by minute 12 (p<0.04) and remained significantly higher throughout minute 42 (p<0.002). In group C, intensity increased significantly by minute 24 (p<0.03) and remained higher throughout minute 60 (p<0.003). (D) Mean (SE) initial and final METS by group. Final METS were significantly higher than initial METS across groups A and B (p<0.007 and 0.0002, respectively). In group C, final METS were significantly higher than initial METS (p<0.001).
DISCUSSION

In this analysis of nearly 13 000 exercise training sessions, we observed very small increases in HR (1–4 bpm) combined with small increases in METS during the DREW exercise training sessions. The strong correlation between the increases in METS and HR during the exercise sessions is direct evidence that increases in METS, and not CVdrift, are responsible for the small increases in HR observed in this study. It should be noted that the study design did not allow for CVdrift as it is typically characterised. That is, participants were not asked to exercise at a constant intensity while their HR was monitored; rather, the exercise prescription was designed to keep HR relatively constant during exercise, and the purpose of this analysis was to determine whether or not reductions in exercise intensity were necessary, as a result of CVdrift, to keep HR within a target range. METS were reduced during exercise in less than 1% of all sessions, suggesting that during the remaining 99% of sessions, HR remained within the prescribed range without the need for reductions in exercise intensity. In summary, in this population of previously sedentary postmenopausal women, we rarely observed reductions in exercise intensity when holding HR constant during exercise.

It is important to note that although the changes in HR and intensity observed in this study achieved statistical significance, these changes were very small and of little clinical importance. The margin of error for HR monitors similar to those used in this study is reported to be ±2 bpm,34 and the average increase in HR observed during the training sessions in this trial ranged from 1 to 4 bpm. Additionally, the average change in exercise intensity ranged from 0.01 to 0.04 METS. This is equivalent to roughly a 0.01–0.05-mph change in treadmill speed. Even in the context of tightly controlled clinical trials, changes of this magnitude are immaterial. Type I error due to large sample size and narrow margin of error is likely responsible for the level of the significance detected in this study. Furthermore, participants were allowed to self-select their exercise intensity on the condition that their HR remained within the desired range. This could explain, in part, the very small elevation in METS and, consequently, HR observed in many of the groups. The greatest mean change in HR seen in this trial was 4 bpm over 60 min, suggesting the exercise intervention staff effectively responded to changes in HR during exercise to keep HR within the desired 10-bpm range.

To our knowledge, this study is the first to examine the implications of CVdrift on using HR to monitor exercise intensity in context of a large clinical exercise training trial composed of sedentary older, adults. While some previous work suggests holding HR constant during exercise results in reductions in exercise intensity,29 this work was done in young men exercising in a warm (35°C) environment. We did not observe a high prevalence of reductions in exercise intensity in response to CVdrift during prolonged moderate-intensity exercise in this population. This may be because of the lower work rate or other environmental condition(s) present in the DREW study, including the tightly controlled thermoneutral environment in the exercise facility or the availability of fans and water during the exercise sessions.

Participants in the DREW study completed all supervised exercise sessions indoors, where the average ambient temperature was maintained at approximately 20°C. In addition, participants had free access to fans, presumably decreasing the thermal strain associated with prolonged exercise.35 Furthermore, the metabolic demand of the prescribed exercise intensity (50% Vo2max) was relatively low. Participants also had ad libitum access to water, which may have contributed to reducing core temperature and/or preservation of plasma volume.36–38 Nearly all research on CVdrift to date, has been done in men22 35 and/or endurance-trained individuals23 36 38–40 exercising at higher intensities, highlighting the importance of exploring CVdrift in other populations and various levels of metabolic demand and different environmental conditions.

With 326 women and nearly 13 000 exercise sessions, this is the largest data set, to our knowledge, in which the effects of CVdrift on workload when using HR to monitor exercise intensity has been examined. Additional strengths of this study include the stringent monitoring and control of exercise intensity and dose by trained, experienced staff members. Conversely, the purpose of this study was not to explore the causes of CVdrift in this population, and therefore, measures of stroke volume, cutaneous blood flow and mean arterial pressure were not made. As previously mentioned, participants in this study had free access to fans and water during exercise, both of which have the potential to greatly influence the occurrence of CVdrift. However, we did not track the use of fans or water consumption and therefore are unable to define the influence of these factors on HR during exercise in this trial. Furthermore, the findings from this study may not be transferable to other populations or in this population under different environmental conditions. For these reasons, we are only able to speculate as to why we did not observe CVdrift in this population. However, we can be confident CVdrift was not a confounding factor in DREW results.

What is already known on this topic

- Cardiovascular drift is characterised by a steady increase in HR during prolonged (>10 min) moderate-intensity exercise, despite maintenance of exercise intensity.
- HR is widely used in exercise intervention trials to monitor relative exercise intensity.
- Controlled exercise intervention trials are dependent on the accurate delivery of an exercise intervention.
- If cardiovascular drift does occur during exercise intervention trials, this may have the undesired effect of “undertraining” study participants, potentially compromising the precision of the delivery of the exercise intervention.

What this study adds

- With 326 women and nearly 13 000 exercise sessions, this is the largest data set, to our knowledge, in which the effects of cardiovascular drift on workload when using HR to monitor exercise intensity has been examined.
- In this population of previously sedentary postmenopausal women, reductions in exercise intensity, while maintaining constant HR during exercise training sessions, were rarely observed.
- Cardiovascular drift was not a confounding factor in DREW results.
- The findings from this study may not be transferable to other populations or in this population under different environmental conditions.
CONCLUSIONS
In this population of previously sedentary postmenopausal women, reductions in exercise intensity, while maintaining constant HR during exercise training sessions, were rarely observed.

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Competing interests: Declared. TSC reports having received honoraria for lectures from scientific, educational and community groups; serving as a consultant for Trestle Tree; and having a book in publication from which he will receive royalties. SNB also reports that he is paid as an executive lecturer by the University of North Texas. He gives these fees to the University of South Carolina Educational Foundation or to other nonprofit groups, and he reports that during the past 5-year period, he has received a research grant from Jenny Craig. CPE reports having received honoraria for lectures from scientific, educational and community groups.

REFERENCES