The Influence of Body Mass Loss on Changes in Heart Rate During Exercise in the Heat: A Systematic Review

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Abstract:

The purpose of this review was to compare the changes in heart rate (HR) for every 1% change in body mass loss (ΔBML) in individuals while exercising in the heat. PubMed, SPORTDiscus, ERIC, CINAHL, and Scopus were searched from the earliest entry to February 2013 using the search terms dehydration, heart rate, and exercise in various combinations. Original research articles that met the following criteria were included: (a) valid measure of HR, (b) exercise in the heat (>26.5° C [79.7 °F]), (c) the level of dehydration reached at least 2%, (d) a between-group comparison (a euhydrated group or a graded dehydration protocol) was evident, and (e) for rehydration protocols, only oral rehydration was considered for inclusion. Twenty articles were included in the final analysis. Mean values and *SDs* for HR and percentage of body mass loss immediately after exercise were used for this review. The mean change in HR for every 1% ΔBML was 3 $b \cdot min^{-1}$. In trials where subjects arrived euhydrated and hypohydrated, the mean change in HR for every 1% ΔBML was 3 and 3 $b \cdot min^{-1}$, respectively. Fixed intensity and variable intensity trials exhibited a mean HR change of 4 and 1 $b \cdot min^{-1}$, respectively. Exercising in the heat while hypohydrated (≥2%) resulted in an increased HR after exercise. This increase in HR for every 1% ΔBML exacerbates cardiovascular strain in exercising individuals, thus causing decrements in performance. It should be encouraged that individuals should maintain an adequate level of hydration to maximize performance, especially in the heat.

Keywords: cardiovascular strain | performance | hydration

Article:

Introduction

Hydration has been implicated in having both health and performance benefits during exercise. Evidence has shown that a change in body mass, resulting in as small as 2% dehydration, causes decreases in exercise performance (19,24,30), increases cardiovascular strain (18,21,31), and increases thermoregulatory strain (5,30,38). The cardiovascular strain that results from hypohydration is of particular importance for this review, especially when exercise is being performed in the heat.

Cardiovascular drift is the term used to describe the effects that prolonged exercise has on cardiovascular function; to maintain cardiac output, there is an increase in heart rate (HR) and decrease in stroke volume (SV). The cause of cardiovascular drift is controversial in that some experts attribute cardiovascular drift to increased skin blood flow and reduced central venous return whereas others assert that cardiovascular drift is caused by a reduction in ventricular filling time directly associated with the increase in HR (44). Cardiovascular drift is exacerbated with dehydration and when in combination with heat stress, there is an additive effect further increasing cardiovascular strain (10,12,45).

Overall, dehydration impairs exercise performance and endangers overall health. During the process of dehydration, blood volume in the body decreases as plasma volume is reduced (30). This directly results in an increase in HR for oxygen and substrates to be delivered to the exercising muscles (42). As the demand for blood increases at the muscle, so does the demand at the skin to remove the metabolic heat produced from the exercising muscle. Increased skin blood flow is important for sweating and thermoregulation. Sweat rates of 1–2 $L \cdot h^{-1}$ are common during intense exercise, and if fluid replacement does not minimize the sweat losses during exercise, an athlete increases their risk of dehydration (11). Dehydration impairs key mechanisms for endurance performance by promoting hyperthermia and impairing cardiovascular function through reduced sweat rate and skin blood flow, respectively (11).

Research examining the influence of dehydration on physiological measures such as core body temperature and HR are well established. Recently, results have shown that when exercising in the heat, core body temperature increases by 0.22° C for every additional 1% body mass loss (BML) (22). Furthermore, when examining the effects BML on cardiovascular drift during exercise in the heat, increased HR and reductions in SV and cardiac output have been shown to correlate with the magnitude of dehydration, ranging from 1.1 to 4.2% body weight loss (21). Although increasing levels of dehydration are correlated with the increased HR during exercise in the heat, there have been inconsistent results within the scientific literature to examine the magnitude of this increase, thus prompting the need for further analysis of HR with increasing levels of dehydration during exercise in the heat.

The purpose of this systematic review was to evaluate and analyze the data regarding the changes in HR for every 1% change in body mass loss (ΔBML) during exercise in the heat. We further analyzed the data to determine whether preexercise hydration state (euhydrated or hypohydrated) influenced the magnitude of HR change during exercise in the heat and whether intensity and mode (running or cycling) of exercise affected the change in HR at a given percentage of change in BML.

Methods

Experimental Approach to the Problem

Although it has been established that during prolonged exercise in the heat HR increases because of cardiovascular drift and is further exacerbated with increasing levels of dehydration, various ranges of the magnitude increase in HR have been reported. To evaluate a more accurate value for the magnitude in which HR increases during intense exercise in the heat at increasing levels of dehydration, a systematic review was conducted. We searched the following electronic databases without limits on language or dates: PubMed, SPORTDiscus, ERIC, CINAHL, and Scopus. The search was performed in February of 2013 using the following search terms in various combinations: dehydration, euhydration, hypohydration, water consumption, heart rate, athletic performance, running, bicycling, triathlon, football, time trial, exercise, exercise and performance, endurance, and strength. Previously identified articles, review articles, and reference lists of available studies were cross-referenced for additional studies that met the inclusion criteria. A total of 245 articles were identified from this search.

Study Selection

The specific inclusion criteria used to identify eligible articles before data analysis included (a) valid measure of HR, (b) exercise in the heat (>26.5° C), (c) the level of dehydration must reach at least 2%, which is the level at which performance is affected, (d) there must be a comparison group (a euhydrated group or a graded dehydration protocol), (e) if experimental design involved a rehydration phase, only oral rehydration was considered for inclusion, and (f) subjects must be healthy active human beings. Studies were excluded based on the criteria outlined in Table 1. A euhydrated group or graded dehydration protocol was used to find the differences in HR between the more dehydrated group and less dehydrated group.

Table 1. Exclusionary criteria used to identify appropriate articles for the systematic review.

Exclusion criteria
1. Control group is not identified (euhydrated group or group rehydrated during protocol)
2. Participants with medications known to influence hydration status (glycerol, sodium)
3. Exercising temperature <26.5° C or did not report temperature
4. Firefighters and protective equipment
5. Subject dropout rate >15%
6. Diuretic-induced dehydration during any part of the protocol
7. Dehydration was not exercise-induced
8. Mean values and *SD*s of HR or BML were not reported in article
9. Group did not act as their own control
10. PEDro score >5

HR = heart rate; BML = body mass loss.

Titles and abstracts of 176 articles were excluded because they did not meet the inclusion criteria specified above. Of the remaining 69 studies, 46 were excluded after a full review of the text. In the remaining 23 articles, 20 (1,2,4,5,7,14,16,17,19–21,23,26–31,39,43,45) of which were included for data analysis (Figure 1). When the articles lacked the necessary data for extraction (e.g., failure to report mean values and SDs for %BML or HR), data were obtained through personal communication with the respective authors.

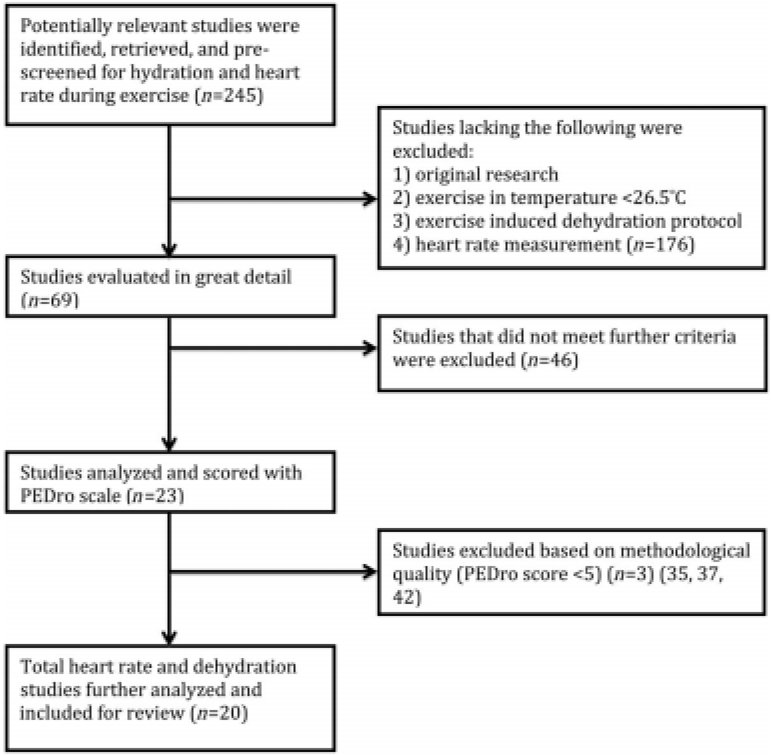

Figure 1. Selection process for articles included for the systematic review. PEDro = Physiotherapy Evidence Database.

Quality Assessment

The methodological quality of the 23 studies was examined using the Physiotherapy Evidence Database (PEDro scale) (46). Two reviewers examined each article. If a discrepancy arose between the scores achieved by both reviewers, an open discussion took place to ensure that one had not missed or misinterpreted an aspect of the study. If the 2 reviewers were unable to come to an agreement after open discussion, an independent third reviewer scored the article. Initial κ statistics revealed an agreement of 1.000.

An a priori inclusion score of 5/10 on the PEDro scale was selected for the study to be included in the data analysis. A PEDro score of 5/10 was chosen because blinding of the participants and researchers was impossible when assessing hydration status in which fluid was restricted or limited before or during exercise. Three studies (32,35,40) did not meet this inclusion score and were removed before data analysis. The final PEDro scores for the remaining 20 studies are shown in Table 2. One study (21) received a score of 5, 7 studies (1,5,14,16,17,28,45) received a score of 6, 12 studies (2,7,18,20,23,25–27,29–31,39) received a score of 7, 1 study (4) received a score of 8, and 1 study (43) achieved a score of 9.

With the exception of 3 studies (4,23,43), none of the studies included blinding of the participants, researchers, or assessors. Because of the methodological design, 1 study (43) was able to blind the participants, researchers, and assessors, whereas another study (4) was able to blind the participants, and a third study (23) was able to blind the assessors of the study. Eight studies (1,5,14,16,17,28,43,45) did not report outcome measures from at least 85% of subjects initially allocated to groups.

Table 2. Characteristics of the 20 studies included in the influence of BML on changes in HR during exercise in the heat.*

Study	Intensity	Participants	Exercise Protocol	Environment	HR change per every 1% increase in BML ($b\cdot min^{-1}$)	PEDro score
Armstrong et al. (1)	Fixed	10	90-minute HST on treadmill at 5.6 $km\cdot h^{-1}$ and 5% grade at 36% VO_{2max}	33° C, 55% RH	–0.5	5
	Fixed	10		33° C, 55% RH	5.75	5
Arnaoutis et al. (2)	Fixed	10	Cycle ergometer: TTE at 75% VO_{2max}	31° C	0	6
	Fixed	10		31° C	–2	6
Below et al. (4)	Fixed	8	Cycle ergometer: 50 minutes at VO_{2max} 5% above LT. Performance test after 50-minute cycling	31.2° C, 54% RH	3.33	8
	Variable	8		31.2° C, 54% RH	0.67	8
Casa et al. (7)	Variable	17	12-km timed trail run: 2 race pace, 2 submaximal pace	26.5° C	1.33	7
	Fixed	17		26.5° C	5.79	7
Ebert et al. (14)	Fixed	8	Cycle ergometer: 2 hours at 55% MAP followed TTE hill climb (88% MAP)	29.3° C, 36.7% RH	4.29	6
	Fixed	8		29.3° C, 36.7% RH	1.74	6
Fujii et al. (16)	Fixed	13	Cycle ergometer: 2 bouts (30-60 minutes) at 50% VO_2peak	35° C, 50% RH	4.21	6
Ganio et al. (17)	Fixed	11	Cycle ergometer: 15, 60, or 120 minutes at 60% VO_2max	30° C, 40% RH	2	6
	Variable	11		30° C, 40% RH	–0.67	6
González-Alonso et al. (20)	Fixed	7	Cycle ergometer: 2 bouts (30 minutes) at 62% VO_2max upright and supine	35° C, 50% RH	3.04	7
	Fixed	7		35° C, 50% RH	1.52	7
González-Alonso et al. (19)	Fixed	7	Cycle ergometer: 100 minutes at 60% VO_2max followed by 30 minutes at 72% VO_2max	35° C	3.18	6
González-Alonso et al. (21)	Fixed	8	Cycle ergometer: 2 bouts of 30 minutes at 72% VO_2max at 1.5, 3.0, and 4.2% BML	35.4° C, 47% RH	3.93	5
	Fixed	8		35.4° C, 47% RH	3.75	5
	Fixed	8		35.4° C, 47% RH	4	5
	Fixed	8		35.4° C, 47% RH	3.7	5
Ishijima et al. (23)	Fixed	6	Cycle ergometer: 90 minutes at 55% VO_2max	28° C, 50% RH	5	6
	Fixed	6		28° C, 50% RH	4.5	6
Kenefick et al. (27)	Fixed	7	75 minutes of dehydration phase, rehydration, and then 75 minutes of heat tolerance test on treadmill at 47% VO_2max	37° C, 42.2% RH	5.63	7
Kenefick et al. (26)	Fixed	8	185 minutes of dehydration phase, oral rehydration, followed by 90 minutes of walk on treadmill at 50% VO_2max	35.9° C, 46.6% RH	2.67	7
Lopez et al. (28)	Fixed	14	12-km submaximal trail run in the heat	27.6° C	0.88	6
Montain et al. (29)	Fixed	7	Cycle ergometer: 2 hours at 62–67% VO_2max	33° C, 50% RH	5	7
Montain et al. (30)	Fixed	8	Cycle ergometer: 2 hours at 62–67% VO_2max	32.7° C, 50% RH	3.75	7

Study	Intensity	Participants	Exercise Protocol	Environment	HR change per every 1% increase in BML (b·min^{-1})	PEDro score
	Fixed	8		32.7° C, 50% RH	5.26	7
	Fixed	8		32.7° C, 50% RH	4.52	7
Montain et al. (31)	Fixed	9	50-minute treadmill walking at 25, 45, and 65% VO_2max at 3 or 5% hypohydration	30° C, 50% RH	0.71	6
	Fixed	9		30° C, 50% RH	3.93	6
	Fixed	9		30° C, 50% RH	3.57	6
	Fixed	9		30° C, 50% RH	2.65	6
	Fixed	9		30° C, 50% RH	3.67	6
Wingo et al. (43)	Variable	12	Three 16-km loop mountain bike race	28° C	4.93	9
Wingo et al. (45)	Fixed	9	45 minutes on a cycle ergometer at 60% VO_2max	35° C, 40% RH	2.27	6
	Variable	9	Graded exercise increasing 25W every 2 minutes on cycle ergometer	35° C, 40% RH	0.45	6

*Fixed = intensity that is constant throughout the duration of exercise; variable = intensity that varies throughout the duration of exercise; BML = body mass loss; HR = heart rate; HST = heat stress test; TTE = time to exhaustion; LT = lactate threshold; MAP = maximal aerobic power; RH = relative humidity

Three studies (5,19,21) examined subjects exercising at 4 different ambient temperatures. Only those exercising in a temperature exceeding the temperature specified in the inclusion criteria (>26.5° C) were included. Two studies (26,27) included trials in which intravenous rehydration was used and were not included in the final analysis. The study by Wingo et al. (43) used glycerol in one of the 3 trials and was not included in data analysis. In the studies conducted by Armstrong et al. (1) and Fujii et al. (16), trials were excluded because BML at the end of exercise did not reach 2%.

Data Extraction and Management

The following information was extracted from the included studies: study design, number of participants, environmental temperature (ambient temperature and relative humidity), types of exercise, duration of exercise, HR after exercise, %BML after exercise, and whether the participants began the experimental trial in a euhydrated or hypohydrated state. Only immediate postexercise HR and %BML was synthesized for this review because these 2 variables were the specific focus of the original research question. The number of subjects, mean, and SD values of HR and %BML from each trial were inputted into RevMan Software Version 5.2 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2012.) to calculate weighted mean difference and 95% confidence intervals (CI) using a random-effects model. The weighted mean difference values were further used to calculate the change in HR for every 1% ΔBML. If any of the studies included multiple trials that examined levels of dehydration compared with a control (graded dehydration protocol) or different protocols (varied intensities or exercise protocols), each separate trial was included for analysis.

As part of the inclusionary criteria, the level of BML because of dehydration must reach at least 2% in addition to a comparison group that is euhydrated or part of a graded dehydration protocol. We termed the groups exceeding 2% BML as “greater dehydrated” and the comparison group (group <2% BML) as “less dehydrated.” For example, for studies in which groups obtained postexercise % BMLs of 1 and 3%, the “less dehydrated” group was the group that had BMLs equally 1%, whereas the group that had BMLs equally 3% were labeled as the “greater dehydrated” group.

Results

Data Synthesis

For each comparison, the change in HR for every 1% ΔBML was calculated by dividing the weighted mean HR difference by the weighted mean % ΔBML. Combined, all included studies (1,2,4,7,14,16,17,19–21,23,26–31,43,45) provided measurements for 682 participants and included a total of 37 trials. Three studies (5,25,39) had to be removed from the final analysis after communication with the authors, which revealed an inability to provide the requested values.

A variety of exercise types, intensities, durations, and environments were used in the selected studies. Seventeen studies (1,2,4,14,16,17,19–21,23,26,27,29–31,45) were laboratory-controlled studies, and the remaining 3 studies (7,28,43) were field studies. Twelve studies (2,4,14,16,17,19–21,23,29,30,45) used a cycle ergometer, 5 studies (1,26,27,31) used a treadmill, 2 studies (7,28) used a trail run, and 1 study (43) used a mountain bike race as their mode of exercise. Seven studies (1,2,7,26–28,31) had their subjects arrive hypohydrated for the hypohydration trial of each study. Eleven studies (4,14,16,17,19–21,23,29,30,43,45) had subjects arrive euhydrated for all trials. Seven studies (2,4,7,14,17,43,45) included trials in which intensity or time was not fixed; these studies included time to exhaustion trials (2,14), time trials (4,7,43), and graded exercise tests to fatigue (17,45). Regardless of the experimental design, 95% (35/37) of the trials demonstrated a higher HR in subjects that achieved a greater level of dehydration vs. the comparison group (Table 2).

Postexercise Measurements

The weighted mean difference in HR between groups (subjects who were more hypohydrated and subjects who were less hypohydrated) in all trials was 8 b·min^{-1} (95% CI, 6–10) (Figure 2), with the greater dehydrated group exhibiting a higher HR after exercise. The weighted mean difference in %BML was greater in the greater dehydrated group (2.53% [95% CI, 2.04–3.02]). Weighted mean difference in HR was greater in the greater dehydrated groups for those arriving euhydrated than hypohydrated (9 b·min^{-1} [95% CI, 7–11] and 8 b·min^{-1} [95% CI, 4–12], respectively). In subjects arriving euhydrated and hypohydrated, the greater dehydrated group exhibited a greater %BML; weighted mean differences were 2.59% (95% CI, 2.07–3.11) and 2.41% (95% CI, 1.57–3.26), respectively. The weighted mean differences in HR in variable intensity and fixed intensity trials were 3 b·min^{-1} (95% CI, −2 to 8) (Figure 3) and 9 b·min^{-1} (95% CI, 7–11), respectively (Figure 4). The mean difference in HR in cycling only trials and running only trials was 8 b·min^{-1} (95% CI, 6–10) and 9 b·min^{-1} (95% CI, 5–14), respectively. Change in HR with increasing levels BML was positively correlated ($R = 0.66$, $R^2 = 0.43$) and is shown in Figure 5.

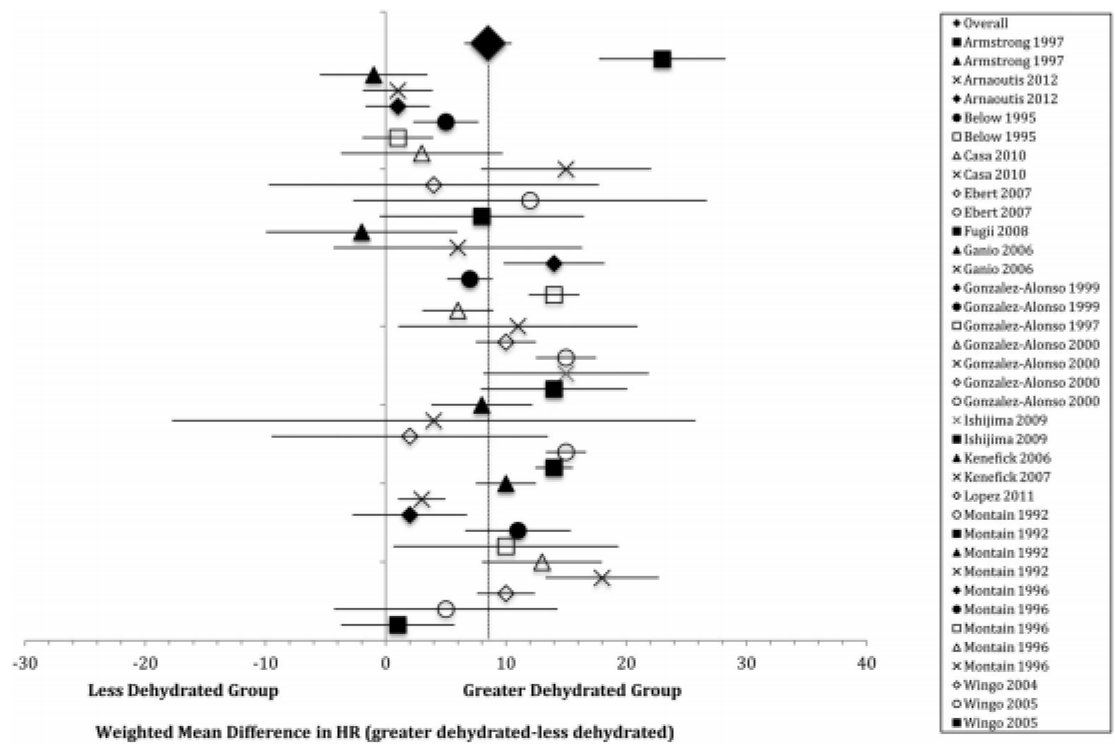

Figure 2. Weighted mean difference in postexercise HR between groups that were more dehydrated (>2% BML) and groups less dehydrated (<2% BML), all trials. BML = body mass loss; HR = heart rate.

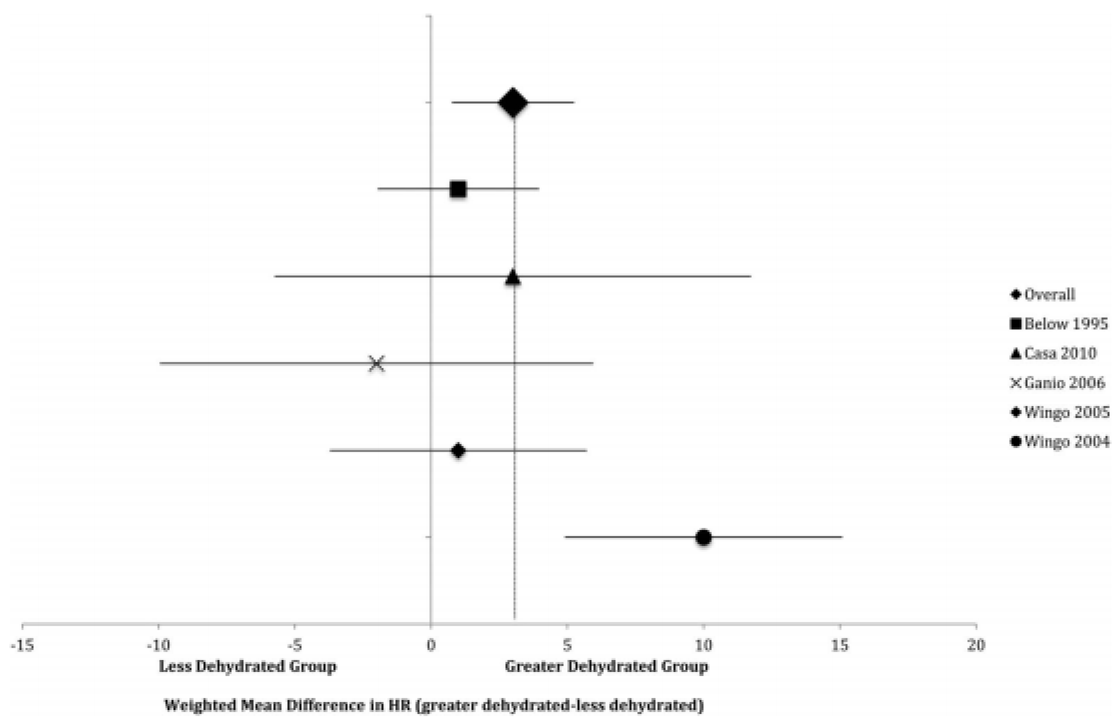

Figure 3. Weighted mean difference in postexercise HR for variable intensity trials between groups that were more dehydrated (>2% BML) and groups less dehydrated (<2% BML). BML = body mass loss; HR = heart rate.

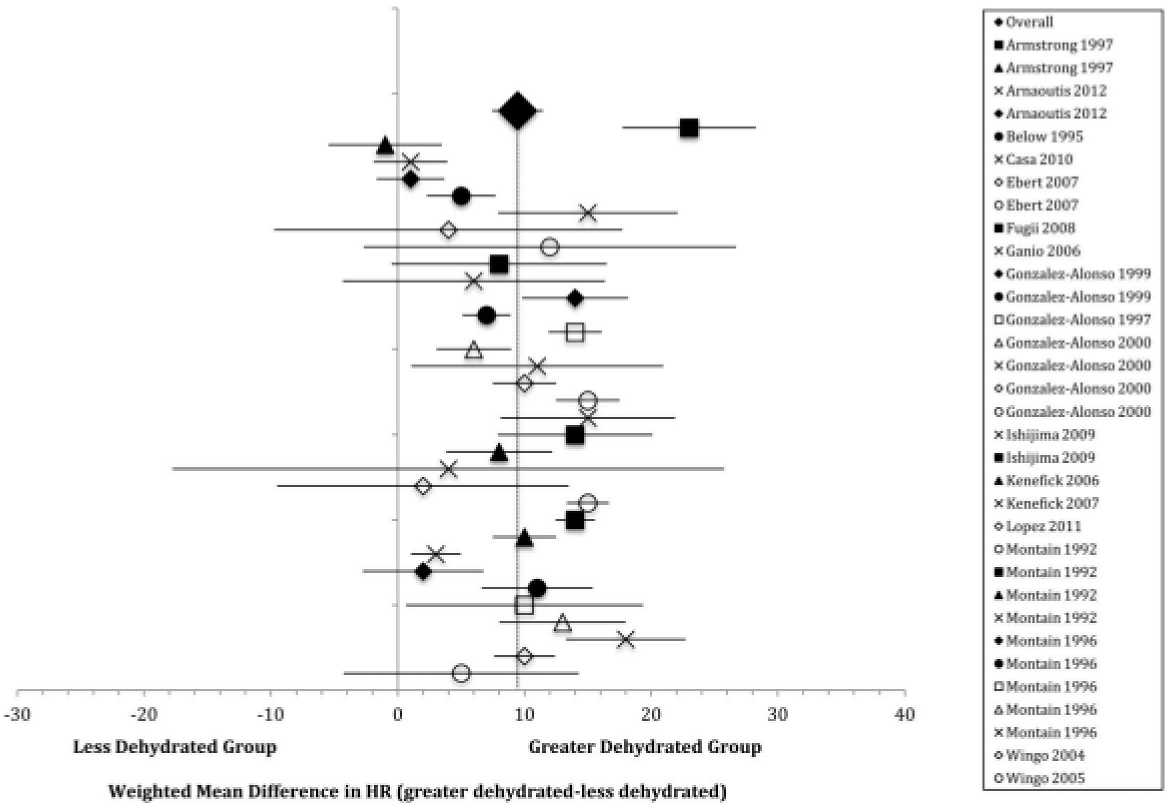

Figure 4. Weighted mean difference in postexercise HR for fixed intensity trials between groups that were more dehydrated (>2% BML) and groups less dehydrated (<2% BML). BML = body mass loss; HR = heart rate.

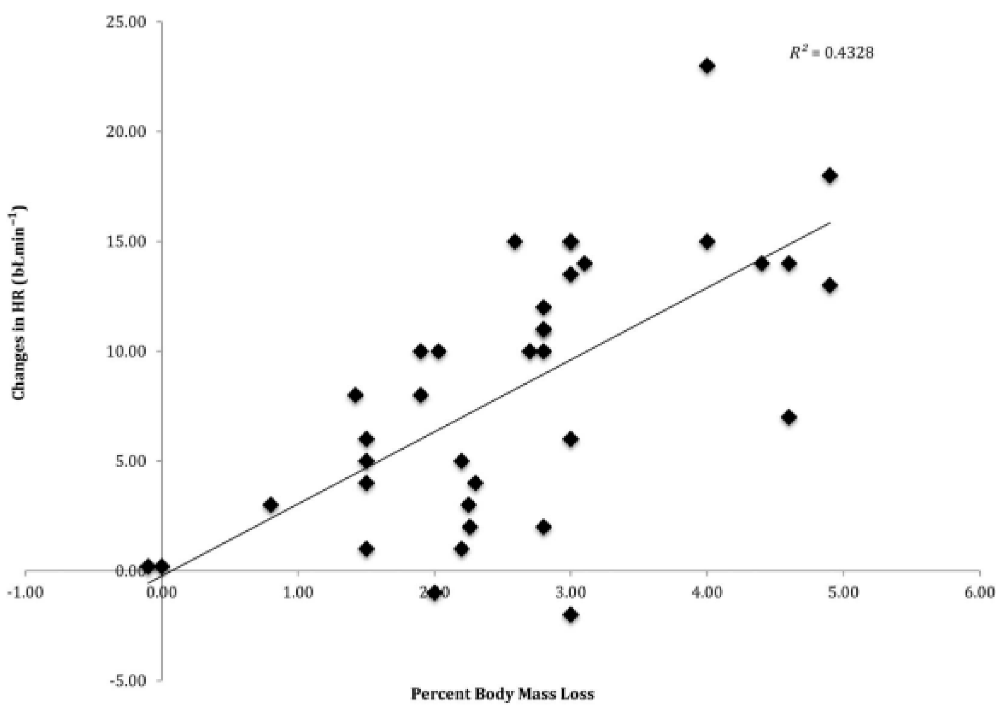

Figure 5. The relationship between the change in HR and increasing levels of body mass loss. HR = heart rate.

Across all trials, the mean change in HR for every additional 1% ΔBML was 3 ± 2 $b \cdot min^{-1}$. For trials where subjects arrived euhydrated, the mean change in HR for every additional 1% ΔBML was 3 ± 5 $b \cdot min^{-1}$. For the trials in which subjects arrived hypohydrated, the mean change in HR for every additional 1% ΔBML was 3 ± 2 $b \cdot min^{-1}$. Analyzing fixed and variable intensity trials (time trials or graded exercise tests), the change in HR for every 1% ΔBML was 4 and 1 $b \cdot min^{-1}$, respectively. Change in HR for every 1% ΔBML for cycling and running only trials was 3 ± 2 and 3 ± 2 $b \cdot min^{-1}$, respectively.

Discussion

The results of this review indicated that HR is increased with increasing levels of dehydration. Our analysis revealed that HR was increased by an average of 3 $b \cdot min^{-1}$ for every 1% ΔBML. The increases in HR as a result of the increased levels of dehydration coincide with the results of Montain and Coyle (30) who showed that the level of dehydration was directly correlated with the factors affecting cardiovascular strain; HR is increased and SV is subsequently decreased. The increase in cardiovascular strain as a result of exercise-induced dehydration has been shown to decrease performance (3,37).

Increased cardiovascular strain, occurring during prolonged physical activity in temperate and hot environments, has been identified as a factor impairing physical performance when exercising in a hypohydrated state (8,33). The decrease in total body water causes the reduction of blood volume and is responsible for the increase in HR and decrease in SV. The reduction in blood volume initiates a cascade of events. A reduction in cardiac filling, in addition to concurrent increases in skin blood flow, increases HR and decreases SV in an attempt to maintain cardiac output (8). Results from our review (17,19–21,30,31,45) show that exercise-induced dehydration further exacerbated cardiovascular drift during exercise in the heat.

Results from our review showed that there were no differences in the change in HR for every 1% ΔBML for subjects arriving either euhydrated or hypohydrated before exercise. The effects of cardiovascular drift have been shown to be in proportion to the degree of dehydration and hyperthermia (17,19,30). For example, if there were 2 athletes performing exercise in the heat with 1 athlete arriving euhydrated and the other athlete arriving hypohydrated, there would be no differences in the magnitude of cardiovascular drift (increase in HR and decrease in SV), if they both lost the same amount of body water during exercise. This might explain why there were no differences in HR between those arriving euhydrated and hypohydrated from our results. When examining performance from the studies included in our review, it is evident that arriving in a hypohydrated state has detrimental effects on performance, thus suggesting hydration status as a key determinant of subsequent exercise performance.

When examining the differences in HR with increasing levels of dehydration in cycling and running trials, our results showed that there were no differences between either exercise modes. This is in support of previous literature (34), which showed that there were no differences in HR between cycling and running, despite greater decreases in cardiac output and SV during cycling. These authors attribute the changes in cardiac output and SV to other mechanisms not associated with the tachycardia occurring during exercise that has been previously examined (15). It can be suggested by our results that the mode of exercise does not affect the changes in HR with increasing levels of dehydration during exercise in the heat.

Studies that required subjects to perform exercise using a time trial or graded exercise protocol saw negligible differences in HR with increasing levels of dehydration (4,7,17,25,45). The small differences in HR between subjects who are greater dehydrated vs. those less dehydrated during variable intensity exercise is most likely because of sensory input: the combination of exercise in the heat and dehydration increase overall physiological strain (9). In other words, when compared with exercise in a euhydrated state, levels of dehydration exceeding ∼2% BML in real-world situations (time trials, and so on) will result in similar exercising HR at the cost of reduced exercise intensity and thus poor performance. During a race, for example, a runner who is dehydrated will have an overall slower finish time over a runner who is hydrated, although both runners are performing at their maximum capacity. This is due to the physiological strain placed on their bodies, in that HR will be higher at a lower intensity in the more dehydrated runner; so although they may perceive themselves performing maximally, they will be running at a slower pace and be unable to pace themselves evening during the duration of the race (7,41).

Increasing levels of dehydration during prolonged exercise, especially in the heat, have profound effects on exercise performance. The American College of Sports Medicine (36) and National Athletic Trainers' Association (6) recommend that minimizing fluid losses during exercise (<2%) will assist in attenuating any decreases in exercise performance. In addition, there is supporting evidence recommending that minimizing fluid losses before and during exercise will enhance performance during prolonged exercise (8,13,33). This current review supports the aforementioned recommendations in that the trials where fluid was replaced, subjects exercised at lower HR intensities than in trials where fluid was restricted (2,4,7,14,17,28). It is suggested that if increases in HR, occurring during cardiovascular drift, are minimized during similar stress or exercise intensity, an athlete will be able to exercise longer before reaching fatigue.

This review was not without limitations. For the purposes of this review, we focused on exercise in the heat. Although we found that HR was increased at increasing levels of BML, we cannot generalize this across all situations because we did not take into account the temperate and cold environmental conditions. Second, all but 3 of the studies were performed in a controlled-laboratory setting and all but 5 studies had subjects exercise at a fixed exercise intensity. To be able to generalize these results during real-world athletic competitions, additional research needs to be conducted analyzing the changes in HR at increasing levels of BML in the field setting. Nonetheless, the presented studies support the notion that HR is increased with increased BMLs during exercise.

Practical Applications

The evidence presented in this review may be useful to both athletes and coaches. The results indicated that there is an additional increase in HR for every 1% change in BML at given exercise intensities during exercise in the heat. This increase in HR with increasing levels of dehydration can cause a decline in athletic performance, not only during training but also during competition. For example, an athlete arriving for a practice session or competition will have an increased HR of about 6–10 $b \cdot min^{-1}$ during exercise if they are 2–3% dehydrated. This increase in HR exacerbates cardiovascular drift and the level of perceived fatigue, thus decreasing exercise performance, especially during endurance events and exercise in the heat.

Beginning exercise in a euhydrated state and minimizing fluid losses throughout exercise will attenuate the increases in cardiovascular strain and increase overall performance. Athletes who begin exercise in a euhydrated state and minimize fluid losses throughout exercise will be able to exercise at a higher intensity and have a lower perception of exertion and fatigue. As a result, athletes will be able to achieve greater gains during training to help maximize athletic performance during competition. In addition, maintaining an appropriate level of hydration during exercise in the heat is of particular importance because the physiological stresses of heat exposure are responsible for performance decrements.

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