The Hydration Debate: Making Sense of the Mixed Messages

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DISCLOSURE

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The statements and opinions contained in this program are solely mine.

DEHYDRATION & AEROBIC PERFORMANCE: CONTROVERSIAL ISSUE?

Contrasting Perspectives

Dr. Sawka

Does Dehydration Impair Exercise Performance?

PREVAILING VIEW

Dehydration (water deficits of >2% body mass, BM) degrades aerobic exercise performance in temperate and warm-hot environments. This prevailing view is supported by:

1. observations made on individuals performing arduous work, with limited fluids, in warm-hot environments;
2. the vast majority of experimental data from laboratory and field studies in temperate and warm-hot environments;
3. paucity of experimental data indicating otherwise; and

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Contrasting Perspectives

CHALLENGING VIEW

It is definitively established that some humans who either (i) begin an exercise test with unreplaced acute fluid losses induced, for example, by prolonged (6 h) exposure to either a hot environment (19) or to prolonged (2 h) prior exercise in uncomfortable heat during which they did not ingest any fluid (21) or after pretreatment with a diuretic that increases urinary water and electrolyte losses (2) by inducing the uncomfortable symptoms of polyuria; or who (ii) drink either nothing or little during exercise [for example, (10, 33,59,75)], will show a measurably impaired exercise performance. Since I am a coauthor of two studies

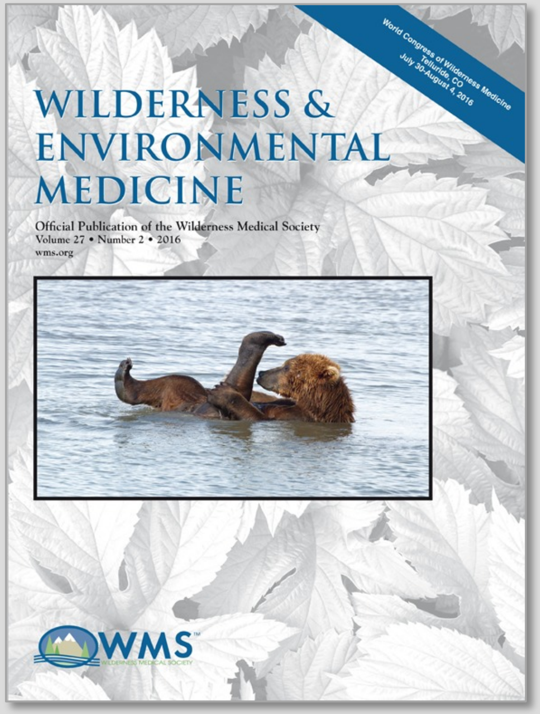
Dr. Noakes

>2% BML (~3% TBW)
Warm-Hot Environments
Aerobic Performance Impaired
Multiple Mechanisms Responsible

Drink to Thirst
“Complex” Model
Some >10% BML, No Impact
Lab Not Field

Sawka & Noakes *MSSE* *2007*

DRINK TO THIRST: CONTROVERSIAL ISSUE?



- **Viewpoints:**
  - **VIEW: Is Drinking to Thirst Adequate to Appropriately Maintain Hydration Status During Prolonged Endurance Exercise? Yes**
    - Martin D. Hoffman, MD; James D. Cotter, PhD; Éric D. Goulet, PhD; Paul B. Laursen, PhD
- **Counterview:**
  - **VIEW: Is Drinking to Thirst Adequate to Appropriately Maintain Hydration Status During Prolonged Endurance Exercise? No**
    - Lawrence E. Armstrong, PhD; Evan C. Johnson, PhD; Michael F. Bergeron, PhD

WILDERNESS & ENVIRONMENTAL MEDICINE, 27, 192–202 (2016)

MAJOR TAKEAWAYS UP FRONT

“Drink to thirst” vs. “Programmed drinking”

- **Both strategies seek to:**
  - Prevent hyper- / hypo-hydration
  - Preserve performance

- **Success of either strategy depends upon context:**
  - **Event characteristics**
    - Duration, intensity, environment, etc.
  - **Participant characteristics**
    - Fitness level, acclimatization status, body size, etc.
  - **Goals of the athlete**
    - i.e. recreational vs. professional

PRESENTATION OUTLINE

Terminology :

Purpose of drink to thirst vs. programmed drinking

Physiology of thirst

- Sensitivity of thirst in maintaining hydration
- Thirst guided drinking research
- Dehydration research
- Research discrepancies
- Programmed drinking
- Recommendations

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DEFINITION OF TERMS

Programmed drinking: pre-established drinking plan
ACSM position stand: exercise and fluid replacement. Med Sci Sports Exerc. 2007;39(2):377–390.

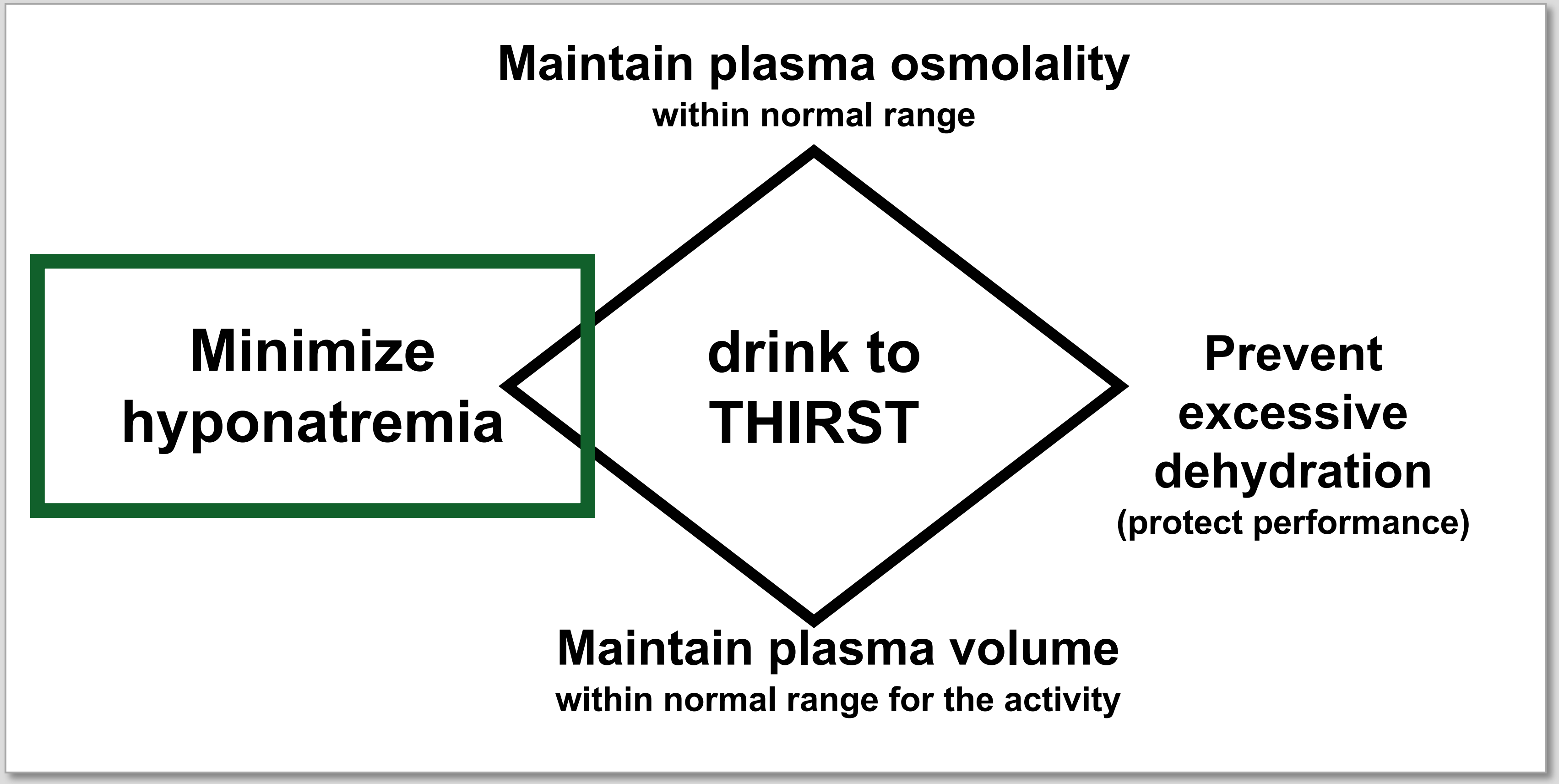
Drinking to thirst: using the sensation of thirst as the only stimulus to drink

Ad libitum drinking: consuming fluid whenever and in whatever volume desired
Nolte et al. Br J Sports Med. 2011;45(14):1106–1112.
Ormerod et al. Int J Sport Nutr Exerc Metab. 2003;13(1):15–28.
Vokes. Annu Rev Nutr. 1987;7:383–406.

- **Drink to thirst has been used synonymously with ad libitum drinking**
  Hew-Butler et al. IMMDA Clin J Sport Med. 2006;16(4):283–292.
  Beis et al. Clin J Sport Med. 2012;22(3):254–261.
- **Drinking to thirst and drinking ad libitum resulted in similar physiologic and perceptual outcomes**
  Armstrong et al. J Athl Train. 2014;49:624–631.

WHY DRINK TO THIRST?

Statement of the Third International Exercise-Associated Hyponatremia (EAH) Consensus Development Conference



Redrawn from ***Clin J Sport Med 2015;25:303–320***

WHY PROGRAMED DRINKING?

Because there is considerable variability in sweating rates and sweat electrolyte content between individuals, customized fluid replacement programs are recommended.

ACSM Position Stand on Fluid Replacement
Medicine & Science in Sports & Exercise, 2007, Volume 39, Issue 2, pp 377-390

- **Prevent excessive dehydration (≥2% body mass)**
- **Prevent heat illness (heat exhaustion, heat stroke)**
- **Prevent hyponatremia**
- **Prevent degradation in performance**
  - Improve cardiovascular stability
  - Improve thermoregulatory responses

FLUID INTAKE GUIDELINES

ACSM, 2016

ACSM, 2007

NATA, 2017

USATF, 2004

IMMDA, 2006

1. Approximate fluid intake to sweat losses
- Prevent >2% body mass change

2. Ingest ~30-60 g carbohydrate/hour
- ~0.5 – 1.0L/h; 6-8% CHO solution

1. Drink *ad libitum* (according to thirst)
2. Drink no more than 0.4 - 0.8L/h

GOALS OF FLUID INTAKE RECOMMENDATIONS

Optimal Fluid Replacement

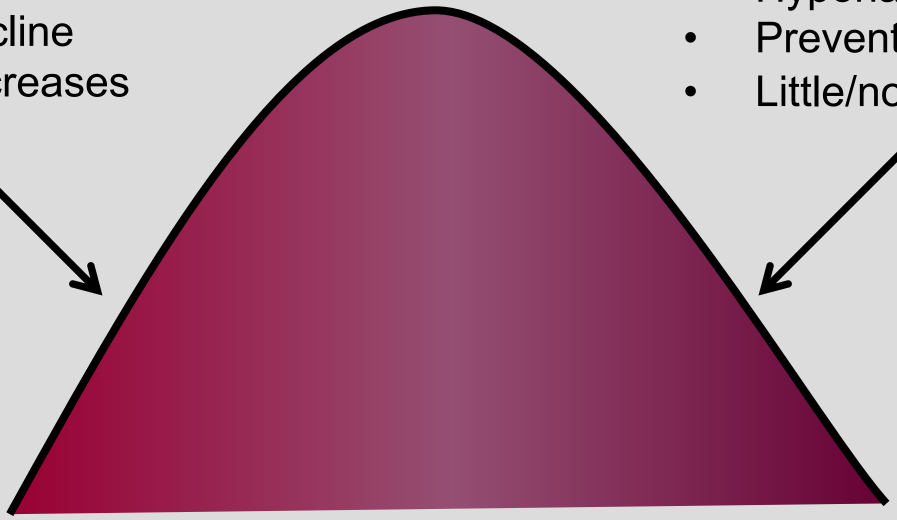
Too Little
(Dehydration)

- Performance decline
- CV, thermoreg decline
- Heat injury risk increases

Optimal

Too Much
(Over-hydration)

- Hyponatremia
- Prevent *excessive* dehydration
- Little/no performance impact



Net loss of body water

Net gain of body water

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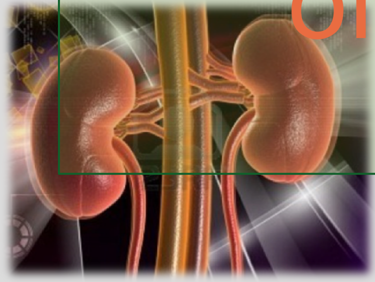
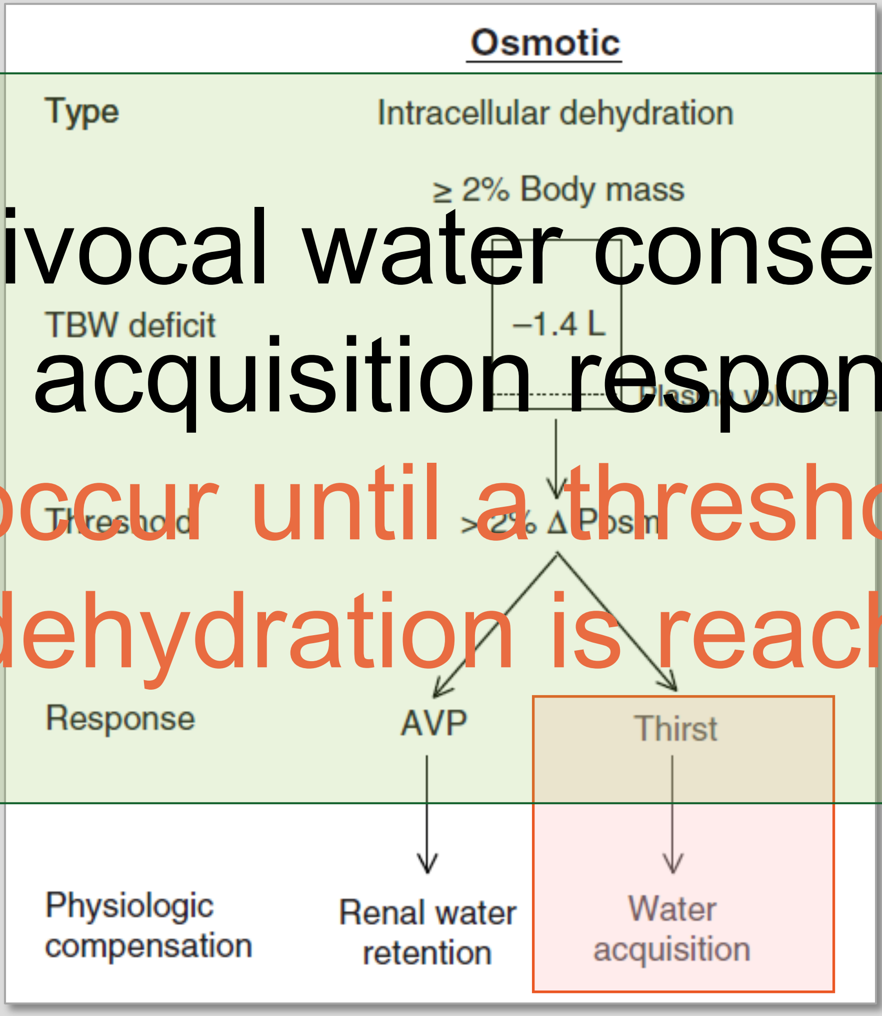
PHYSIOLOGICALLY DRIVEN THIRST





Unequivocal water conservation and acquisition responses do not occur until a threshold level of dehydration is reached

Cheuvront & Kenefick. 2014. *Comp Physiol*

THIRST AND FLUID INTAKE

Phillips et al., 1984; de Castro et al., 1988; Engell et al., 1988

Most fluid intake occurs with meals

- When food and fluids are freely available

Humans take in fluid for reasons outside of thirst

- Social / psychological

During exercise fluid consumption may be for reasons other than thirst

- Fuel intake
- Xerostomia- dry mouth

Scully, Crispian (2008). Oral and maxillofacial medicine: the basis of diagnosis and treatment (2nd ed.). Edinburgh: Churchill Livingstone. pp. 17, 31, 41, 79–85.

HISTORICAL REVIEW:

AD LIBITUM FLUID REPLACEMENT NOT ADEQUATE DURING EXERCISE-HEAT STRESS

"Man – undergoes a decrease in body weight when water is drunk *ad libitum*" (Boulder City, NV Walks in Desert)

Dill et .al. American Journal of Physiology 1933

"No man drank enough water voluntarily to replace that lost by sweating while working and all developed water deficits"

Bean & Eichna Federation Proceedings 1943

"Since it lags behind water need, thirst constitutes an insensitive guide to the water requirement"

Eichna et.al. Bulletin Johns Hopkins Hospital. 1945

"Over the short period, thirst is often suppressed, even though a progressive deficit in water is being incurred"

Johnson. Journal American Dietetic Association 1964

DB Dill

HOW SENSITIVE IS THE SENSATION OF THIRST?

Most larger mammals, including the dog, burro and camel rehydrate rapidly following water loss

Adolph. Am. J. Physiol. 125: 75-86, 1939.
Adolph and Dill. Am. J. Physiol. 123:369-378, 1938.
Schmidt-Nielson et al. Am. J. Physiol. 185:185-194, 1956.

Man rehydrates much more slowly when water is lost either by sweating or water deprivation

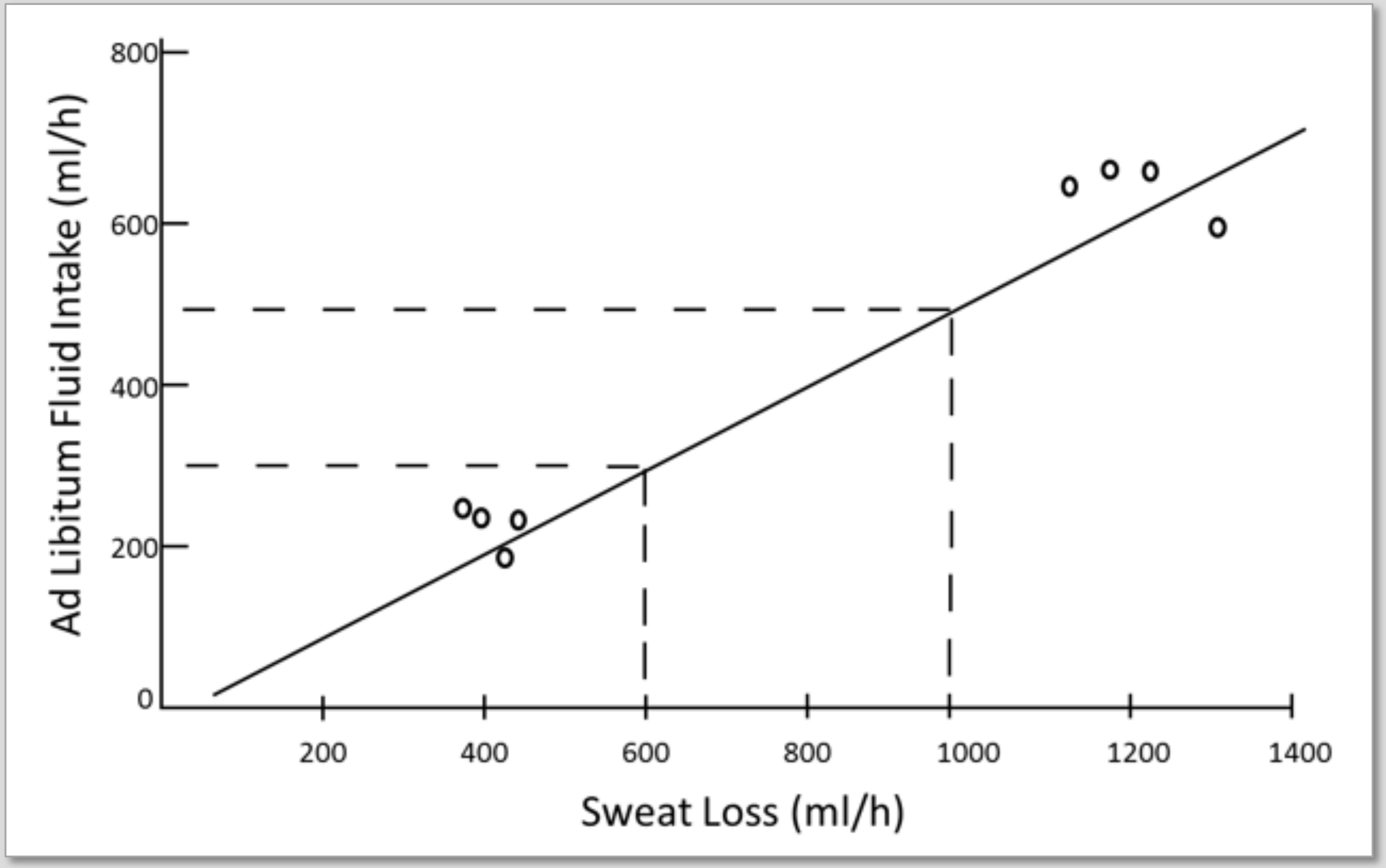
Robinson et al. Am. J. Physiol. 140:168-176, 1943.
Black et al. J. Physiol., London. 102:406-414, 1944.

When a man and a dog walked 32km in a hot environment the dog maintained its weight balance while the man lost about 3kg of his body weight – water was available ad libitum to both

Dill et al. Am. J. Physiol. 104:36-43, 1933.

AD LIBITUM FLUID REPLACEMENT NOT ADEQUATE DURING EXERCISE-HEAT STRESS

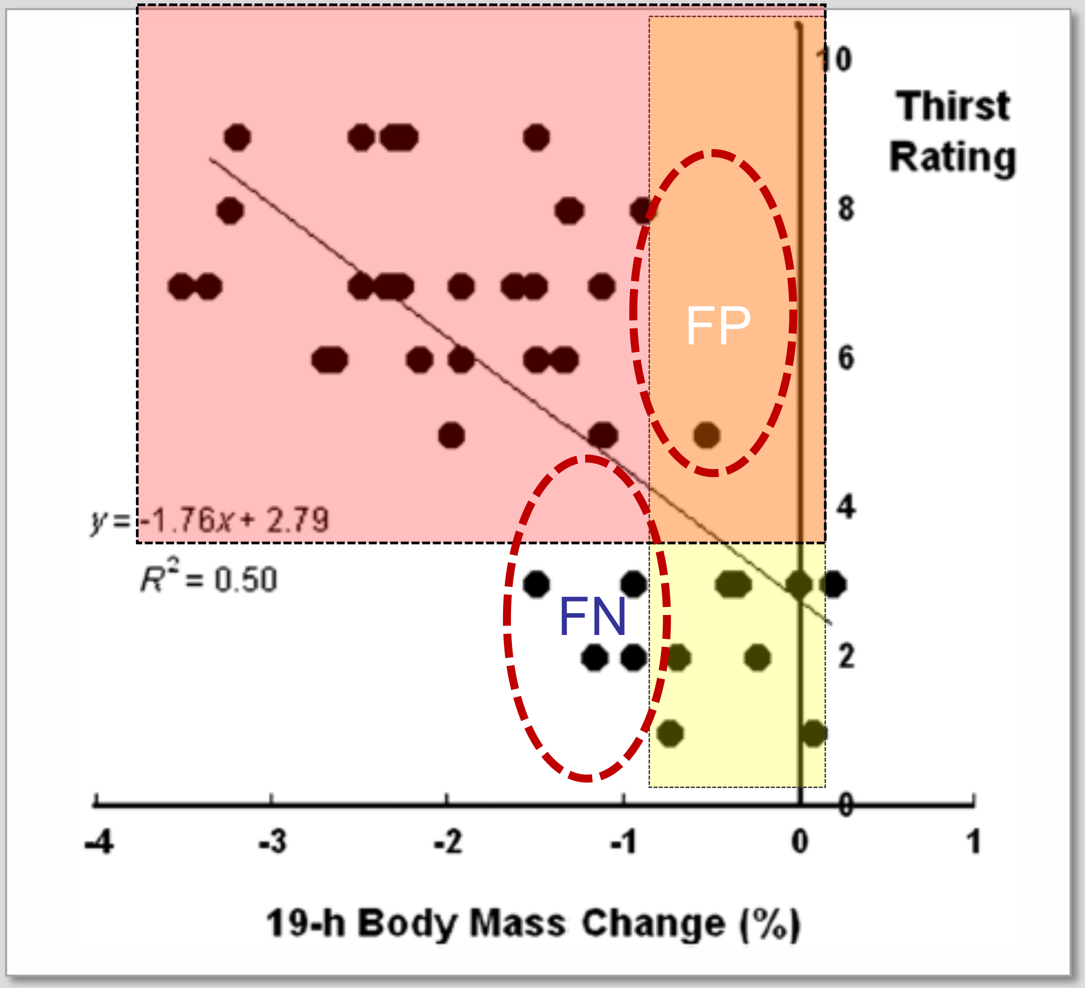
Ad lib **drinking results in ~50% fluid replacement relative to sweat loses**



Greenleaf & Sargent JAPPL 1965

HOW SENSITIVE IS THIRST?

9	Very, very thirsty
8	
7	Very thirsty
6	
5	Moderately thirsty
4	
3	A little thirsty
2	
1	Not thirsty at all



Armstrong et al. Appl. Physiol. Nutr. Metab. 39: 138–144 (2014)

FN = False negative; FP = False positive

SUMMARY: THIRST

Thirst works well only at rest

(Greenleaf et al. JAP2, 0(4):719-24 1965.)

Thirst develops after dehydration is present & alleviated before euhydration is achieved

(Greenleaf . Med Sci Sports Exerc 24: 645-656, 1992.)

Usually not perceived until 2% BM is already lost

(Shirreffs et al. Br J Nutr. 91(6):651-8, 2004.)

Limited application to elderly

Kenney & Chiu. MSSE 2001

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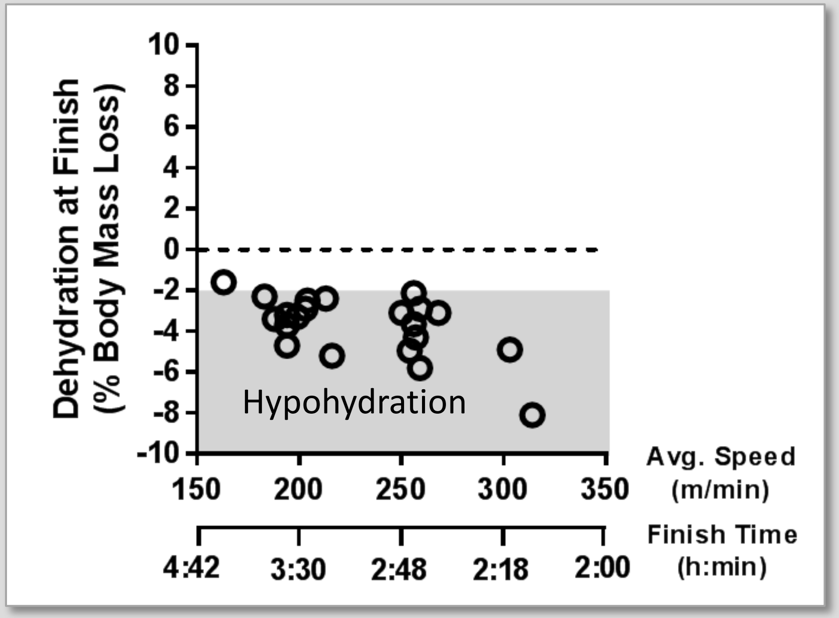
DRINK TO THIRST

Is *ad libitum* drinking efficacious to prevent >2% dehydration during a marathon?



- Data are group means from 14 studies
- Marathon finishing times from 2 h 10 min to 4 h; Ta = 10 – 28°C
- Drink to thirst (ad libitum) leads to excessive dehydration

Compiled from: Cheuvront and Haymes, 2001

AD LIBITUM DRINKING RESEARCH

Study	N	Environ.	Distance/Mode
Knechtle B. et al., Asia Pac J Clin Nutr. 2010	11 F	8-18°C	100km/ Run
Hoffman MD. et al., Med Sci Sports Exerc. 2013	669	14-38°C	161km / Run
Hoffman MD. et al., Res Sports Med,. 2014			161km / Run

Ad libitum fluid in take during 100 to 161 km running

- No hyponatremia
- 2-3% body mass loss, no performance impact
- Drinking beyond thirst not required for ultra endurance events in heat

Daries HN, Noakes TD Med Sci Sports Exerc. 2000	8 M	25°C	Treadmill 90 mins ~65% VO_{2peak} 30 min time trial
Beis LY et al., Clin J Sports Med. 2012	10 M	15.3 ± 8.6°C	42km
Dion T et al., Eur J Appl Physiol. 2013	10 M	30°C	21.1km treadmill w/ extra air flow

Ad libitum vs. programmed drinking
21 and 42 km running

- Plasma osmolality & volume not different
- Small elevations in HR and core temperature
- ~10% body mass loss, no impact on performance

Dugas JP et al. (Noakes TD), Eur J Appl Physiol. 2009	6M	33°C	80km TT
Berkulo M et al. (Noakes TD), Eur J Sports Sci. 2016	12M	35.2 ± 0.2°C	<70 mins 40km TT 7m/sec air velocity
Costas NB et al., Med Sci Sports Exer. 2017	10M	32°C	30km

Ad libitum vs. programmed drinking - Cycling TTs

- Thermoregulation, CV responses not different
- No performance differences
- No need to replace 100% sweat losses
- >2% body mass loss not achieved until finish

WHAT CAN WE CONCLUDE FROM AD LIBITUM/DRINK TO THIRST LITERATURE?

- Plasma osmolality and volume not different
- No/small impact on thermoregulatory responses
- No/small impact on CV responses
- 2 to 3%, 10% BM loss no impact on performance
- Drinking beyond thirst not recommended
- No hyponatremia

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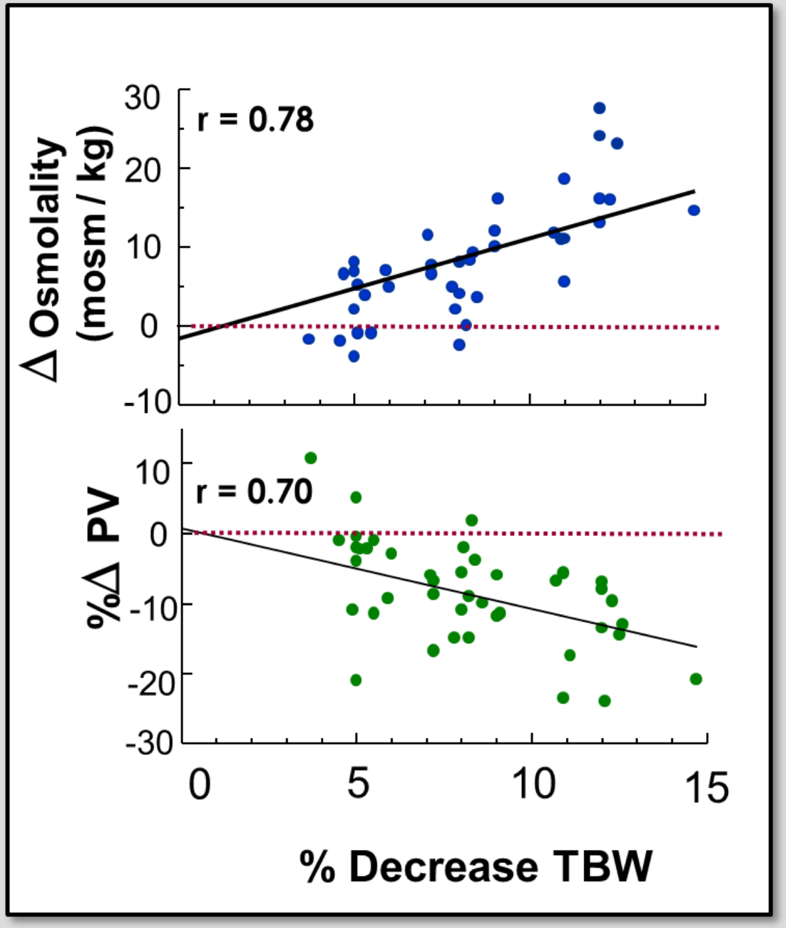
BODY WATER BALANCE BASICS

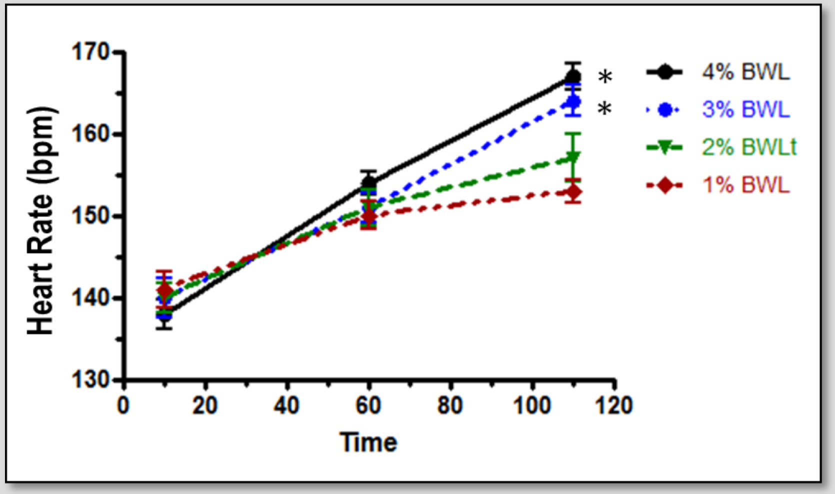


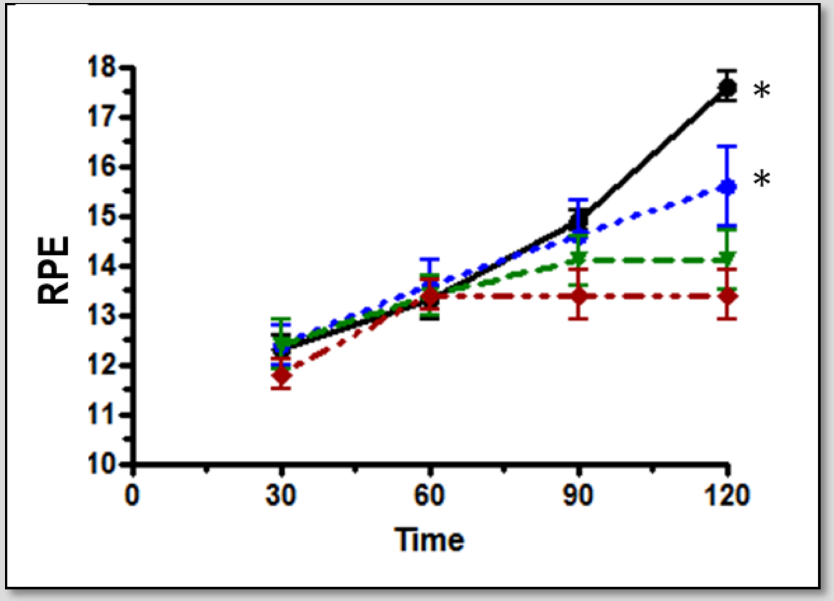
Sawka et al., 1996

- Dehydration occurs when there is a mismatch between fluid input and fluid output
- Sweat losses and water unavailability are primarily responsible
- Dehydration most commonly results in resting plasma hypertonicity (↑osmolality) and hypovolemia (↓plasma volume)

DEHYDRATION INCREASES HEART RATE & RATINGS OF PERCEIVED EXERTION (RPE)

33° C, 50% rh; ~60% VO_{2max}

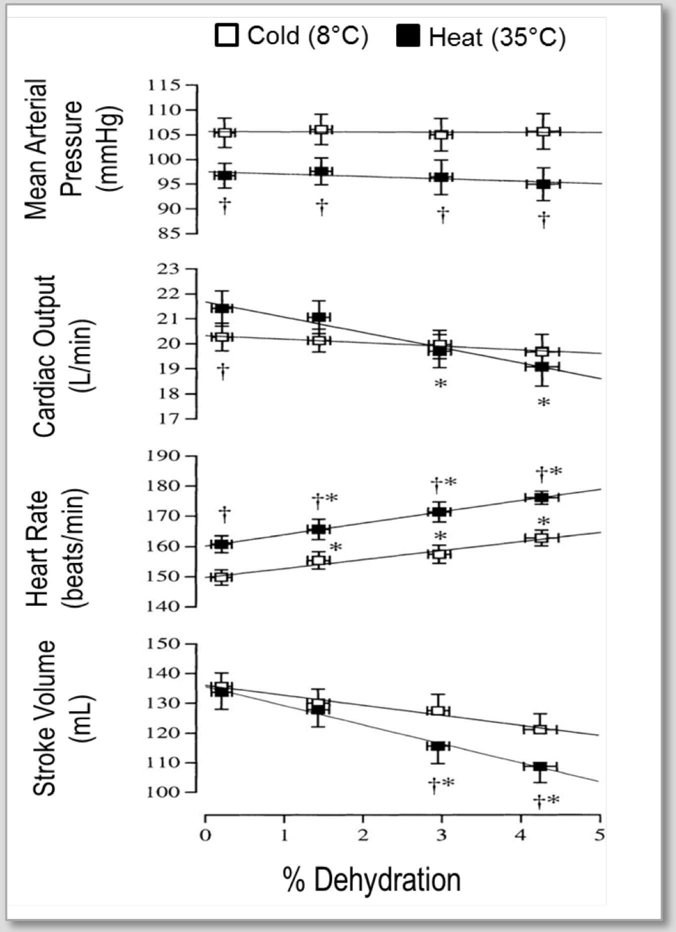




Even when starting exercise -2 to -4% BWL, HR and RPE not appreciably different until > 60 min.

Montain et al. *JAP*, 1992

CARDIOVASCULAR RESPONSES TO DEHYDRATION



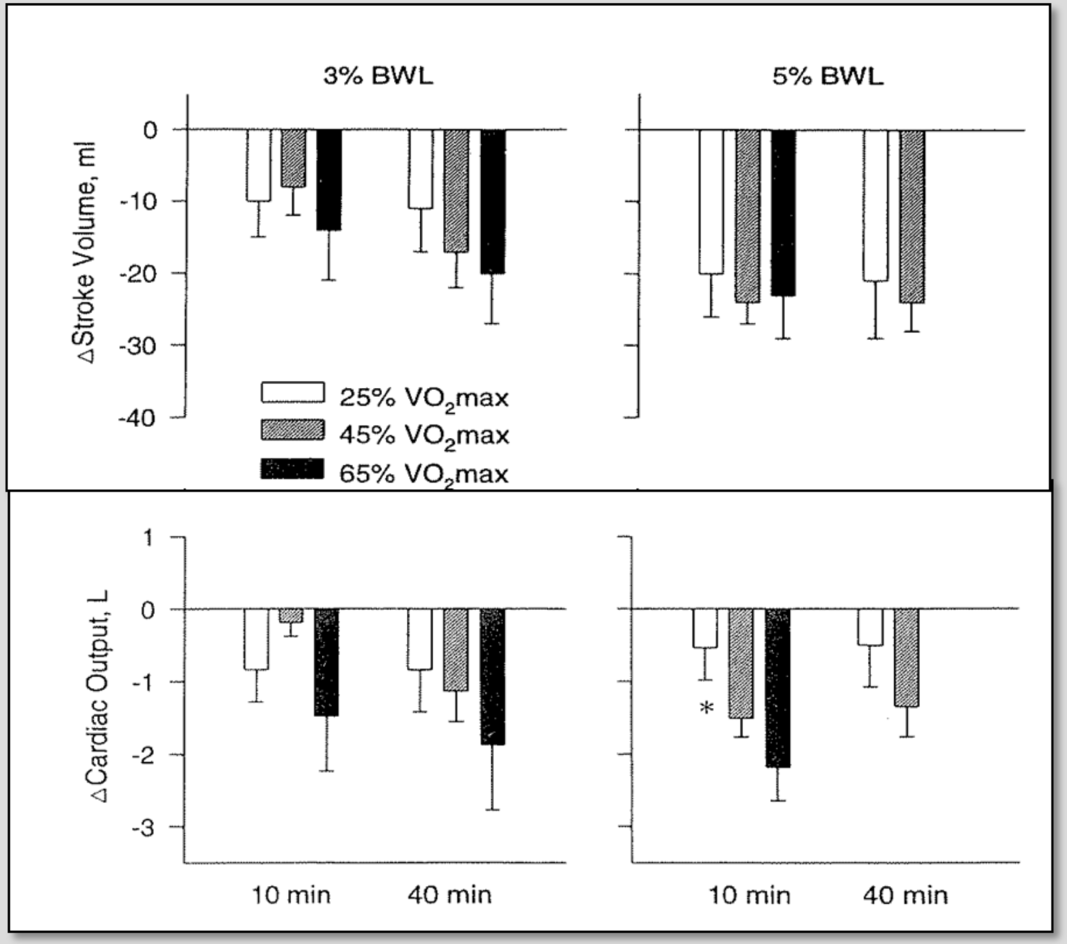
- 20- to 30-min of exercise in cold (8°C) & in heat (35°C)
- Euhydrated and dehydrated by 1.5, 3.0, and 4.2% of body weight
- * Significantly different from euhydrated condition, $P < 0.05$.
- † Significantly different from exercise in 8°C, $P < 0.05$.

Gonzalez-Alonso J, Mora-Rodriguez R and Coyle EF. Stroke volume during exercise: interaction of environment and hydration. *Am J Physiol Heart Circ Physiol* 278: H321-H330, 2000.

DEHYDRATION REDUCES CARDIAC OUTPUT DURING EXERCISE-HEAT STRESS

Higher Intensity Greater Reduction

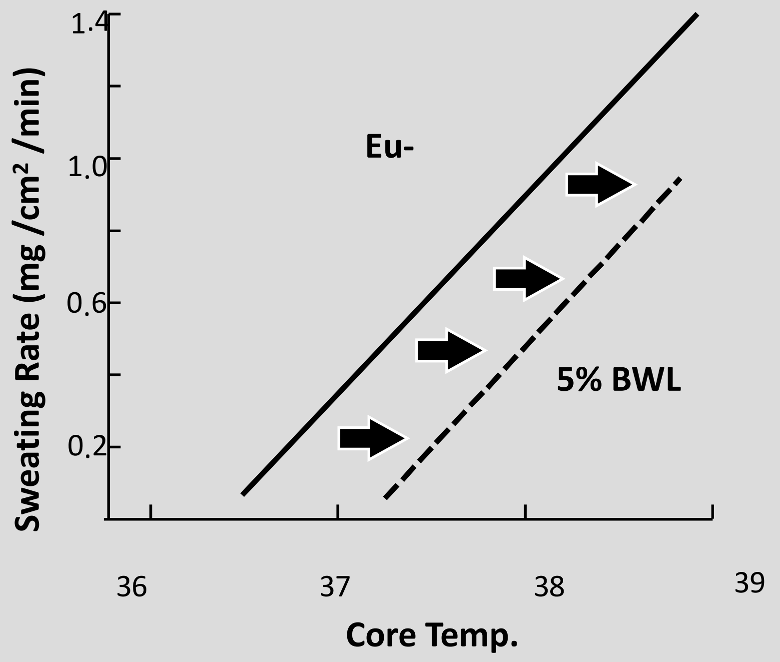
- 30° C
- 50% rh
- 50 min treadmill exercise



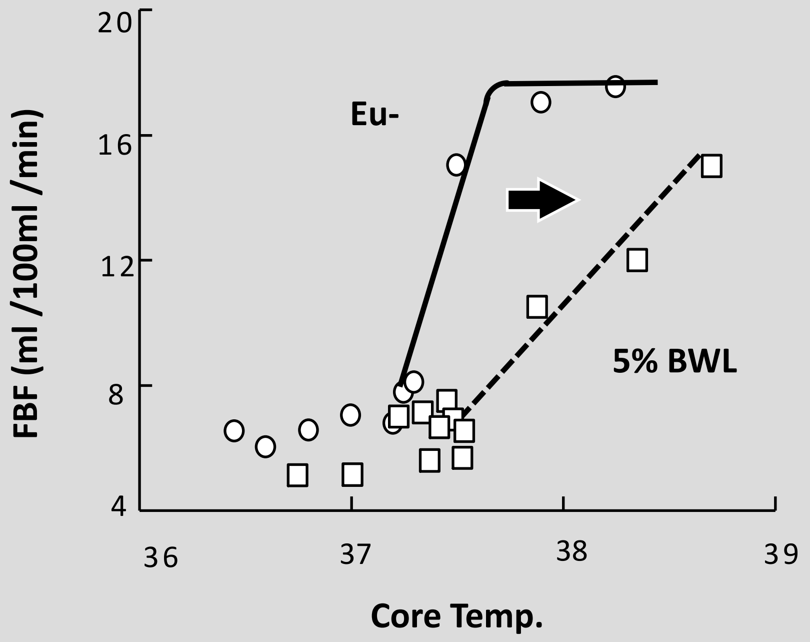
Montain et.al. IJSM 1997

* Different (P<0.05) than 65% VO2max

DEHYDRATION REDUCES SWEATING & SKIN BLOOD FLOW DURING EXERCISE-HEAT STRESS

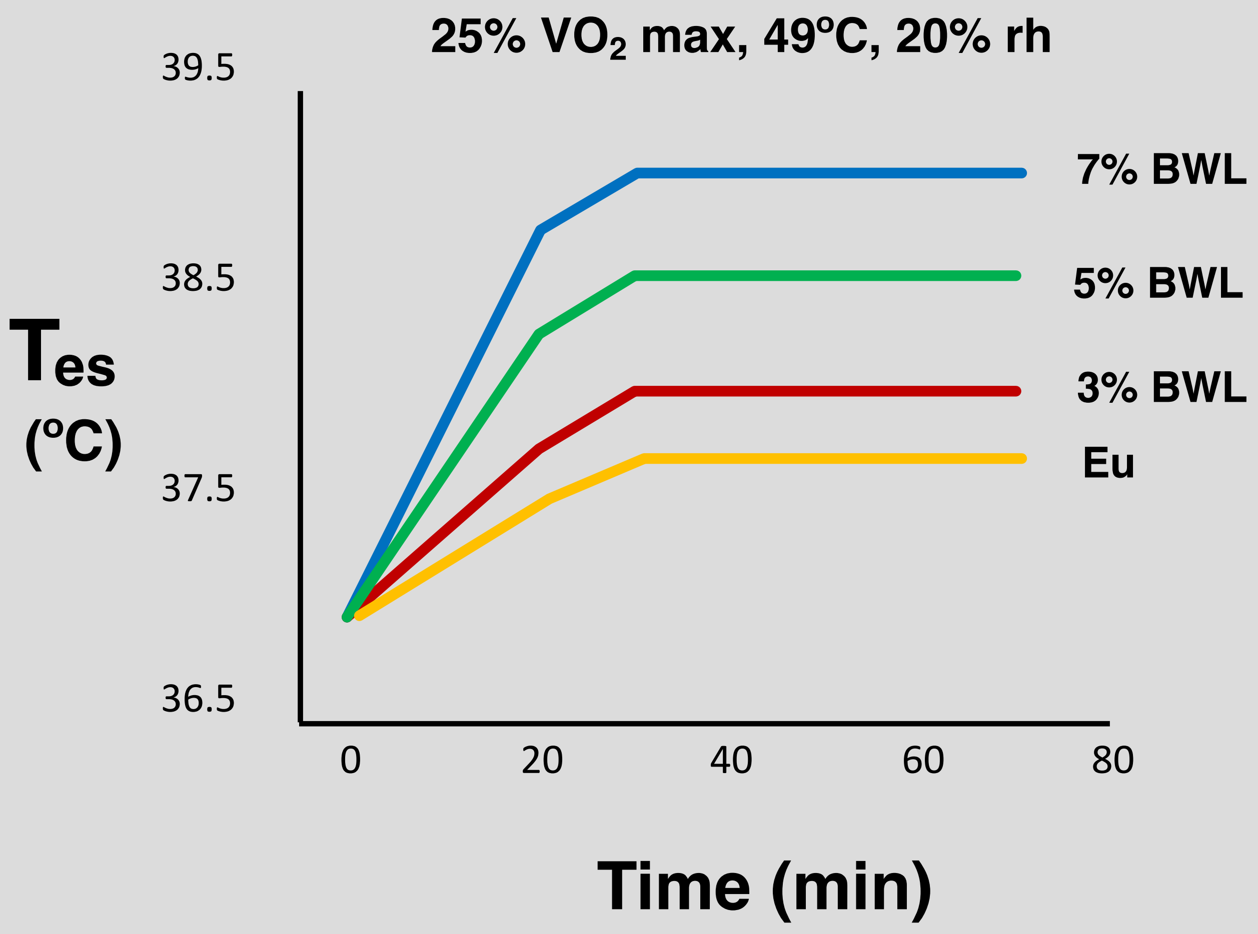


Sawka et al. AJP 1989



Kenney et al. JAP 1990

DEHYDRATION INCREASES CORE TEMPERATURE DURING EXERCISE-HEAT STRESS



Sawka et al., JAP, 1985

SUMMARY: CV & THERMOREGULATORY RESPONSES

Dehydration

- $\downarrow$ Stroke Volume
- $\uparrow$ Heart Rate
- $\downarrow$ Cardiac Output

- $\uparrow$ Temp Threshold Sweating
- $\downarrow$ Sweat Rate
- $\downarrow$ Skin BF
  - Results in elevated T_{core} during exercise
  - Responses are related to hypovolemia and $\uparrow$ P_{osm}

Responses are mediated by:

- Degree of Dehydration
- Environment
- Exercise Intensity

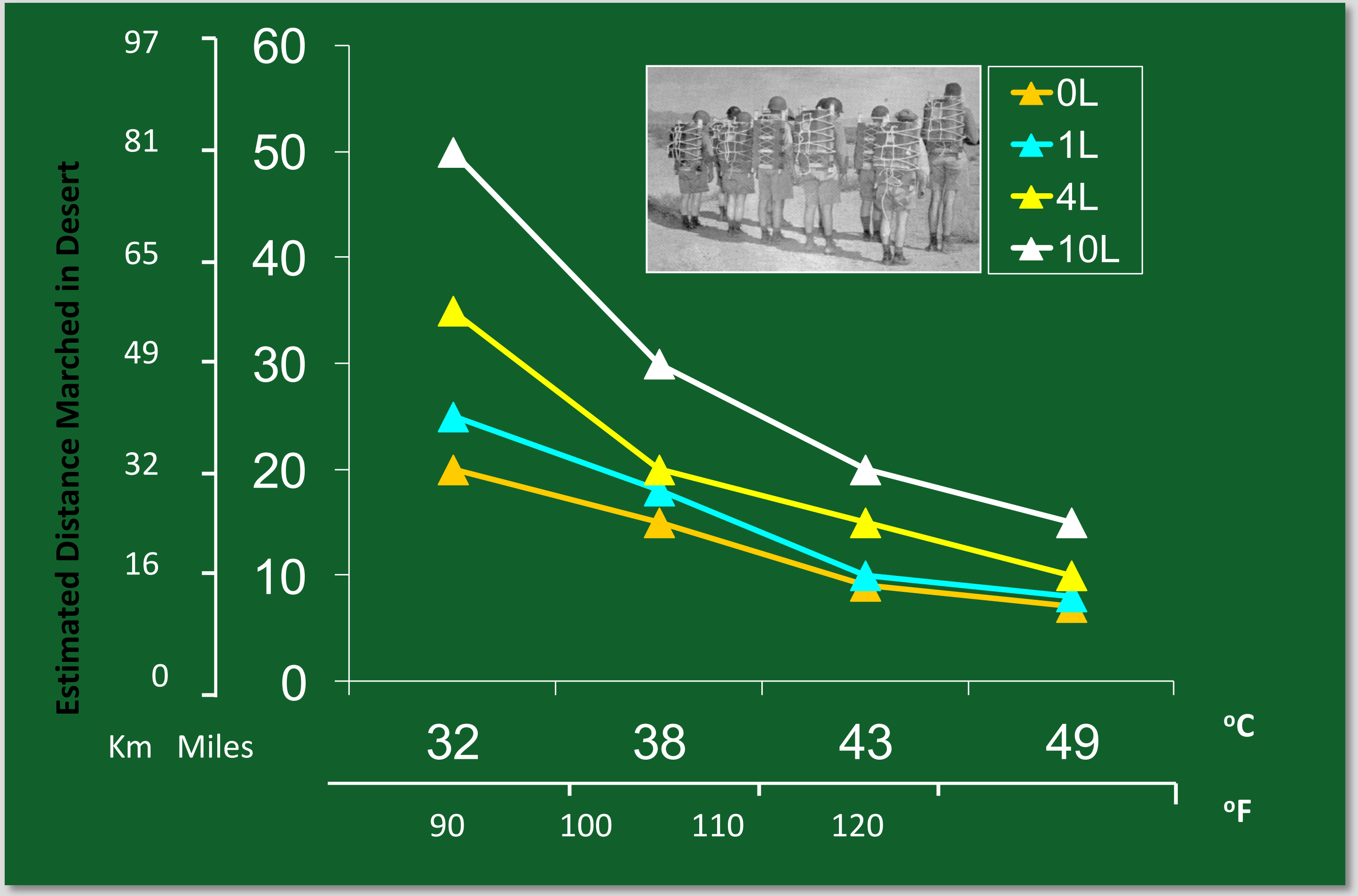
Greater impact with:

$\uparrow$ %BWL

$\uparrow$ Temperatures

$\uparrow$ Exercise Intensity

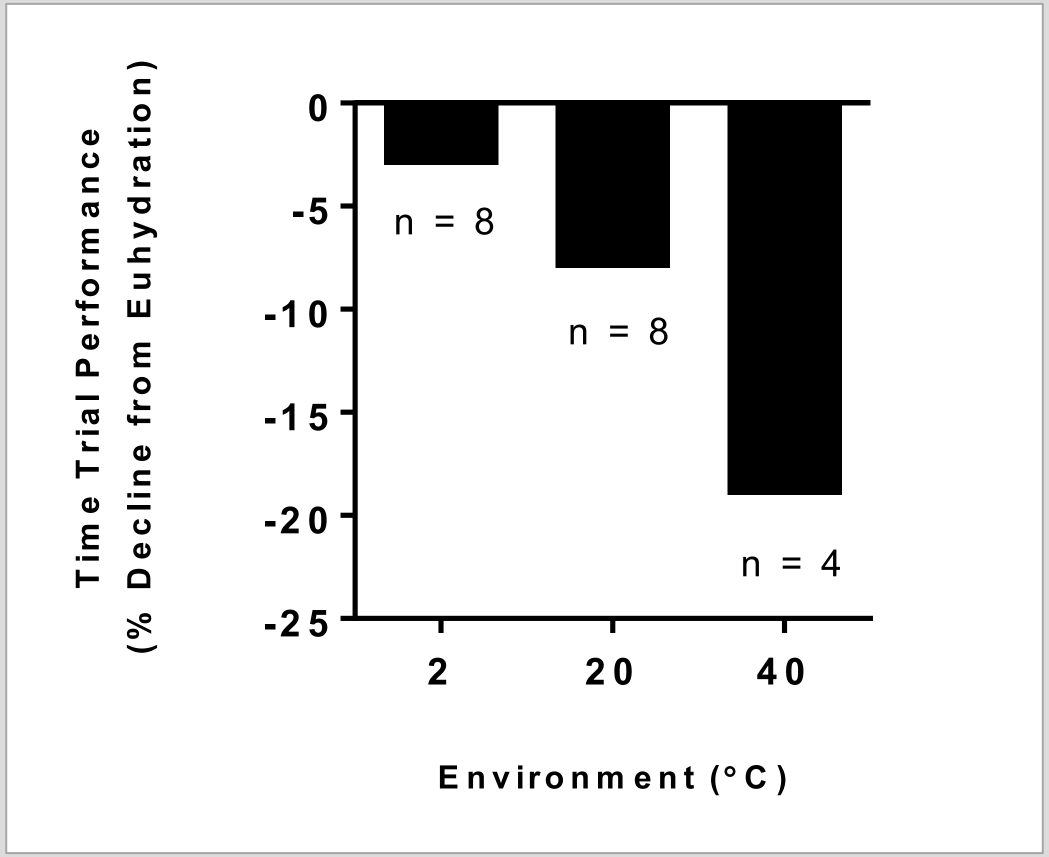
WATER RESTRICTION REDUCES SELF-PACED PERFORMANCE IN THE HEAT



Adolph & Associates, Man in Desert, 1947

DEHYDRATION ON CYCLE EXERCISE PERFORMANCE IN THREE ENVIRONMENTS

Dehydration (3% BWL) Degrades Aerobic Performance More in Warmer Environments



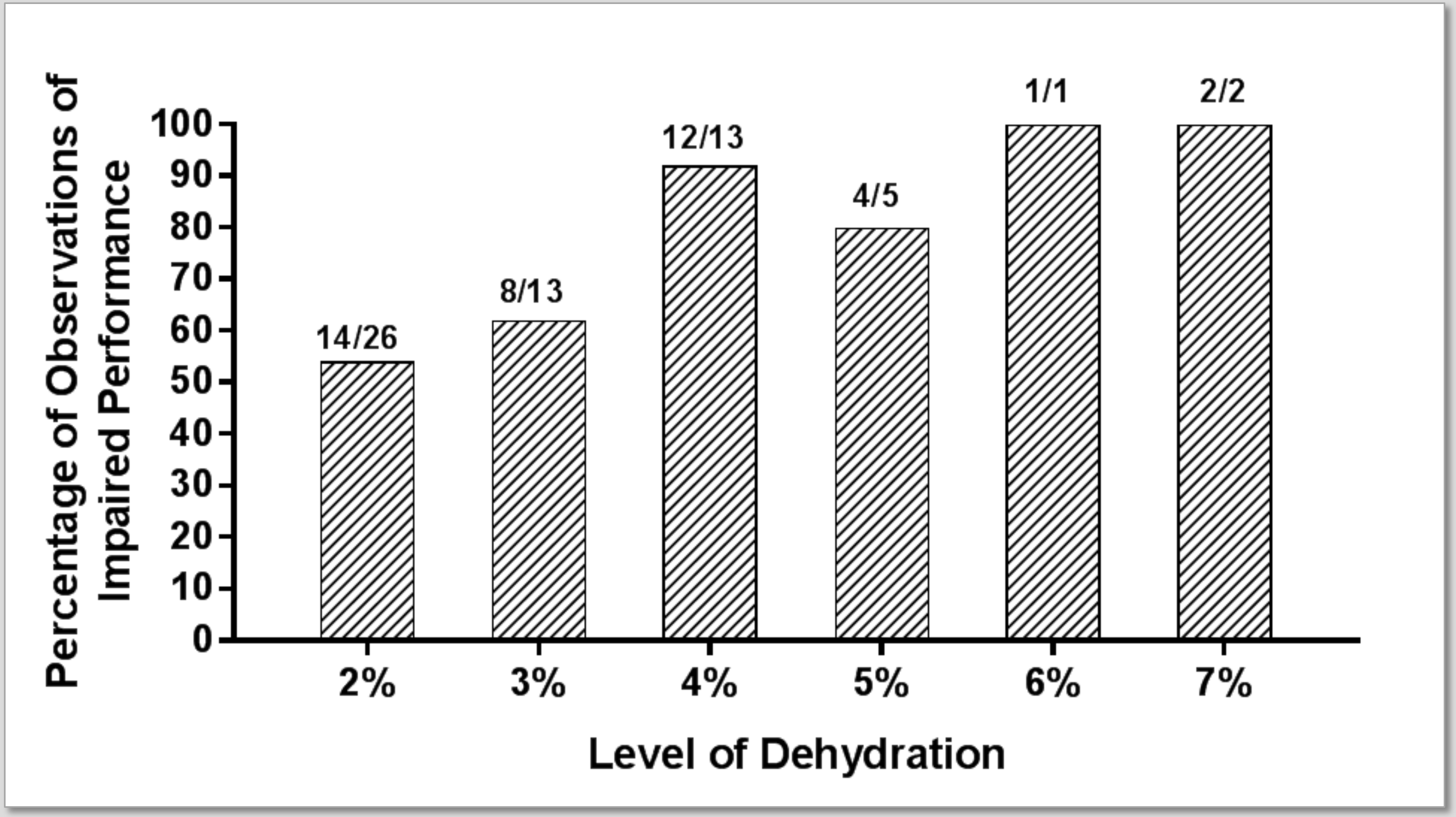
Cheuvront et.al. JAP 2004 & 2005

DEHYDRATION DEGRADES AEROBIC PERFORMANCE: MAXIMAL INTENSITY

Study	N	Environ.	% BWL	VO_{2max} Change	PWC* Change
Craig & Cummings JAP 1966	9	46°C	-2%	-10%	-22%
			-4%	-27%	-48%
Buskirk et.al. JAP1958	13	26°C	-5%	-0.2 L	-
Caldwell et.al. JAP 1984	47	Temperate	-4%	-3%	-17%
Herbert & Ribisl RQ 1972	6	Temperate	-2%	-	-8%
	6		-4%	-	-16%
Nybo et.al. JAP 2001	6	15°C Perfused Suit	-4%	-6%	-29%
	6	44°C Perfused Suit	-4%	-16%	-56%
Saltin et.al. JAP 1964	9	19°C	-4%	ND	-34%
Webster et.al. MSE 1988	7	Temperate	-5%	-7%	-7%

*PWC = Physical work capacity

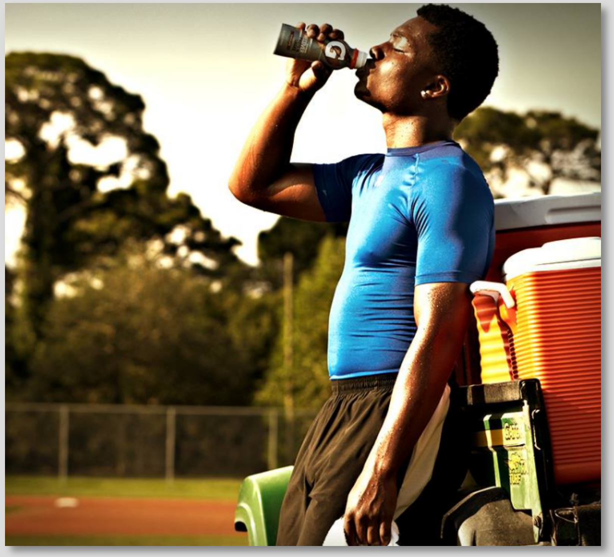
REVIEW OF DEHYDRATION EFFECTS: 68% OF ALL ENDURANCE OBSERVATIONS SHOW ⬇PERFORMANCE



S.N. Cheuvront and R.W. Kenefick. *Comprehensive Physiology.* Dehydration: Physiology, Assessment and Performance Effects. *Comprehensive Physiology*. Jan 1;4(1):257-85, 2014.

SUMMARY: DEHYDRATION & PERFORMANCE

- Dehydration degrades physical work capacity relative to environment, %BWL
- Dehydration degrades submaximal exercise performance, muscle endurance, VO2max?
- Review of literature, 68% endurance exercise studies show degradation ($P<0.05$)



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DISCREPANCIES BETWEEN DRINK TO THIRST AND DEHYDRATION LITERATURE

Studies are "observation" vs. "experimental"

- Pre- or post-event questionnaires
- Extrapolated fluid intake and body mass loss
- Two hours or less duration
- Low exercise intensity (ultra-marathons)
- Low ambient temperatures with wind speed
  - air flow + forward motion = greater heat loss
- Exercisers start euhydrated and progressively dehydrate
  - ≥ 2% BML not achieved until end of event
  - Performance not impacted

DISCREPANCIES BETWEEN DRINK TO THIRST AND DEHYDRATION LITERATURE

Literature supports that dehydration impairs CV, thermoregulation function and exercise performance relative to % dehydration & heat stress

Most lab based, exercise-heat stress studies:

- BWL was established prior to performance trial
- Dehydration equal to TBW deficits of 2.5 to 5.0 L (>2% BWL)
- Compare very hot (≥40°C) and temperate (≤ 25°C) environments
- Minimal airflow
- High exercise intensities
- High TSK (perfused suits)
- Studies may exaggerate strain of exercise-heat stress & dehydration

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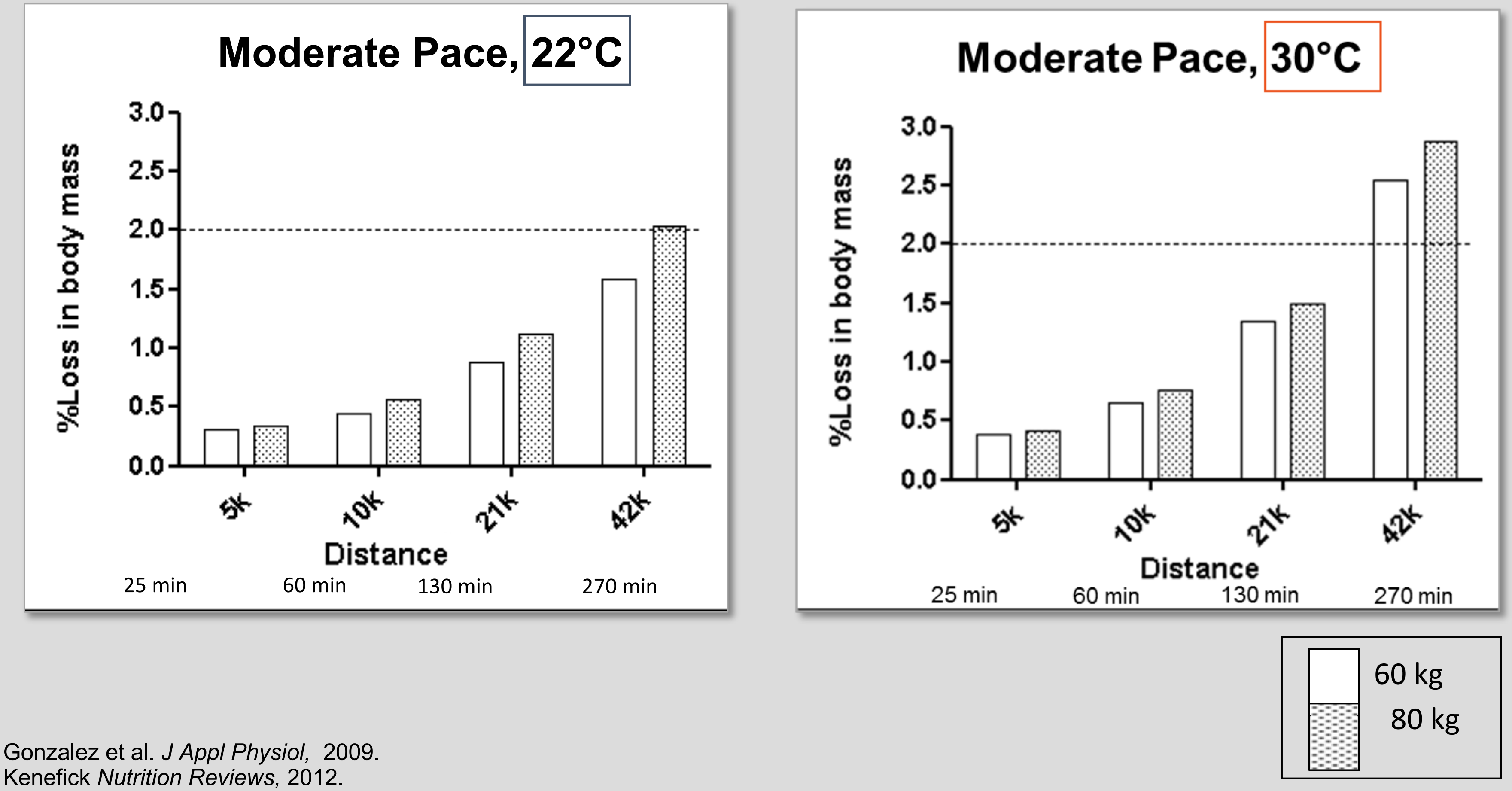
CHANGE IN BODY MASS FROM PREDICTED SWEAT RATES FOR VARIOUS RUNNING DISTANCES



Gonzalez et al. *J Appl Physiol,* 2009.
Kenefick *Nutrition Reviews,* 2012.

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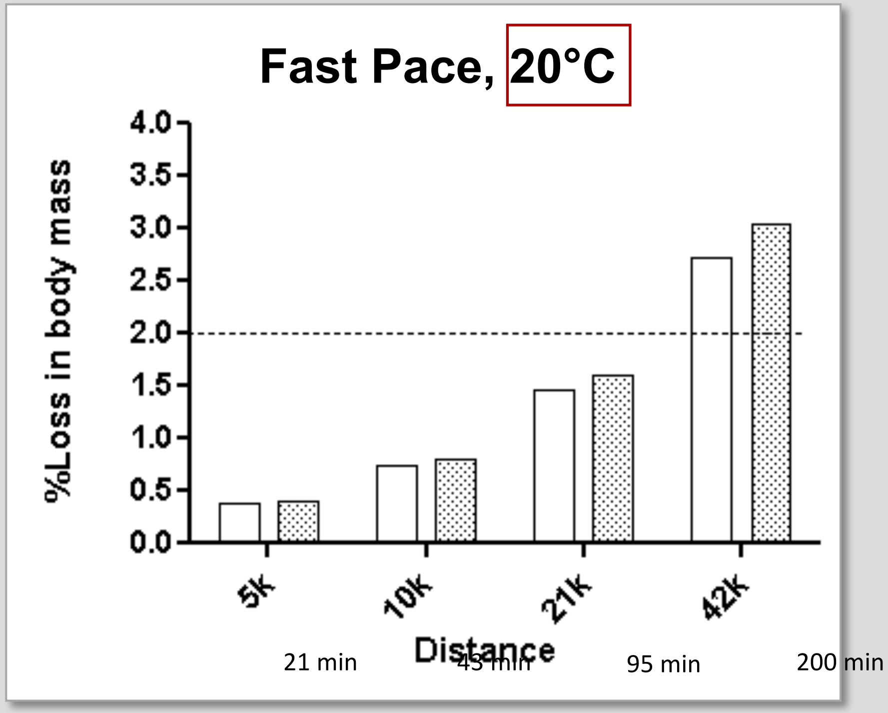
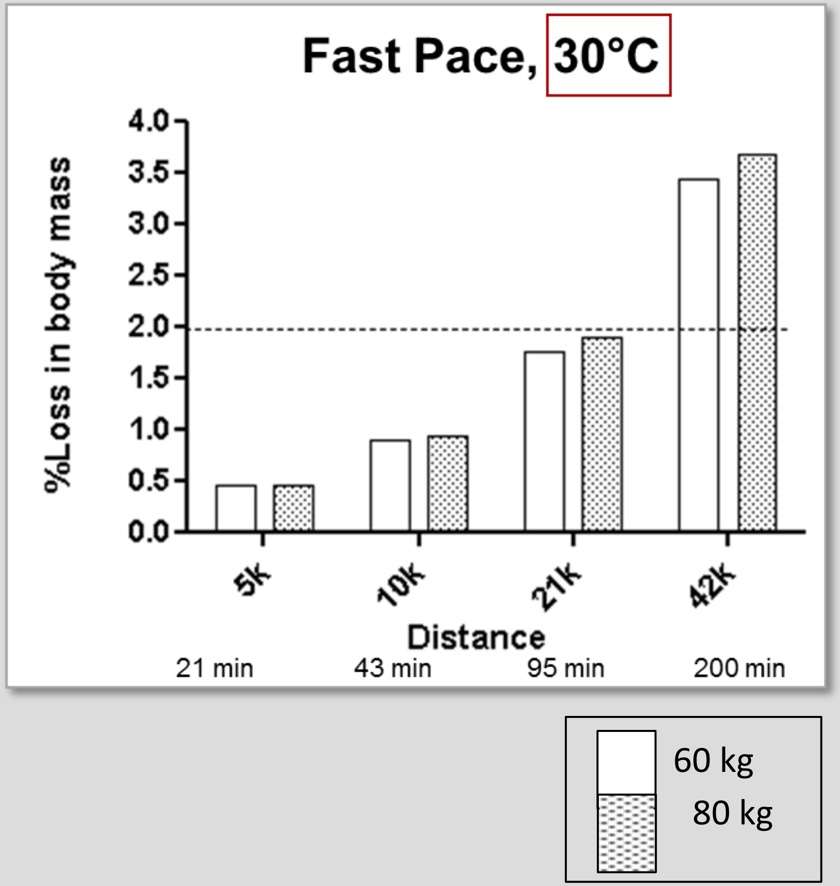


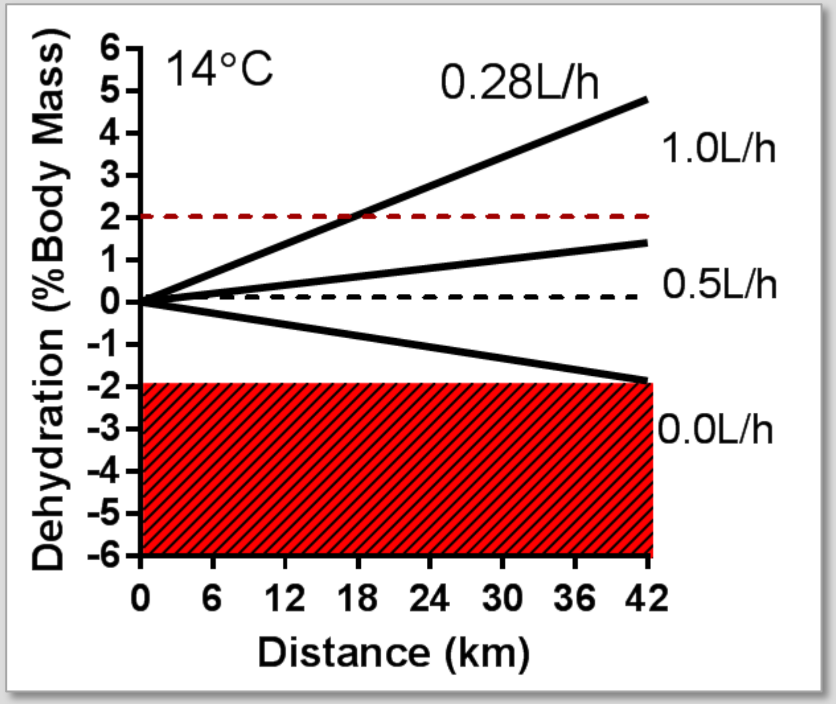


Gonzalez et al. *J Appl Physiol,* 2009.
Kenefick & Cheuvront *Nutrition Reviews,* 2012.

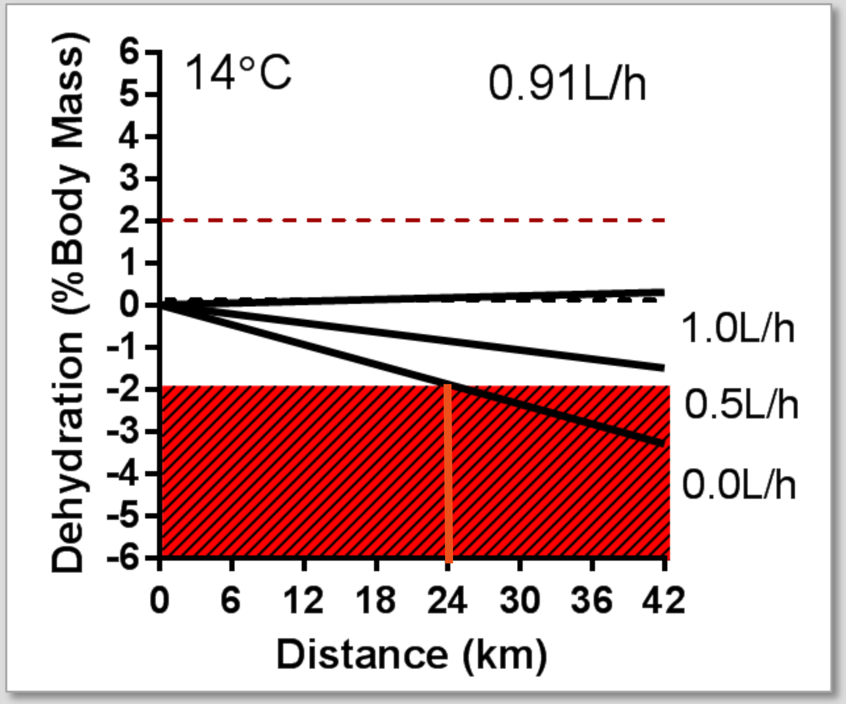
SITUATIONAL APPLICATION OF PROGRAM DRINKING

Goal: prevent hypo- or hyper-hydration

60 kg; 4h marathon



60 kg; 2h 10 min marathon



Adapted from: Cheuvront et al., 2007

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DOES DRINK TO THIRST OR PROGRAMMED DRINKING APPLY TO ALL SITUATIONS

Circumstances where "Drink to Thirst" *MAY* be sufficient:

- Short duration exercise < 1hr to 90min
- Exercise in cooler conditions
- Lower intensity exercise

Circumstances where "Drink to Thirst" will *NOT* be sufficient:

- Longer duration activities >90min, particularly in the heat
- Higher intensity exercise
- High sweat rates
- Exercise performance is a concern

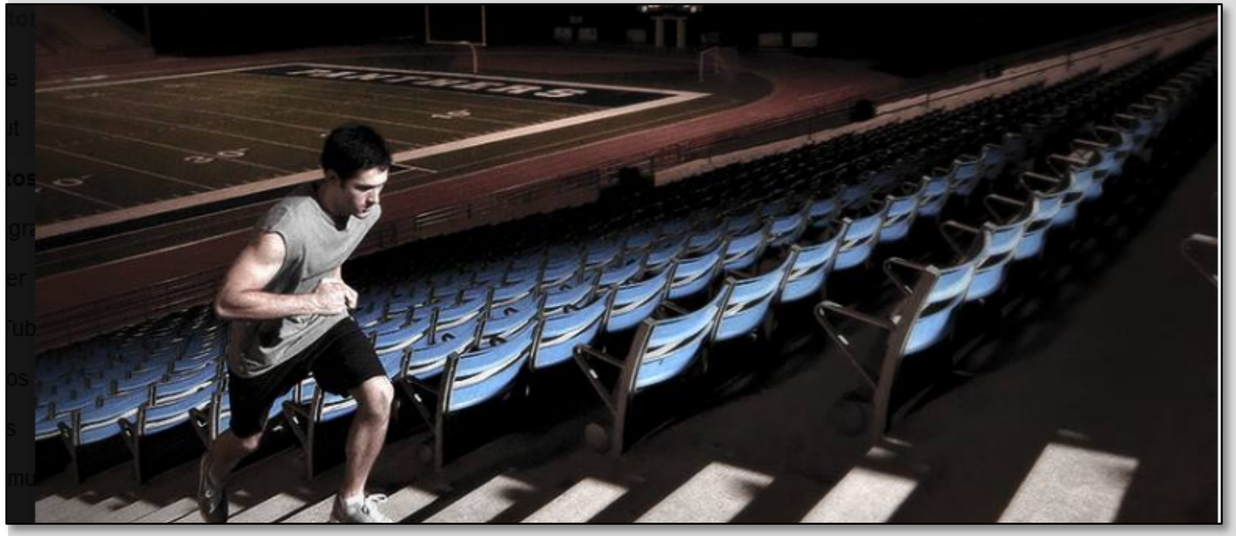
Where performance is a concern:

- Determine sweat rate under conditions (pace and environment) that are similar to the anticipated race
- Tailor drinking to prevent body mass losses >2%
    - Never drink so much that weight is gained
- Despite low fluid losses with slower paces in warm/hot temps- activity > 1hr should intake CHO and electrolyte

DOES DRINK TO THIRST OR PROGRAMMED DRINKING APPLY TO TEAM SPORTS

- **Technically, either strategy is difficult in team sports settings**
- **Fluid intake during team sports depends upon context:**
  - **Sporting characteristics**
    - How many breaks, how long, modality (aerobic vs. anaerobic), etc.
  - **Participant characteristics**
    - Athletes' attire, equipment, acclimatization status, etc.
  - **Environment characteristics**
    - Indoor vs. outdoor, cold vs. hot, etc.
- **Athletes should always practice hydration strategies before reaching competition.**

Questions?



BONUS SLIDES

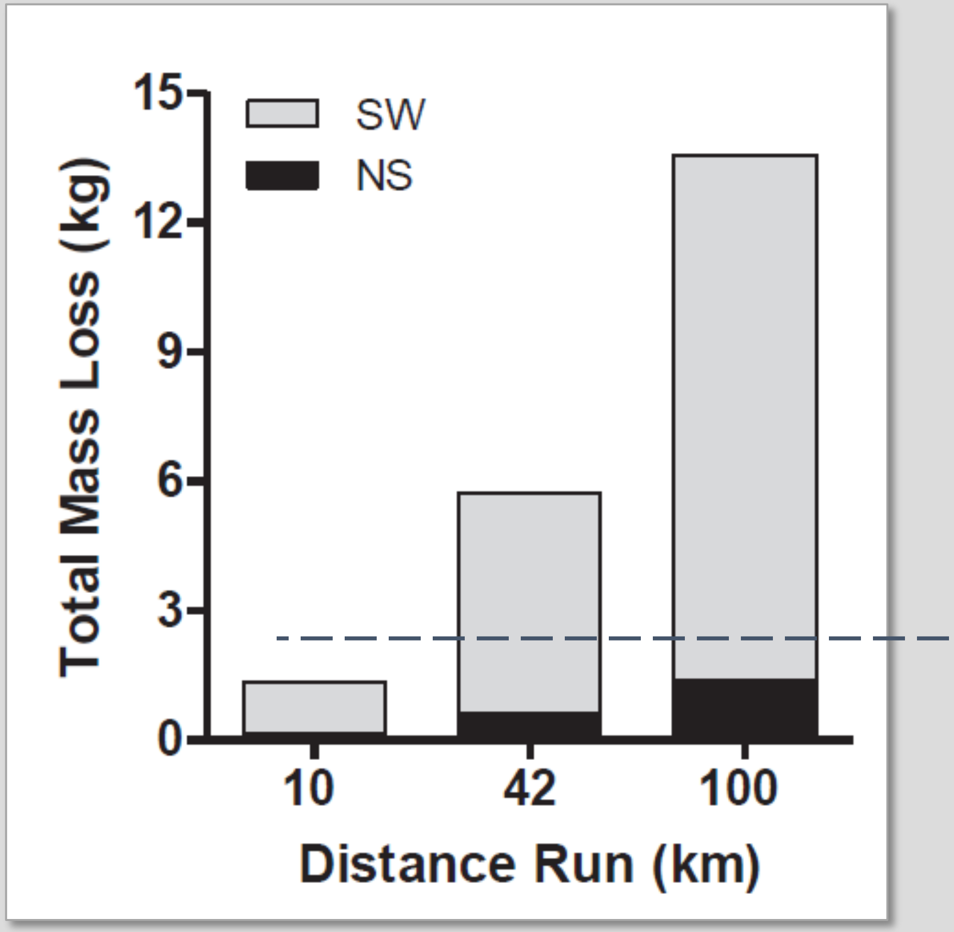
RECENT CLAIMS STATE "DEHYDRATION DOES NOT IMPAIR EXERCISE PERFORMANCE IN THE HEAT"

Does "blinding" hydration status impact outcomes?

- When cyclists DEH to ~3% with IV infusion to prevent reaching further levels of DEH - with or without mouth rinse - **no difference in performance observed compared to EUH**
  - Wall et al. 2011 *Br J Sports Med*; Cheung et al. 2015 *Scand Med Sci Sports*
- IV fluids prevent cardiac strain seen in exercise-induced DEH
  - Very unrealistic performance scenario

- When cyclists DEH to ~2.5% while drinking and using a gastric tube to prevent reaching further levels of DEH, difference in performance observed compared to EUH
  - James et al. 2017 *Physiol Rep*
- Data supports previous literature while still blinding subjects

SUM OF SWEAT (SW) AND NON-SWEAT (NS) MASS LOSSES



Cheuvront & Kenefick *J Appl Physiol.* 2017; Cheuvront & Montain *Exp Physiol.* 2017

- **Assumes**
  - 28°C air temp
  - 70kg mass
- **Sweat losses (SW) calculated from required evaporative heat losses**
- **Non-sweat (NS) losses ~0.20g/kcal**
- **NS = 2.0% BML for 100km**
  = 3.2% BML for 160km

CYCLING PERFORMANCE META-ANALYSIS

- High-intensity [1 h cycling]
  - Equivocal fluid intake recommendations exist

- Moderate-intensity [>1 h cycling]
  - Consuming fluid to prevent greater than 2% DEH vs. no fluid results in performance improvement

Goulet *Br J Sports Med* 2011; Holland et al *Sports Med* 2017

Myths and Methodologies

Myths and methodologies: Making sense of exercise mass and water balance

Samuel N. Cheuvront and Scott J. Montain

Exp Physiol. 2017 Sep 1;102(9):1047-1053.

$$\Delta\text{body mass} - 0.20\ \text{g}\bullet\text{kcal}^{-1} = \Delta\text{body water}$$

$$\text{running energy expenditure} = 1 \bullet \text{kcal}^{-1} \bullet \text{kg}^{-1} \bullet \text{km}^{-1}$$

$$\%\ \text{dehydration} = \left[\frac{(\Delta\text{body mass} - 0.20\ \text{g} \bullet \text{kcal}^{-1})}{\text{starting body mass}}\right] \times 100$$


SAMPLE SWEAT LOSS EXAMPLE

Runner completes 10 km in 1 hour

Pre weight = 66.0 kg
Post weight = 65.0 kg

Δ body mass = 1.0 kg

Running energy expenditure = $1 \bullet kcal^{-1} \bullet kg^{-1} \bullet km^{-1}$

$(1 \bullet kcal^{-1} \bullet kg^{-1} \bullet km^{-1})$ x 66 kg x 10 km = 660 kcal

Body weight correction = 0.20 g•kcal−1 x 660 kcal ÷ 1000 = 0.132 kg

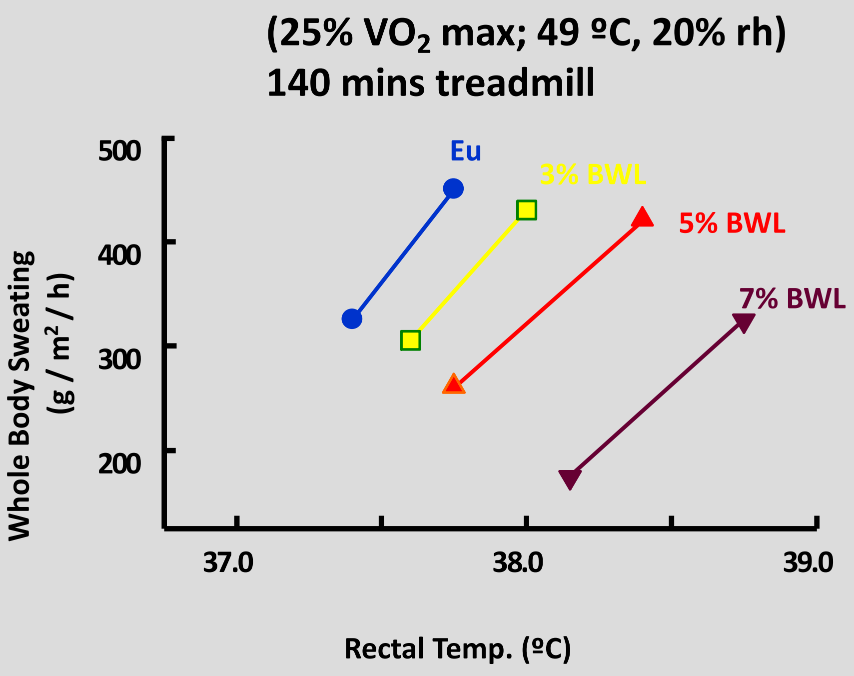
Δbody mass − 0.20 g•$kcal^{-1}$ = Δbody water

1.0 kg – 0.132 kg = 0.868 L / hr

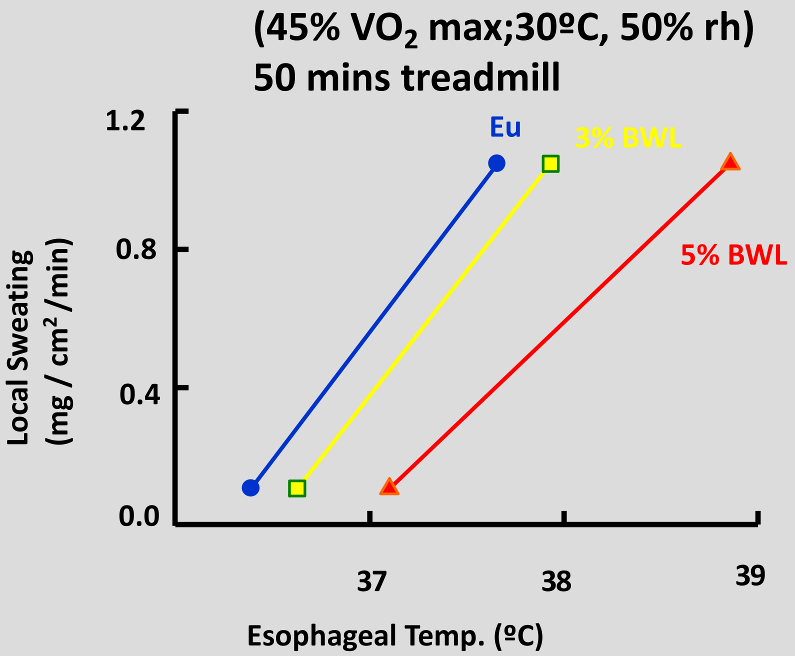
= 1.3% DEH

Cheuvront & Montain *Exp Physiol.* 2017

DEHYDRATION REDUCES SWEATING RATE IN PROPORTION TO WATER DEFICIT



Sawka et al. JAP 1985



Montain et al. JAP 1995