# Chapter 7

## Comments on Baker et al.'s "Change in body mass accurately and reliably predicts change in body water after endurance exercise"

**Article:**

Nolte HW and Noakes TD. 2010. Comments on Baker et al.'s "Change in body mass accurately and reliably predicts change in body water after endurance exercise". European Journal of Applied Physiology, 108(5): 1061-1064.*

***Referencing format in the text and list applied as required by the European Journal of Applied Physiology.

## 7.1 Background to letter

A manuscript by Baker et al. (2009) was published in the European Journal of Applied Physiology stating that changes in body mass accurately and reliably predicts changes in TBW and could therefore by used as an indication of hydration status during prolonged exercise.

Since the results of Baker and associates were in direct conflict with the results of the studies presented in this thesis document, a thorough review of their methods and results were performed. A letter was addressed to the Editor of the European Journal of Applied Physiology in order to raise concerns over the results and the manner in which they were calculated.

## 7.2 Letter to the editor

To the Editor:

We read with some interest the article reporting research of Baker et al. (2009). The authors concluded that the change in body mass (ΔBM) during exercise is due to a change in total body water (TBW) alone since these two variables are significantly correlated (r=0,77) in subjects who completed exercise with 4 different levels of body mass change (+1.8% BM, -0.2% BM, -2.1% BM, -3.3% BM). As a result, the authors conclude that the change in body mass during exercise is "an accurate and reliable method to assess" exercise-related changes in TBW. This finding supports the argument (Baker et al. 2009; Convertino et al., 1996; Eichner, 2002) that athletes should drink enough to insure that they do not lose any body mass during exercise.

We found the authors' conclusion surprising since many others conclude that water is not the sole constituent of the mass lost during exercise (Maughan et al. 2007). While the authors address these issues in their paper (p965), they nevertheless conclude that their findings finally disprove these contrary arguments. Given the importance of this contrary conclusion, we scrutinized the study to determine whether or not there were any obvious explanations for their unexpected finding.

First we noticed (Experimental procedure, p2) that eight subjects each took part in 12 possible trials for a total of 96 individual experiments. Yet it appears that only 62 of these experiments were included in the final analysis. The authors failed to explain why they excluded 35% of the experimental data from their final analysis. Without an adequate explanation for these exclusions, the validity of their findings cannot be convincingly assessed. We note however in the authors' companion paper that five out of eight subjects were unable to complete the -3.3% BW trial since they could not reach high enough sweating levels during the exercise period (Baker et al., 2008). The inclusion of a table indicating the reasons why data were excluded is important.

The missing data also do not appear to be evenly distributed between the four experimental conditions. Thus it appears from Figure 1 that 18 of 24 (75%) possible trial data were included in the +1.8% BM trial, 15 of 24 (63%) for the -0.2% BM trial, 22 of 24 (92%) in the -2.1% BM trial but only 7 of 24 (29%) for the -3.3% BM trial. Under–representation of data in the trial with the greatest body weight loss could have biased the conclusions.

Second, we find it surprising that carbohydrate (CHO) was included in the tested solution. While we appreciate that this study is funded by a commercial company that produces a carbohydrate-containing “sports” drink, the presence of the CHO in the solution ingested during this experiment confounds the interpretation of the data.

For example the ingestion of glucose will reduce the rate of oxidation of the endogenous CHO stores (Bosch et al., 1994). This will influence the amount of endogenous fuel irreversibly oxidized during prolonged exercise. Although the influence of this effect is probably small, the point remains that the tested solution was not the most appropriate choice for these experiments.

Third the authors claim that they studied *prolonged* exercise whereas in fact they studied 105 minutes of interval running interspersed with 14 minutes of rest between exercise bouts. The extent of irreversible oxidation of endogenous fuels is determined by both the intensity and the duration of exercise and will therefore be greater the longer the duration of exercise. Thus, as already pointed out by Weschler (2008), exercise bouts of at least 4 or more hours would have provided a more appropriate test of the hypothesis that exogenous fuel oxidation does not contribute to the mass loss during exercise. The authors’ apparent finding that body mass loss accurately predicts TBW changes may not apply to more prolonged exercise like the 226 km Ironman Triathlon, in which irreversible oxidation of endogenous fuels can theoretically contribute as much as 0.875 kg to the body mass loss during exercise (Noakes, 2000).

Fourth we have certain concerns with the manner in which body mass and TBW were measured. For example, during each of the rest periods of the interval runs subjects were towelled off before their body mass was measured whereas at the end of exercise, convective cooling was used to promote the evaporation of sweat. What was the reason for this difference?

The text states that: "*Subjects drank fluid or no fluid during recovery to maintain the desired %BM change*" (p3). However the authors do not describe the time sequence for this intervention. If subjects drank water less than 1-2 hours before sampling (blood or urine) then that fluid would not be in equilibrium with the TBW and therefore might not add to the dilution of the tracer. The effect would be to reduce the extent of the body mass loss for the measured change in the TBW pool. This would underestimate the extent of the body mass loss for any change in TBW and would favour the authors' conclusion that irreversible fuel oxidation does not contribute to the mass loss during prolonged exercise.

Next, the authors used the "rinse" technique during the $D_2O$ dosing procedure (p3). This is an acceptable methodology but requires that the amount of rinse water, consumed to ensure complete consumption of the tracer, be subtracted from the total body water pool. Importantly the authors do not clearly state whether they indeed corrected for this 100 ml tracer water by subtracting it from the total body water pool.

Furthermore the authors state that: "*When serum [$D_2O$] measurements were not available (e.g., when there was not enough sample volume or the sample was contaminated during the $D_2O$ extraction procedure), the pre-dose urine [$D_2O$] or post-experiment urine [$D_2O$] was used in place of the pre-dose serum [$D_2O$] or post-experiment serum [$D_2O$], respectively, to complete the calculation of Npost*".

We are not aware of any previous publication in which this particular method has been adopted and its accuracy and reliability evaluated. Due to differences in equilibration time required for the different sampling fluids (blood or urine), this untested method could have introduced a methodological error and may therefore explain the wide range of ΔTBW that were measured for each level of dehydration (their Figure 1 and our figures added here). The authors do not present evidence that they validated this method by taking multiple samples in order to insure that the $D_2O$ enrichment reached stable levels within the sampling period. For example error could have been introduced if the pre-exercise TBW was determined from blood measurements whereas the post-exercise TBW in the same individual was determined by urine sampling on the assumption that the equilibration period was the same for the both methods.

In addition, another problem with urine sampling is that often the first post-dose urine sample contains un-enriched urine that had been collecting in the bladder prior to dosing. Since the authors did not detail when either urine of serum was used for the TBW calculation, nor if they sampled the first or second urine voiding, they do not provide sufficient evidence to evaluate the real accuracy and repeatability of the test methods.

We also note that 3 athletes were able to produce a BM loss of ~4% within 105 minutes of exercising requiring a sweat rate of about 1.2L.hr in their average 66kg subjects. We note that the study was undertaken in the heat which produces a greater water loss at a lower overall metabolic rate (and hence a lesser irreversible oxidation of endogenous fuel stores) than would exercising at a higher metabolic rate but in much cooler environmental conditions especially if convective cooling was inappropriate (Saunders et al., 2005) as is usually the case in many exercise laboratories.

Finally and most importantly we have major concerns with the manner in which the data were analysed (their Figure 1, reproduced here). Thus the authors designed the experiment so that 4 different levels of body mass loss would be produced. They then analysed the total data as if all came from a single experiment and not from four different experiments. However if the linear one-to-one relationship they apparently found between the change in TBW and BM is valid for the total experiment, then it must be equally valid for each of the 4 separate experiments that were conducted.

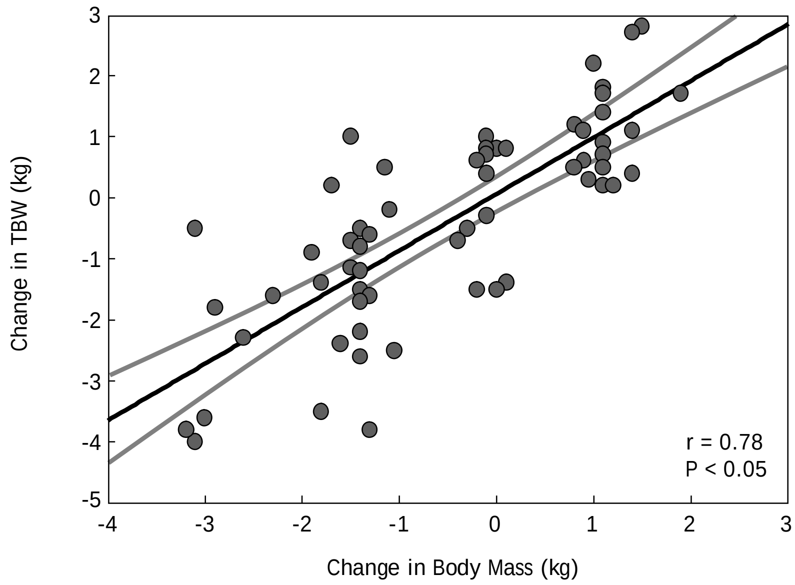


**Figure 1:** All data points plotted together (p<0.05, r=0.78) (replicated from Baker et al., 2009) with 95% confidence intervals included

Accordingly we analysed the data individually for the four separate experiments in which data for TBW and BM loss were reported, according to our analysis, for 18, 15, 22 and 7 subjects in the four different experiments. We have plotted those data separately below (Figures 2a-2d).

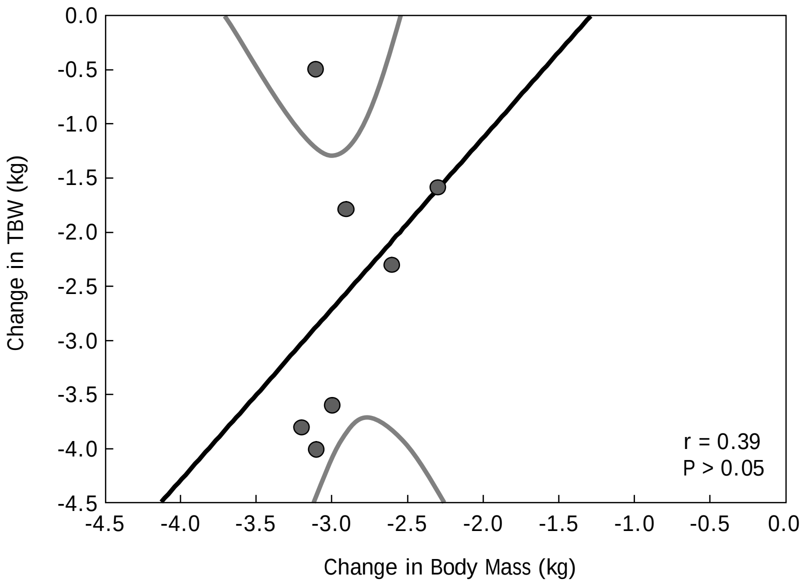


**Figure 2a:** Data for the -3.3%ΔBM group (p>0.05)

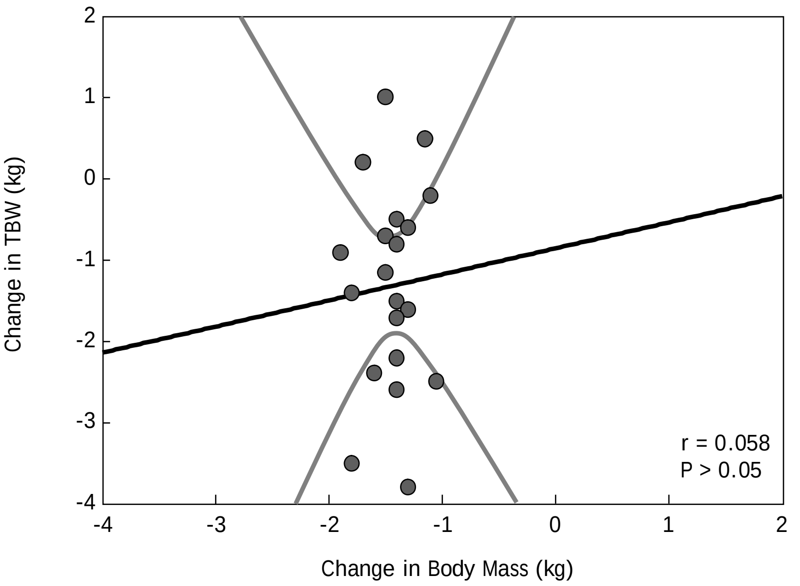


**Figure 2b:** Data for the -2.1%ΔBM group (p>0.05)

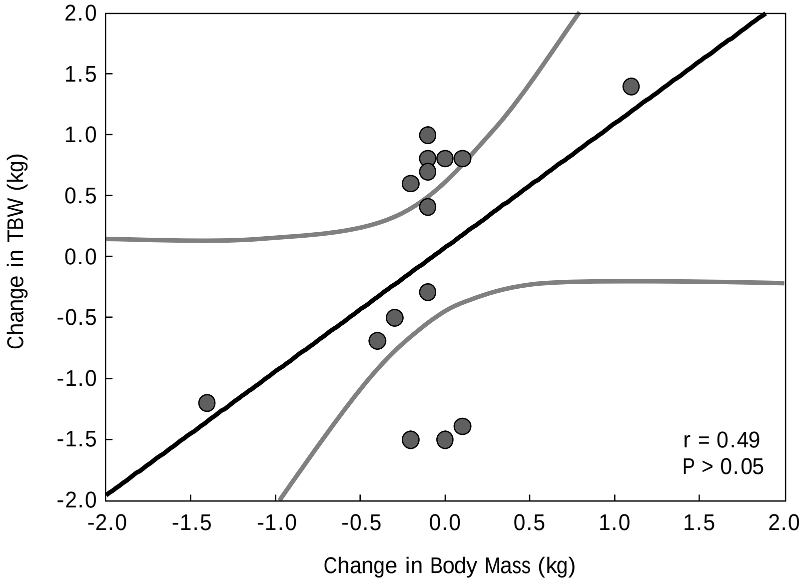


**Figure 2c:** Data for the -0.2%ΔBM group (p>0.05)

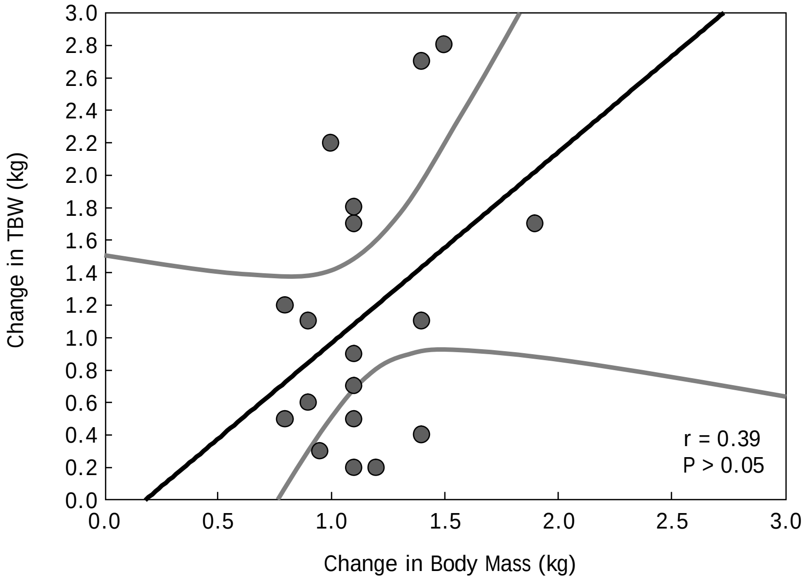


**Figure 2d:** Data for the +1.8%ΔBM group (p>0.05)

The first observation is the wide variation in the estimated TBW change with each %BM loss. Thus for a mass loss of ~3% (Figure 2a), the variation in range of calculated TBW change was -4 to –0.5L. For %BM losses of -2.1%, -0.2% and +1.8% BM, the respective ranges were -4 to +1L (Figure 2b), -1.5 to +1L (Figure 2c), and +0.2 to +2.8L (Figure 2d). This suggests either that there is a wide individual variability in this response or that the techniques for measuring changes in TBW during exercise are particularly inaccurate.

But more importantly, in contrast to the finding for the complete data set, in none of these 4 experiments was the BM loss significantly related to the change in TBW. This was true also for the three experiments in which there were 15 or more data points.

This analysis shows that the conclusion of Baker et al. (2009) that the change in body mass accurately predicts the change in TBW during exercise is an artefact of the manner in which they analysed their data and is probably confounded by the unusual manner in which they used different biological samples (urine or serum) to measure changes in TBW in the same individuals. Rather a more careful analysis of their data (Figures 2a-2d) shows that changes in BM during exercise were unable to accurately predict changes in TBW in their experiments.

We welcome the authors' views on these various issues.

HW Nolte

TD Noakes

## 7.3 References

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# Chapter 8

## Summary, general conclusions and recommendations

## 8.1 Introduction

The extent to which humans need to replace their fluid losses during exercise remains contentious despite more than 60 years of focused research. Unfortunately, apart from the inherent physiological risk associated with “under” or “over” hydration, providing an excess of water contributes to the burden of the payloads imposed on the dismounted foot soldier. By determining the optimal water requirements of soldiers, one can ensure their safety and physiological comfort while optimising their payload burdens. The correct water replacement strategy will provide safe hydration levels without affecting soldier performance, while potentially reducing the payload burden imposed on the modern soldier.

This debate has special relevance for the military since soldiers ingesting fluid *ad libitum* will drink less than those who are forced to drink in order to lose less than 2 % of their body mass during exercise. While it is now accepted that exercisers should not be encouraged to drink “as much as tolerable” there is still no consensus of the optimum rate of fluid ingestion during exercise. The modern emphasis is now on individualised drinking behaviours, these individualised strategies aim to limit “body water losses” to <2% by using changes in body mass as a surrogate for changes in TBW during exercise.

This altered emphasis has provided the opportunity to determine the optimal rates of fluid ingestion by military personnel. In turn, this could reduce the mass in the form of water, soldiers might need to carry on military missions. Accordingly the purpose of this body of research was to investigate the efficacy of *ad libitum* fluid replacement to maintain safe fluid balance in soldiers during prolonged (~4 hours) exercise.

## 8.2 Main findings

The main findings of this research effort, in relation to the objectives presented in the general introduction are:

**1. What are the rates of fluid ingestion freely chosen by soldiers during exercise?**

The results of Chapter 2 were unable to detect any superiority of an *ad libitum* drinking regime (525 ml/hr) compared to a restricted regime (300ml/hr) on fluid balance and performance during selected soldiering tasks. However, we believe that drinking *ad libitum* is probably the more appropriate response even though there was no measurable benefit associated with the slightly higher rate of fluid intake under the conditions of this experiment. Contrary the results in Chapter 6 showed that subjects drank profusely during exercise, maintaining rates of fluid intake that exceed by far rates of fluid intake achieved by athletes in competition.

The mean *ad libitum* fluid intake of soldiers ranged from 383 ml/hr to 1264 ml/hr during the studies conducted for this thesis. These findings indicate the freely chosen rates of fluid ingestion and highlight that these rates are highly variable due to its dependence on factors such as work rate, clothing configurations and environmental conditions.

**2. Are these freely chosen (*ad libitum*) rates of fluid ingestion sufficient to protect against major fluid and electrolyte imbalances as evaluated by TBW, serum [$Na^+$] and POsm?**

The results from Chapter 4 indicate that soldiers participating in a 16 km route march regulated their serum [$Na^+$] and POsm within the normal range while drinking "*ad libitum*" at a mean rate of 383 ml/hr even though this drinking rate replaced only 61% of their measured hourly body mass loss (626 ml/hr). In Chapter 5 we showed that there were no significant changes to TBW, USG or UOsm in any of the subjects despite an average body mass loss of 1.3 kg (1.98%). The results in Chapter 6 showed that despite significant sweat losses, possibly resulting in unreplaced sodium losses in excess of 240 mmol, subjects increased their serum [$Na^+$] by drinking only water *ad libitum* during exercise. Thus a*d libitum* fluid ingestion was sufficient to protect against any fluid and electrolyte imbalances by maintaining POsm, serum [$Na^+$] and TBW despite mean body mass losses ranging from 1.4% to 3.8% during the studies conducted for this thesis.

This is compatible with the finding that sodium ingestion is not required to maintain serum [$Na^+$] during exercise. Rather it is the inappropriate regulation of the TBW that determines the extent to which the serum [$Na^+$] falls during prolonged exercise. This is because the serum [$Na^+$] and not the body mass is the homeostatically regulated variable during exercise. In contrast drinking to stay "ahead of thirst" by "drinking as much as tolerable" must cause serum [$Na^+$] to fall if renal free water clearance is insufficient to prevent an increase in TBW. This occurs when arginine vasopressin (ADH) secretion is not appropriately suppressed by an increasing serum osmolality. In contrast our data show that an increase in TBW produced a fall in serum [$Na^+$] whereas a fall in TBW produced a rise in serum [$Na^+$]. This data is compatible with our findings that an increase in body mass (and hence TBW) is the major determinant of exercise-associated hyponatraemia (EAH).

**3. Are these freely chosen (*ad libitum*) rates of fluid ingestion sufficient to maintain safe thermoregulation during exercise?**

The results shown in Chapter 4 indicates that the relatively low core body temperatures measured in our subjects indicate that none was under extreme physiological stress or suffering from excessive thermal strain. Accordingly we conclude that their *ad libitum* fluid intake was adequate to maintain a safe thermoregulation during the march for the particular environmental conditions. Chapter 5 indicated that there was no relationship between % body mass loss or fluid intake and the post-exercise core temperature. Instead core temperatures were homeostatically regulated within a normal range unrelated to the degree of mass loss during exercise. Most importantly the results from Chapter 6, recorded under extreme hot and dry environmental conditions, indicate that although the subjects drank profusely during exercise their high rates of fluid intake did not explain their low body temperatures. Furthermore, all completed the study successfully and none presented with either the signs or symptoms of "heat illness".

The lower temperatures in these subjects would be explained by the relatively lower exercise intensities and hence metabolic rates that can be sustained for exercise lasting ~ 4 hours. In addition it is clear that the core temperatures fluctuate according to the pacing of each individual. The observed behaviour during the march was that of individuals performing periods of exercise followed by periods of rest, typically stopping, sitting down (in shade when available) and drinking water. The patterns of the core temperatures follow these periods of increased or decreased exertion.

Accordingly we conclude that no relationship was found between the rates of fluid consumption and mean peak core body temperatures during exercise in any of the studies conducted for this thesis. Thus *ad libitum* fluid intakes (between 60-70% of sweat losses) were adequate to maintain safe thermoregulation during exercise for the particular environmental conditions despite significant body mass losses. Our findings that some selected humans are able to perform competitive exercise in severe environmental conditions are indeed compatible with the historical interpretation that humans are the mammals with the greatest capacity for exercising in extreme heat and that this adaptation must have evolutionary significance.

**4. Can changes in body mass be used as an accurate surrogate measure for changes in TBW during prolonged exercise?**

The first conclusion of Chapter 4 was that changes in body mass did not accurately predict changes in TBW in these soldiers that lost 1.4% of their body mass during exercise. The results of this study however did not exclude the possibility that greater levels of body mass loss may not be detrimental to either health or performance in those who drink to prevent the development of thirst during exercise. Chapter 5 showed no significant changes in TBW despite an average body mass loss of 1.3 kg (1.98%). Thus although the subjects developed "voluntary dehydration" as classically described they did not show a decrease in TBW and so were not "dehydrated". Instead TBW increased marginally by about 197 g during the route march.

The results from Chapter 6 indicate that a magnitude of body mass loss of nearly 4%, almost double that considered desirable during exercise, was clearly the homeostatically-regulated response of the subjects who drank *ad libitum* during exercise. Similarly in these subjects changes in body mass were not related exactly to changes in TBW according to a 1:1 relationship.

The debate of whether the change in body mass (in kg) during exercise can be used as a 1:1 predictor of the change (in litres) in TBW is crucially important since it raises the question of whether or not there is a body fluid reserve of perhaps up to 2 litres that may not require replacement in order to insure that whole body fluid homeostasis is maintained during exercise. Thus we conclude that changes in body mass does not accurately nor reliably predict changes in TBW during prolonged exercise and should not be used as a surrogate for fluid balance change. The results supports the theory that certain body mass loss during exercise may, at least theoretically, not contribute to body water losses including metabolic water production, substrate oxidation and the release of water associated with the storage of glycogen.

Until recently it was advised that full replacement of body mass losses should be achieved during exercise. Currently this position has been revised so that the newest ACSM Position Stand proposes that the mass loss during exercise should not exceed 2% of the starting body mass. The findings of this research effort do not support this prescription and indicates that large changes in body mass did not cause changes in TBW that is associated with deleterious physiological changes.

The study raises questions about the validity of the term “voluntary dehydration” that was first coined more than 60 years ago. Indeed this study invites a more thorough interrogation of the use of the term “dehydration” which should be used only when there is a proven reduction in TBW and not, as this study shows, merely a reduction in body mass during exercise.

## 8.3 Recommendations for research and practice

Further the following recommendations for future research:

1. TBW as determined by the diluted isotope method should be used to assess fluid changes during prolonged exercise together with serum [$Na^+$] when possible.
2. When applying the diluted isotope method (deuterium oxide) to assess acute changes in TBW a concurrent TBW measure by

the tracer oxygen-18 should be performed where possible. This will allay anecdotal fears that a second deuterium oxide dose might result in an over estimation of the post-exercise TBW. Unfortunately this might seldom be possible due to the exorbitant cost of the oxygen-18 tracer.

3. While corrections for increased isotope loss during the post-exercise TBW measures proofed of almost no significance under the experimental conditions of this study it is still recommended as the prudent approach for future studies. Increased isotope loss during post-exercise TBW measures might be more pronounced according to the magnitude of excess post-exercise oxygen consumption and the current study have not investigated this effect under more prolonged and/or higher intensity exercise.
4. More data points should be gathered to increase the confidence levels of the data collected during this study in order to assess the effects of significant body mass loss (>2%) on TBW and serum [$Na^+$] during prolonged exercise.
5. Controlled laboratory studies should be conducted to investigate the amount of water that is associated with the storage of glycogen and which become available to the total body water pool during prolonged exercise. While we and others assume that water contributing to the total body water pool in this manner is indeed considered by the deuterium oxide tracer there are currently no definitive studies that have investigated this particular question.

Further the following recommendations for practice:

6. Fluid replacement to match body mass loss during exercise should not be advocated, and is not necessary to prevent voluntary dehydration.
7. The term dehydration should be used only when there is a proven reduction in TBW and not, as this study shows, merely a reduction in body mass during exercise.
8. *Ad libitum* fluid intake should be the fluid replacement strategy of choice during exercise.
9. *Ad libitum* fluid intake is sufficient to maintain safe serum [$Na^+$] levels without the supplementation of sodium during exercise through fluid intake.