**Paper:**
Love, T., Baker, D., Healey, P. & Black, K. (2018). Measured and perceived indices of fluid balance in professional athletes. The use and impact of hydration assessment strategies. *European Journal of Sport Science*, 1-8.
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# Title: Measured and perceived indices of fluid balance in professional athletes. The use and impact of hydration assessment strategies

**Running Head: Perceived fluid balance**


## ABSTRACT

**Background**: To determine athletes perceived and measured indices of fluid balance during training and the influence of hydration strategy use on these parameters. **Methods**: Thirty-three professional rugby union players completed a 120 minute training session in hot conditions (35°C, 40% relative humidity). Pre-training hydration status, sweat loss, fluid intake and changes in body mass (BM) were obtained. The use of hydration assessment techniques and players perceptions of fluid intake and sweat loss were obtained via a questionnaire. **Results**: The majority of players (78%) used urine colour to determine pre-training hydration status but the use of hydration assessment techniques did not influence pre-training hydration status (1.025 ± 0.005 vs. 1.023 ± 0.013 $g\cdot ml^{-1}$, *P*=0.811). Players underestimated sweat loss (73 ± 17%) to a greater extent than fluid intake (37 ± 28%) which resulted in players perceiving they were in positive fluid balance (0.5 ± 0.8% BM) rather than the measured negative fluid balance (-1.0 ± 0.7% BM). Forty eight percent of players used hydration monitoring strategies during exercise but no player used changes in body mass to help guide fluid replacement. **Conclusion**: Players have difficulty perceiving fluid intake and sweat loss during training. However, the use of hydration monitoring techniques did not affect fluid balance before or during training.


**Keywords:** rugby, hydration, fluid intake, sweat loss, hydration assessment, hydration beliefs

## INTRODUCTION

Dehydration has been shown to increase cardiovascular and thermoregulatory strain as well as reduce cognitive function and physical performance in some situations (American College of Sports et al., 2007; Grandjean & Grandjean, 2007). Conversely, excessive fluid consumption can decrease performance and lead to health issues (Noakes, 2007). Given the potential impact of hydration on sports performance, the assessment of fluid and electrolyte balance in athletes has been reported in a large number of studies. Research amongst team sports is predominantly in football and American Football with limited data on rugby union (Davis, Baker, Barnes, Ungaro, & Stofan, 2016; Duffield, McCall, Coutts, & Peiffer, 2012; Jones, O'Hara, Till, & King, 2015; Godek, 2010; Cosgrove et al., 2014; Meir, Brooks, & Rogerson, 2011). This research shows that players attend training in a state of hypohydration (Volpe, Poule, & Bland, 2009) and can lose substantial amounts of sweat and electrolytes, particularly sodium during training (Baker, Barnes, Anderson, Passe, & Stofan, 2016; Davis et al., 2016; Nuccio, Barnes, Carter, & Baker, 2017). Players typically replace fluid at a rate less than sweat loss which results in mean body mass loss of approximately 1-2% body mass (BM), but substantial inter-individual variation is reported, with some players incurring substantially greater losses (Nuccio et al., 2017).

There are many methods to monitor hydration status, some of which involve the collection of urine, blood, changes in body mass, recording an individual's perceptions of thirst or subjective symptoms of hydration (Armstrong, 2007). No single method is considered the gold standard and whilst the preferred monitoring tool is situation specific, it is recommended that multiple methods are used (Armstrong, 2007). Although there are limitations to using changes in body mass during exercise to assess dehydration, it is generally considered to be representative of fluid balance (Maughan, Shirreffs, & Leiper, 2007). The utilisation of these techniques is advocated by recent fluid replacement guidelines in an attempt to develop individualised hydration strategies rather than generic guidelines that have typically involved hourly ingestion rates (Maughan & Shirreffs, 2008).

Knowledge of and use of hydration strategies has been shown to enhance hydration status in children (Kavouras et al., 2012), thereby suggesting that education and utilisation of hydration strategies could be a potential tool to improve the hydration status of athletes. However, the use of hydration strategies by athletes is not well known. Only twenty percent (n=55/276) of non-elite runners reported that they monitored their hydration. Of these 55 runners, urine colour was the most commonly used method (28%). Other methods used were thirst, urination, sweating, hydration-related symptoms or changes in body mass (O'Neal et al., 2011). A separate study, reported that 94% of collegiate athletes were aware that urine colour could be used to monitor hydration and 91% believed it was a good indicator of hydration, but only 73% of athletes employed this technique to measure hydration status (Nichols, Jonnalagadda, Rosenbloom, & Trinkaus, 2005). Interestingly, despite 66% of athletes being aware that changes in body mass could be used to help determine the amount of fluid to consume, only 14% of individuals utilised this technique. There is very limited information about athletes perceived sweat loss (Caufield et al., 2013; O'Neal et al., 2012; Thigpen, Green, & O'Neal, 2014) and only one study has determined athletes perceptions of sweat loss and fluid intake (Passe, Horn, Stofan, Horswill, & Murray, 2007). These studies generally report athletes have difficulty perceiving sweat loss, but this has not been determined in field-based team sport.

Given the potential implications of fluid imbalance on the risk of heat illness and hyponatremia and the prevalence of pre-training hypohydration in athletes, the aim of the current study is to determine indices of fluid balance in elite rugby union players during training and the influence of player perceptions on these variables.

## Method

Participants

Thirty three elite rugby union players (age 24 ± 3 y, height 187 ± 6 cm, body mass 103.7 ± 13.8 kg, sum of 7 skinfolds 66.1 ± 6.5 mm) provided written informed consent prior to their participation in this study which had received ethical approval for all protocols used from the University of Otago Human Ethics Committee and complied with their ethical standards which are in line with those of the Declaration of Helsinki.

Experimental Design

Testing took place during the afternoon (2:00 pm) training session. In the morning before the testing session, players completed team training and video analysis followed by lunch and a team meeting (approximately 30 minutes prior to testing). Players were allowed to consume foods and fluids ad libitum throughout the morning and at lunch.

Upon arrival at the training session players were asked to rate their perception of thirst using a nine-category scale of thirst (Engell et al., 1987) which ranged from 1 (*not thirsty at all*) to 9 (*very, very thirsty*) and to provide a urine sample which was later analysed for specific gravity (Uricon, Atago, Tokyo, Japan) and colour as described by Armstrong et al 2005 (Armstrong, 2005), The urine sample was collected in a clear plastic container and placed on a white piece of paper whilst it was compared to previously published scale (Armstrong,

2005) in a well lit room. Players were then weighed in minimal clothing (Digi DI-10 Wedderburn 150 kg, Wedderburn, Dunedin, New Zealand).

Players completed a typical 120 minute training session which consisted of team training, line drills and running exercise which was designed by the team trainers. Environmental conditions were 35 °C and 40% relative humidity (Endeavour, Auckland, New Zealand). During training, players had ad-libitum access to individually labelled bottles of sports drink (76 g carbohydrate$\cdot L^{-1}$,12 mmol$\cdot L^{-1}$ $Na^{+}$) (Powerade, Coca-Cola Company, Auckland, NZ) supplied in a 750 mL bottle and water (Pump water, Coca-Cola company, Auckland, NZ) provided in 825 mL bottles. Players were asked to drink only from their bottles and to only use the fluid as a drink. Regular breaks in training were scheduled and the time of each break was noted. Following each break, drinks bottles were weighed and refilled if requested. Players were monitored throughout the training session to ensure that they did not urinate or rinse the fluid in their mouths and then spit it out. A separate bottle was provided for players should they wish to just rinse their mouths, however, no player used this during testing.

Upon the completion of training, players were re-weighed and asked the following questions to determine perceived sweat loss and perceived fluid intake.1) How much sweat did you lose during training? 2) How much fluid did you ingest during training? Players were given the option to respond with “don’t know”, in an attempt to 1) increase completion rates and 2) to avoid a random guess (Waters, Hay, Orom, Kiviniemi, & Drake, 2013) as we believed this data to be more informative in determining subsequent educational strategies. Perceived fluid balance was subsequently calculated using perceived sweat loss and perceived fluid intake. Perceived dehydration was calculated from perceived fluid balance and pre-exercise body mass. To determine the use of hydration assessment techniques, players were asked the following questions: 1) How do you monitor your hydration status prior to training? 2) How do you monitor your hydration status during training?

**Statistical Analysis**

All data were tested for normality of distribution (Shapiro Wilks test) and for outliers using IBM SPSS Statistics v22. A paired t-test was used to determine differences in perceived and measured indices of fluid balance or Wilcoxon signed-rank test when data was found not to be normally distributed. An independent T-Test was used to determine the influence of pre-exercise hydration strategy use on urine colour and specific gravity or by a Mann-Whitney test when data was found not to be normally distributed. Correlations were assessed using Pearson's correlation or Spearmans Rank when found not to be normally distributed. A two-way mixed ANOVA was used to determine the influence of hydration strategy use during exercise on perceived and measured indices of fluid balance. Following a significant interaction effect, a paired t-test and independent t-test were used to determine differences between actual-perceived indices of fluid balance and hydration strategy use or non-use, respectively. Parametric data are expressed as mean ± SD and non-parametric data as a median. Based on the findings of (Thigpen et al., 2014) using their data on sports specific training and male participants, In order to detect a difference in estimated sweat loss and actual sweat loss with a power of 0.8 and an alpha of 0.05, 25 players would be required. Given the possibility of injury and nature of team training 33 players were recruited. Statistical significance was set at $P<0.05$.

**RESULTS**

**Part A - Fluid balance**

The specific gravity and urine colour of pre-training urine samples was 1.024 ± 0.008 g·ml$^{-1}$ and 5 ± 3, respectively. Sweat loss during training was 3.33 ± 1.12 L which corresponds to a sweat rate of 1.67 ± 0.56 L·hr$^{-1}$. Fluid intake during training was 2357 ± 775 ml which corresponds to an ingestion rate of 1179 ± 387 ml·h$^{-1}$. The contribution of water (1512 ± 693 ml) to total fluid intake was significantly greater than sports drink (845 ± 605 ml; $P$=0.001). Players replaced 74 ± 22% of sweat loss during training. There was no difference between those classed as euhydrated or hypohydrated (USG>1.020 g·ml$^{-1}$) and either actual ($P$=0.947) or perceived ($P$=0.951) fluid intake in the subsequent training session. This resulted in a body mass change of -1.0 ± 0.8 kg (-2.9 to +0.5 kg) which is equivalent to a level of dehydration of 0.9 ± 0.8% body mass (BM) (3.1 to -0.6% BM). Six players gained weight and 2 players lost greater than 2% body mass. Thirst did not change from PRE (5 ± 2) to POST (5 ± 2; $P$=0.519) training.

**Part B - Perceived and measured indices of fluid balance**.

Six players responded don't know to perceived fluid intake and 13 players responded don't know to perceived sweat loss. No differences were observed in measured sweat loss ($P$=0.806), fluid intake ($P$=0.874), fluid balance ($P$=0.713) or % dehydration ($P$=0.756) between those players who responded don't know to perceptual based questions and those that did. The following data refer to 27 players (fluid intake) and 20 players (sweat loss, fluid balance, % dehydration) who reported perceived indices of fluid balance.

Players perceived sweat loss (898 ± 575 ml) was significantly lower than measured sweat loss (3291 ± 948 ml; $P$<0.001) by 73 ± 17% (figure 1). Players perceived fluid intake (1386 ± 574 ml) was significantly lower than measured fluid intake (2342 ± 793 ml; $P$<0.001) by 37 ± 28% (figure 1). Players perceived fluid intake replaced 153% of perceived sweat loss, which was significantly greater than measured (64%; *P*=0.001). Consequently players perceived fluid balance was significantly different to measured fluid balance. Players perceived fluid balance to be positive (461 ± 772 ml) compared to the measured negative fluid balance (-1015 ± 734 ml; *P*<0.001) (figure 1) which corresponded with a perception that they gained body mass (0.5 ± 0.8% BM) compared to the measured loss of body mass (-1.0 ± 0.7% BM; *P*<0.001). Importantly, 55% of players were dehydrated, yet perceived they gained body mass. One player was dehydrated, but perceived that body mass remained the same. The remaining 20% of players correctly perceived they gained body mass and 20% correctly perceived they lost body mass. No player gained body mass but perceived they lost body mass.

The relationship between perceived and measured fluid intake was moderate and significant (r =0.46; *P*=0.017) but the relationship between perceived and measured sweat loss (r =0.08; *P*=0.754), perceived and measured fluid balance (r=0.35; *P*=0.131) and perceived and measured dehydration (r =0.30; *P*=0.202) were trivial-to-moderate and non-significant.

**Part C - Hydration strategy use**

Some players did not answer the question pertaining to the use of hydration strategies, therefore the use of hydration strategies before and during exercise is based upon 26 and 29 players, respectively. Players reported using urine colour (78% of players) and daily fluid intake (7%) to determine pre-training hydration status. No player reported using thirst, body mass or sweat loss to monitor pre-training hydration status. Fifteen percent of players did not use any strategy and only one player used two techniques. There was no difference in pre-training hydration status between those players that reported using a strategy (1.025 ± 0.005 $g \cdot ml^{-1}$) and those that used no strategy (1.023 ± 0.013 $g \cdot ml^{-1}$; *P*=0.811). Neither was there a difference in urine colour between those who used (5 ± 2) or did not use (4 ± 3; *P*=0.637) a hydration assessment strategy.

Players reported using sweating (3% of players), urine colour (10%), thirst (17%) and fluid intake (17%) to determine hydration status during training. No player reported using changes in body mass and 52% of players did not use any strategy during exercise. Due to the low number of players using one specific hydration assessment strategy, players were placed into two groups, those that used a strategy (Method) and those that did not (No Method). The following data refers to 24 players (fluid intake) and 18 players (sweat loss, fluid balance and dehydration) for which data on perceived and measured indices of fluid balance, and hydration strategy use were available. Measured fluid intake was higher in players that used a strategy during exercise than those that did not (2696 ± 727 ml vs 1890 ± 566 ml; *P*=0.008), but no differences between groups were observed for perceived fluid intake (1429 ± 504 ml vs 1192 ± 482 ml, respectively; *P*=0.260). Perceived fluid intake was lower than measured fluid intake in players that used (*P*<0.001) and did not use (*P*=0.001) a hydration assessment strategy. Perceived sweat loss (928 ± 585 ml) was lower than measured sweat loss (3280 ± 989 ml; *P*<0.001) but there was no influence of hydration assessment use on these variables (*P*>0.05). Perceived fluid balance (359 ± 715 ml) was significantly different to measured fluid balance (-1067 ± 700 ml; *P*<0.001) but there was no influence of hydration assessment use on these variables (*P*>0.05). Perceived change in body mass (0.4 ± 0.7% BM) was significantly different to the measured change in body mass (-1.0 ± 0.7% BM; *P*<0.001), but there was no influence of hydration assessment use on these variables (*P*>0.05).

The difference between actual and perceived sweat loss (-2731 ± 1241 ml vs -2049 ± 763 ml, *P*=0.170), fluid balance (1519 ± 1186 ml vs 1351 ± 627 ml, *P*=0.704) and change in body mass (1.5 ± 1.2% BM vs 1.4 ± 0.7% BM, *P*=0.756) was similar between players that used and did not use hydration assessment strategies, respectively (figure 2). But, the difference between actual and perceived fluid intake was greater for players that used a hydration assessment method compared to those that did not (-1268 ± 751 ml vs -698 ± 428 ml; *P*=0.043) (figure 2).

## DISCUSSION

The main finding of this study was that professional rugby player's perceptions of fluid intake and sweat loss was poor, despite them potentially having greater nutrition education than the general population and the use of hydration assessment strategies did not improve these perceptions. Nevertheless, the majority of players incurred only minimal dehydration (<2% BM) during training.

There is a large inter-individual variability in sweat rate and composition. Players lost ~3.3 L of sweat which equates to a sweat rate of ~1.7L$\cdot$h$^{-1}$. Players underestimated measured sweat loss to a greater extent (~73%) than those previously reported in male basketball players and runners (29-50%) (O'Neal et al., 2012; O'Neal et al., 2011; Passe et al., 2007; Thigpen et al., 2014). In addition, previous studies have reported runners to be perceptive of whether they were light or heavy sweaters (O'Neal et al., 2012), but only a trivial correlation between perceived and measured sweat loss was observed in the current study. As sweat rates were similar between studies, it is possible that the higher ambient temperatures and/or extended duration of training in the current study and consequently the greater total volume of sweat lost was responsible for the reduced ability of players to perceive measured losses. Previous studies also suggest that individuals fail to account for evaporative sweat loss or the sweat absorbed in clothing in their estimates (Cheuvront, Montain, & Sawka, 2007) and this could be responsible for the underestimation in the current study, although we did not weigh removed clothing to confirm this.

Although we observed a moderate correlation between perceived and measured fluid intake, players significantly underestimated fluid intake by ~37%. Passe et al (2007) (Passe et al., 2007) reported no difference between actual and perceived fluid intake but fluid intake in that study was low (500 ml) and was conducted on runners, whom typically consume smaller volumes of fluid in an attempt to minimise gastrointestinal (GI) discomfort. Players ingested ~2.4 L of fluid during training in the current study which is greater than those reported previously during running (Passe et al., 2007) and during other team sports (Maughan, 2005; Godek, 2010). Fluid intake is influenced by many factors (Garth & Burke, 2013) but we considered the provision of fluids, which was in accordance with the normal routine at the club, to provide a favourable environment for fluid ingestion. Although a sports drink has been reported to increase fluid intake compared to water ingestion when given alone, the provision of both drinks in combination may allow further ingestion, especially given athletes preference for water (Cosgrove et al., 2014).

As a result of sweat loss and fluid intake, players were in a state of negative fluid balance following training. The magnitude of this fluid deficit was small (~1% BM), but six players gained weight and 2 players lost greater than 2% body mass. Based upon perceived fluid intake and perceived sweat loss, perceived fluid balance and dehydration were determined. This is important as knowledge of fluid balance rather than sweat loss is essential to determine the efficacy of a player’s current hydration strategy during exercise and has implications for evaluating and designing effective rehydration strategies.

Fifty five percent of players perceived they were in positive fluid balance but were in negative fluid balance according to measured variables. Whilst fluid intake is affected by many factors, the involuntary dehydration that typically occurs during exercise may be linked to a perception that sweat loss has been replaced. Twenty percent of players accurately perceived they were dehydrated, but we did not determine if this was due to GI discomfort limiting fluid intake or for another reason. Interestingly 20% of players intentionally drank in excess of sweat loss and gained weight. We have previously reported players to consume a volume of fluid greater than sweat loss during resistance training sessions (Cosgrove et al., 2014). Whilst this may be due to a reduced sweat loss or increased fluid availability, it could also be due to players intentionally trying to rectify the pre-training hypohydration that is typically present. Although the 4 individuals who gained weight and perceived they gained weight were considered hypohydrated before training, a large majority of players were hypohydrated and did not adopt this approach. Other studies have reported that players attending training hypohydrated did not consume fluid in excess of sweat loss and consequently incurred a further loss in body mass (Merry, Ainslie, Walker, & Cotter, 2008). Whilst the majority of fluid and electrolyte balance studies in an applied setting report similar results, there are reports that some players drink in excess of sweat loss and in some cases this has resulted in hyponatremia (Horswill et al., 2009).

Players reported using sweating, urine colour, thirst and fluid intake to determine hydration status during training. Despite this there was no difference in measured dehydration between those who reported using a monitoring method or not. But it does appear that those who reported using a monitoring strategy did consume more fluid during training, suggesting that using a monitoring method does have some impact on drinking behaviour. Nevertheless the use of a strategy did not influence the magnitude of difference between actual and perceived sweat loss and instead increased the difference between actual and perceived fluid intake. This latter finding may be attributed to the greater volume of fluid consumed by players that used a strategy. Importantly, ten percent of players used urine colour during exercise, but the use of urine to determine acute changes in fluid balance is inappropriate (Kovacs, Senden, & Brouns, 1999). Furthermore, no player used changes in body mass to guide fluid ingestion, this is surprising as it is considered a useful tool to guide individualised hydration strategies (American College of Sports et al., 2007; Maughan & Shirreffs, 2008). O'Neil et al (2012) (O'Neal et al., 2012) reported that despite 7 (18%) runners using pre-post changes in body mass to determine sweat loss, they were not more accurate in estimating sweat losses than those who failed to use this technique. The lack of implementation of hydration monitoring techniques has been previously reported (Nichols et al., 2005), although reasons for this were not determined.

A misperception of fluid balance has potential implications for recovery. Although influenced by drinking strategy and fluid composition, it is typically recommended that 125-150% of body mass loss is ingested following exercise given the obligatory losses of fluid that occur during the recovery period (Thomas, Erdman, & Burke, 2016). Although speculative, the discrepancy between perceived and measured fluid balance may explain the high prevalence of pre-training hypohydration reported in many studies including the current study as players typically perceive themselves to be in a more positive state of fluid balance than measured variables would suggest. Players underestimated sweat loss to a greater extent than fluid intake and consequently players underestimated the magnitude of negative fluid balance. However, few players lost in excess of 2% body mass. Nevertheless, knowledge of sweat rates to guide fluid ingestion strategies during exercise and recovery is important to help minimise dehydration and over-hydration which can have serious implications even for the team sport player (Maughan & Shirreffs, 2008).

Limitations

It is possible that the results of this study have underestimated sweat losses due to the sweat trapped in clothing not being accounted for in the post-training measure, however, players were weighed in minimal clothing therefore any trapped sweat is likely to be small.

We only asked players if they monitored their hydration status and if so what method they used, we did not ask players to explain how the method is used or for its interpretation showed if they were hydrated or not i.e. drinking to thirst can mean many things (Armstrong, 2016) and consequently, this does limit the usefulness of this section of the study. Neither did we ask players why they thought they had sweated as much as they have so our explanations for the over estimations by the players are speculative. However, to ask more in depth questions would have required more of the players time and increasing participant burden, which is not possible when working with professional athletes in the applied setting due to their training and recovery demands.

## CONCLUSION

Players underestimated sweat loss and fluid intake during training which led to a misconception of fluid balance. Those players that did monitor hydration did not demonstrate an improved assessment of fluid balance, but few players used recommended strategies to monitor hydration. Although only 2 players exceeded 2% dehydration, this may have implications for rehydration in elite rugby players and needs to be considered when providing hydration advice.

## Conflict of Interest

The authors have no conflicts of interest.

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Table 1: Fluid balance measures for those who used and did not use a hydration strategy.
Note: *Difference between method and no method. USG = Urine Specific Gravity.[a] n = 18, [b] n= 8.

| | All | Method | No method | *P*-value* |
|---|---|---|---|---|
| **Pre-training** | *n = 26* | *n=22* | *n = 4* | |
| Urine colour | 5 ± 3 | 5 ± 2 | 4 ± 3 | 0.637 |
| USGa (g.ml−1) | 1.024 ± 0.008 | 1.025 ± 0.005 | 1.023 ± 0.013 | 0.811 |
| **During training** | | | | |
| *Actual* | *n = 29* | *n = 14* | *n = 15* | |
| Fluid intake (ml) | 2363 ± 762 | 2696 ± 727 | 2051 ± 676 | 0.020 |
| Sweat rate (ml.h−1) | 3314 ± 1177 | 3510 ± 1370 | 3130 ± 980 | 0.396 |
| % Dehydration | −0.92 ± 0.80 | −0.79 ± 0.1.01 | −1.05 ± 0.55 | 0.398 |
| | | | | |
| *Perceived* | *n = 24* | *n = 14* | *n = 10* | |
| Fluid intake | 1339 ± 499 | 1192 ± 482 | 1429 ± 504 | 0.260 |
| Sweat rate | 928 ± 585a | 812 ± 525b | 1021 ± 642 | 0.534 |
| % Dehydration | 0.38 ± 0.69a | 0.59 ± 0.71b | 0.22 ± 0.66 | 0.366 |

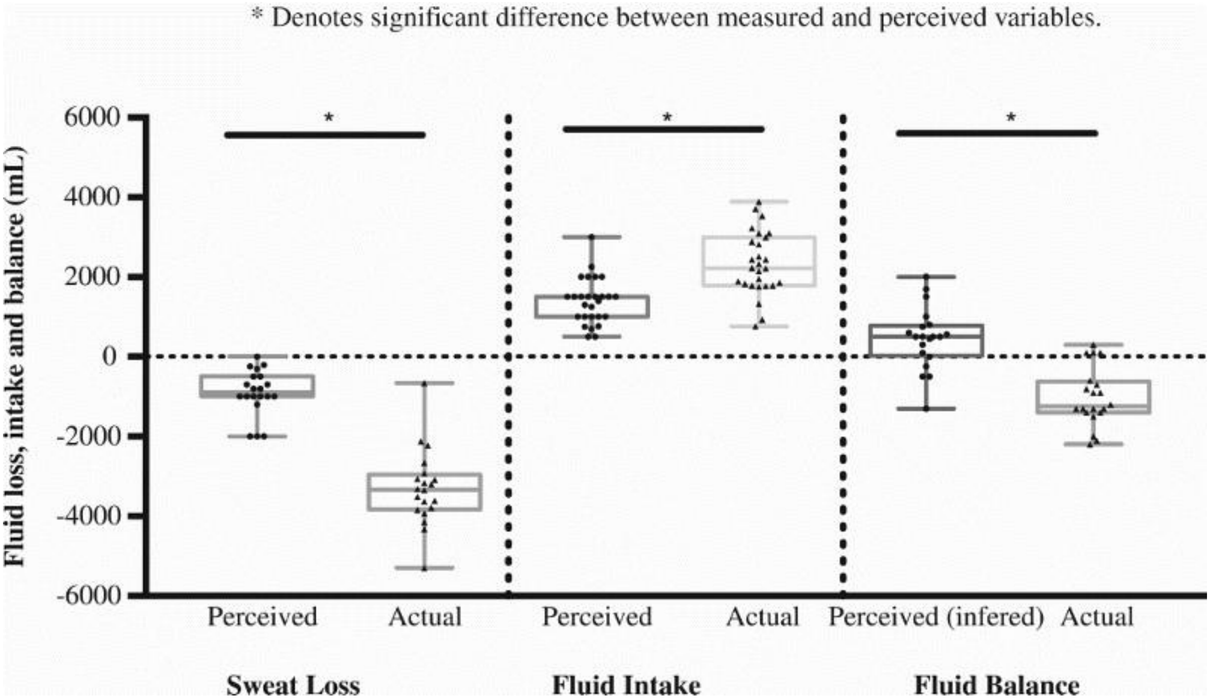


Figure 1 Median, 25th to 75th percentiles, minimum and maximum and individual measured and perceived sweat loss, fluid intake and fluid balance (ml)

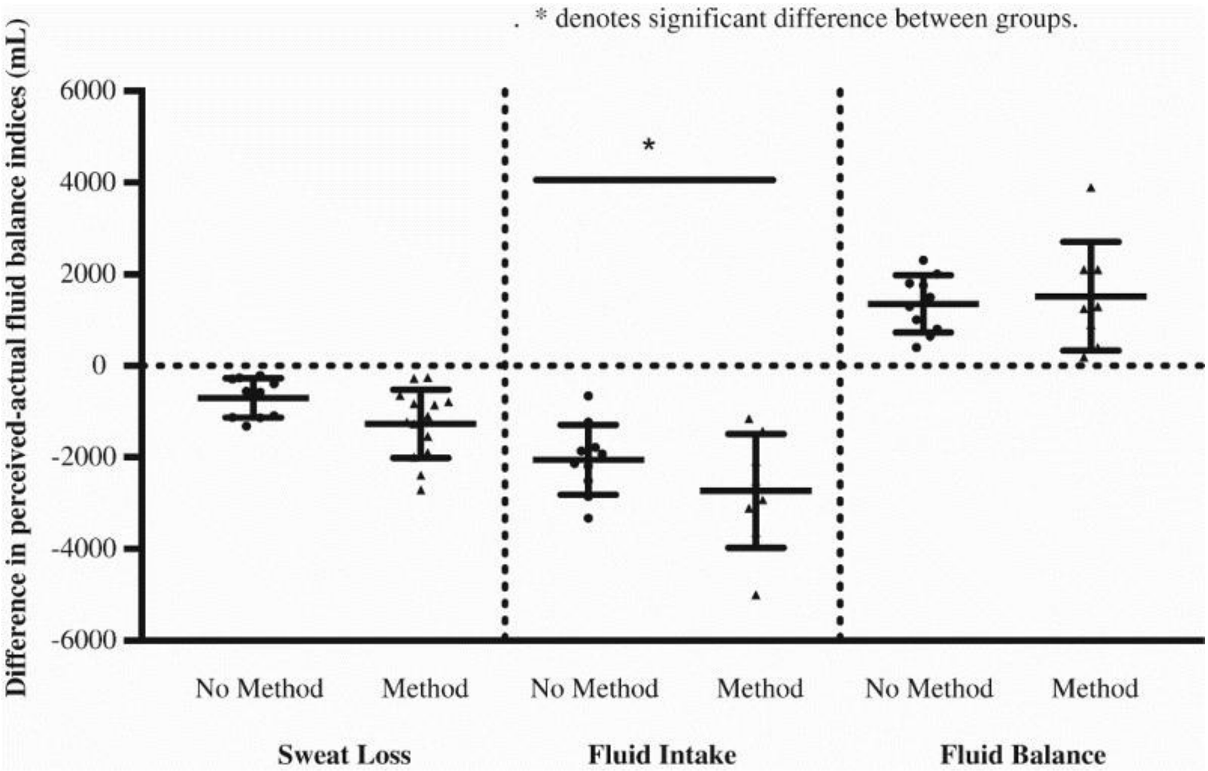


Figure 2: Mean (SD) and individual difference between perceived and actual indices of fluid intake, sweat loss and fluid balance (ml) for players that used an hydration assessment strategy (Method) and those that did not (No Method).