

## Water loss as a function of energy intake, physical activity and season

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Although water is an important nutrient, there are no recommended intake values. Here, water intake, energy intake, physical activity and water loss was measured over 1 week in summer and in winter. Subjects were healthy volunteers, forty-two women and ten men, mean age of 29 (SD 7) years and mean BMI 21.8 (SD 2.2) kg/m<sup>2</sup>. Water intake was measured with a 7 d food and water record. Physical activity level (PAL) was observed as the ratio of total energy expenditure, as measured with doubly labelled water, to resting energy expenditure as measured in a respiration chamber. Water loss was measured with the deuterium elimination method. Water loss was highly reproducible and ranged from 0.20 to 0.35 l/MJ, independent of season and activity level, with higher values in women. Water loss was related to water and energy intake in summer ( $r$  0.96,  $P$ <0.0001 and  $r$  0.68,  $P$ <0.001, respectively) as well as in winter ( $r$  0.98,  $P$ <0.0001 and  $r$  0.63,  $P$ <0.01, respectively). Water loss was, for men, higher in subjects with a higher physical activity in summer ( $r$  0.94,  $P$ <0.0001) and in winter ( $r$  0.70,  $P$ <0.05). Normalizing water loss for differences in energy expenditure by expressing water loss in litres per MJ resulted in the same value for men in summer and winter. For women, physical activity-adjusted values of water loss were higher, especially in summer. In men, water turnover was determined by energy intake and physical activity, while seasonal effects appeared through energy expenditure. Women showed a higher water turnover that was unrelated to physical activity.

### Water requirement: Deuterium elimination method: Doubly labelled water: Energy expenditure

Water is a major component of the body and is involved in many functions. Water plays a key role in maintaining homeostasis of the internal environment for optimum function of cells. The normal intake of water, as mentioned in textbooks, averages about 2.5 l/d (Guyton & Hall, 2000; McArdle *et al.* 2001). The routes of body water loss are urine, faeces, sweat and insensible loss by diffusion through the skin and by evaporation from the respiratory tract. Major determinants of water loss seem to be food and water intake, environmental conditions, and physical activity (Guyton & Hall, 2000; McArdle *et al.* 2001), but no accurate measurements are available. Although water is quantitatively the most important nutrient, there are no RDA or adequate intake (AI) values (Manz *et al.* 2002). For practical purposes, 1 ml/kcal of energy expenditure is recommended as the water requirement for adults under average conditions of energy expenditure and environmental exposure. Subsequently, the specific water requirement is increased to 1.5 ml/kcal to cover variations in activity level, sweating and solute load (National Research Council (US), 1989).

Daily water loss through insensible loss via the skin and the respiratory tract, urine, sweat and faeces amounts to, respectively, 0.7, 1.4, 0.1 and 0.1 l/d or a total of 2.3 l/d for an average subject at a normal ambient temperature (Guyton & Hall, 2000). The most variable and quantitatively most important routes of water loss in humans are the sweat glands and the kidneys. Total sweat loss in sedentary subjects is only 0.1 l/d, but can be as much as

8–12 l/d under conditions of extreme physical activity (McArdle *et al.* 2001). Thus, water loss seems to be influenced strongly by activity level. The solute load of the body and the minimum and maximum osmolarity of urine set the water loss with urine. An average solute load of an adult subject requires a urine volume of about 0.5 l/d. The average urine volume of 1.4 l/d, mentioned above, is more than sufficient for the average solute load and urine volumes can reach extreme high values in subjects with a high fluid intake such as beer drinkers.

The estimation of water requirement is highly variable and quite complex. The purpose of this study is to assess water turnover in relation to energy intake, physical activity and season, by measuring accurately each of the following variables: water intake, energy intake, physical activity and water loss. Observations were performed under conditions of a temperate sea climate in The Netherlands, in mid-summer (July, August) and in mid-winter (January, February).

### Subjects and methods

#### Subjects

Subjects were healthy volunteers, forty-two women of whom twenty-seven were dietitians, and ten men, with a mean age of 29 (SD 7) years (range 22–60) and a mean BMI of 21.8 (SD 2.2) kg/m<sup>2</sup> (range 15.6–26.1). Most of

them were working at the university or the university hospital. The Ethics Committee of Maastricht University approved the protocol of the study.

Subjects were observed in summer and winter apart from seven dietitians, who were observed in summer only. Water loss was measured in all subjects ( $n$  52). Food and water intake was measured in the dietitians ( $n$  27). Physical activity was measured in all other subjects ( $n$  25).

#### Food and water intake

The dietitians recorded water intake with a 7 d food record including water. Subjects were instructed to weigh everything they ate and drank on an electronic scale (EKS; S  letstat, Smalandsstenar, Sweden) and recorded it in a structured food diary. The food records were converted into intakes of total energy and water with a computer program based on food tables (Becel Nutrition Program, 1988; Nederlandse Unilever Bedrijven BV, Rotterdam, The Netherlands).

#### Physical activity and water loss

Physical activity level (PAL) was calculated as the ratio of total energy expenditure (TEE), as measured with doubly labelled water, to resting energy expenditure (REE) as measured overnight in a respiration chamber. TEE was measured with doubly labelled water according to the Maastricht protocol (Westerterp *et al.* 1995). In short, after the collection of a baseline urine sample (day 0), subjects drank a weighed amount of  $^2\text{H}_2^{18}\text{O}$  resulting in an initial excess body water enrichment of 150 ppm for  $^2\text{H}$  and 300 ppm for  $^{18}\text{O}$ . Subsequent urine samples were collected in the morning of day 1, day 8, day 15 and the evening of day 1, day 7 and day 14. REE was measured during an overnight stay in a respiration chamber. The chamber measures  $14\text{ m}^3$  and is equipped with a bed, table, chair, freeze toilet, washing bowl, radio, television and computer (Schoffelen *et al.* 1997). Subjects entered the room at 21.00 hours in the evening and left the room at 07.30 hours in the morning. Energy expenditure was calculated from  $\text{O}_2$  consumption and  $\text{CO}_2$  production according to Weir's formula (Weir, 1949). REE was defined as

the average metabolic rate during at least 3 h of sleep with the lowest activity measured by Doppler radar.

Water loss was measured with the deuterium elimination method (Westerterp, 1999). Subjects drank a weighed amount of  $^2\text{H}_2\text{O}$  or  $^2\text{H}_2^{18}\text{O}$  resulting in an initial excess body water enrichment of 100–150 ppm for  $^2\text{H}$ . Elimination was calculated from two urine samples directly after dosing, in the morning and evening of day 1 and in the evening of day 7 and the morning of day 8.

#### Data presentation and statistics

Data are presented for dietitians ( $n$  27, group A) and the other subjects ( $n$  25, group B) separately or combined where appropriate. Summer and winter values were compared with a paired  $t$  test. Reproducibility between seasons was calculated with intra-class correlation. Simple regression analysis was used to assess the contribution of energy intake, water intake and physical activity to water loss. Water loss was normalized for differences in energy turnover by expressing water loss in litres per MJ energy intake (group A) or expenditure (group B) where appropriate. Additionally, measured water loss was compared with estimated water requirements based on the values of the National Research Council (US) (1989) of 0.24 l/MJ (1 ml/kcal) and 0.36 l/MJ (1.5 ml/kcal). All analyses were done with Statview for Macintosh (SAS Institute Inc., Cary, NC, USA).

#### Results

Reported intakes of energy and water in summer and winter, and measured water loss and physical activity over the corresponding interval, are presented in Table 1. Reported energy intake was higher in winter than in summer ( $P < 0.01$ ) while reported water intake was not different in the two seasons. Water loss was related to water and energy intake in summer ( $r$  0.96,  $P < 0.0001$  and  $r$  0.68,  $P < 0.001$ , respectively) and in winter ( $r$  0.98,  $P < 0.0001$  and  $r$  0.63,  $P < 0.01$ , respectively). Subjects reporting a higher water intake and a higher energy intake showed a higher water loss as well. Coffee, tea and non-alcoholic drinks included on average the largest

**Table 1.** Reported intakes of energy and water, and measured water loss in twenty-seven women (A), and measured water loss and physical activity in fifteen women and ten men (B) (Mean values, standard deviations and range)

	Summer			Winter		
	Mean	SD	Range	Mean	SD	Range
A	( $n$ 27)			( $n$ 20)		
Energy intake (MJ/d)	8.5	1.2	6.1–11.9	9.4	1.4	7.1–12.1**
Water intake (l/d)	2.4	0.7	1.4–5.0	2.5	0.8	1.5–5.3
Coffee and tea	0.6	0.3	0.0–1.3	0.6	0.4	0.0–1.5
Non-alcoholic drinks	0.7	0.5	0.2–2.9	0.7	0.5	0.2–2.4
Water loss (l/d)	3.1	0.7	2.0–5.7	3.0	0.9	2.1–5.9*
B	( $n$ 25)			( $n$ 25)		
Energy expenditure (MJ/d)	11.6	2.4	9.2–19.8	11.5	2.1	8.1–17.2
Water loss (l/d)	3.6	0.9	2.2–5.9	3.3	1.0	2.0–6.2***
Total/resting energy expenditure	1.87	0.22	1.56–2.42	1.76	0.18	1.45–2.10***

\* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$  for difference between summer and winter.

part of daily water intake. Water loss was highly reproducible (Fig. 1; intra-class correlation 0.92; 95 % CI: lower 0.86, upper 0.96), and was 0.2 (SD 0.3) l/d higher in summer than in winter ( $P < 0.0001$ ).

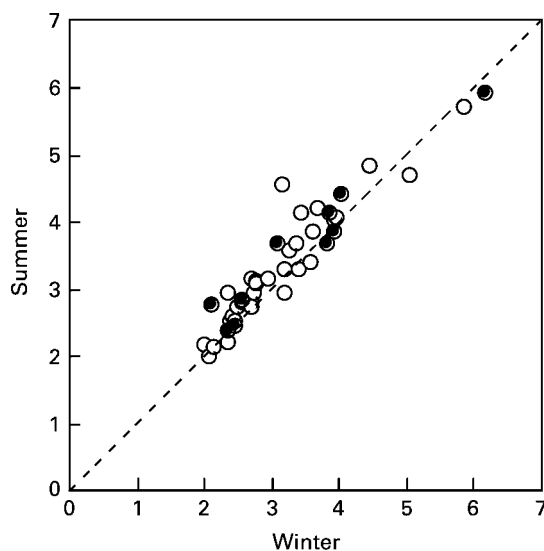
Physical activity was higher in summer than in winter ( $P < 0.001$ ) and the difference was higher for men than for women ( $P < 0.04$ ). Water loss was, for men, higher in subjects with a higher physical activity in summer ( $r = 0.94$ ,  $P < 0.0001$ ) and in winter ( $r = 0.70$ ,  $P < 0.05$ ). For women, there was no relation between water loss and physical activity. In nine of the fifteen women, in summer, the physical activity-adjusted water loss was higher than in men (Fig. 2).

Normalized water loss (l/MJ) was the same for men in summer and winter. For women, values were higher in summer than in winter and, in summer, values were higher than in men (Table 2). Subjects with a water loss below the mean value of 0.275 l/MJ as observed in men had a water intake with coffee and tea or non-alcoholic drinks below 0.3 l/d. For women, water loss was higher than the estimated water requirement of 0.24 l/MJ (1 ml/kcal) and the same or lower than the estimated water requirement of 0.36 l/MJ (1.5 ml/kcal; Table 3). For men it was the other way around, water loss was the same or higher than the estimated water requirement of 0.24 l/MJ (1 ml/kcal) and lower than the estimated water requirement of 0.36 l/MJ (1.5 ml/kcal).

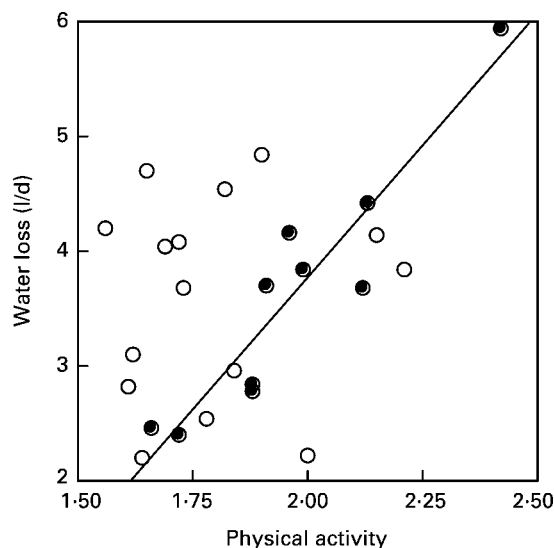
## Discussion

In men, water turnover was determined by energy intake and physical activity while seasonal effects appeared through energy expenditure. Women showed higher water turnover that was unrelated to these factors.

Water loss, as measured with the deuterium elimination method, is an accurate reference for the estimation of water requirement. It is superior to reported water intake, which is liable to misreporting as has been shown for food intake



**Fig. 1.** Water loss (l/d) in summer (July, August), plotted as a function of water loss in winter (January, February) in thirty-five women (○) and ten men (●), with the line of identity (intra-class correlation 0.92; 95% CI: lower 0.86, upper 0.96).



**Fig. 2.** Water loss in summer, in women (○) and men (●), plotted as a function of physical activity, expressed as the ratio of total over resting energy expenditure, with the linear regression line for men.

(Westerterp & Goris, 2002). Thus, water requirement should be based on measured water loss rather than reported water intake similar to measured energy expenditure as a reference for energy requirement instead of reported food intake (World Health Organization, 1985).

Here, we selected dietitians to get the most accurate information on reported water intake. Reported water intake was on average 0.6 l/d lower than measured water loss. The difference can be explained by the addition of metabolic water and water input from atmospheric exchange. Metabolic water was on average 0.4 l/d for the subject group in the two seasons (Goris & Westerterp, 1999, 2000). The water input from atmospheric exchange can account for 3–10 % of water turnover, or 0.1–0.3 l/d in the current study, depending on the inspired air volume and absolute humidity (Schoeller & Van Santen, 1982). On the other hand, reported energy intake in summer was estimated to be 16 % lower than habitual intake due to under-eating (Goris & Westerterp, 1999). Underreporting of energy intake in winter was eliminated by confrontation of the subjects with the results of the first (summer) measurement. Energy intake in summer, corrected for under-reporting, was with a mean value of 9.9 MJ/d slightly higher than in winter. The higher energy intake in summer is in line with the higher water loss in summer for the same subject group.

Water loss was systematically higher in summer than in winter. One of the reasons could be the higher ambient temperature in summer inducing increased water loss through sweating. The evidence in the current study is the positive relation between water loss and physical activity and the higher physical activity in summer, especially in men (Plasqui & Westerterp, 2004). The higher activity-adjusted water loss in the majority of the women may be explained by weight consciousness. Many women drink extra water to prevent overeating. Water intake reduces feelings of hunger (Lappalainen

**Table 2.** Energy expenditure normalized water loss in twenty-seven women (A), and in fifteen women and ten men (B)  
(Mean values, standard deviations and range in l/MJ)

		Summer			Winter		
		Mean	SD	Range	Mean	SD	Range
A	Women	0.37	0.06	0.24–0.53 <sup>†††</sup>	0.32	0.07	0.19–0.49 <sup>**</sup>
B	Women	0.34	0.09	0.20–0.51 <sup>†</sup>	0.31	0.10	0.21–0.55 <sup>*</sup>
	Men	0.28	0.03	0.20–0.32	0.27	0.06	0.19–0.36

\* $P < 0.05$ ; \*\* $P < 0.01$  for difference between summer and winter.

† $P < 0.05$ ; ††† $P < 0.001$  for difference between sexes.

**Table 3.** Measured water loss and estimated water requirements in forty-two women and ten men in summer and in thirty-five women and ten men in winter  
(Mean values, standard deviations and range in l/d)

	Summer			Winter			
	Mean	SD	Range	Mean	SD	Range	
Women							
	Measured	3.28	0.81	2.02–5.73	3.11	0.86	2.01–5.87
	Estimated (0.24 l/MJ)	2.21	0.41	1.45–3.47 <sup>***</sup>	2.39	0.40	1.70–3.45 <sup>***</sup>
	Estimated (0.36 l/MJ)	3.32	0.61	2.18–5.21	3.58	0.59	2.55–5.18 <sup>**</sup>
Men							
	Measured	3.63	1.08	2.41–5.94	3.43	1.21	2.09–6.16
	Estimated (0.24 l/MJ)	3.11	0.68	2.26–4.73 <sup>**</sup>	2.99	0.57	2.21–4.10
	Estimated (0.36 l/MJ)	4.67	1.03	3.39–7.09 <sup>***</sup>	4.49	0.85	3.32–6.16 <sup>***</sup>

\*\* $P < 0.01$ ; \*\*\* $P < 0.001$  for difference between measured and estimated values.

*et al.* 1993), though more recent evidence shows only water incorporated in food but not served with food decreases energy intake (Rolls *et al.* 1999). Water intake has even been shown to be thermogenic, possibly through a sympathetic response (Boschmann *et al.* 2003). Thus, water loss in men was more a reflection of physiological requirement than in women.

Recommended water requirement is based on daily energy expenditure (Plasqui & Westerterp, 2004). The figure of 1 ml/kcal or 0.24 l/MJ 'under average conditions' is slightly lower than the average figure of 0.275 l/MJ observed in men in the current study. The minimum value of 0.20 l/MJ was similar for all three subject-groups in the two seasons. The minimum value of 0.24 l/MJ in the first observation of the dietitians was an over-estimation due to under-reporting of energy intake as mentioned above. For instance, in the Dutch temperate climate condition, water requirement ranges from 0.20 to 0.35 l/MJ as observed in men, independent of season and activity level. Higher values are observed in women, possibly as a result of weight consciousness.

The high reproducibility of water loss within subjects, despite a systematic and small seasonal difference, is very intriguing. There was a large difference between subjects when water loss was expressed per MJ energy expenditure. The lower limit of 0.20 l/MJ was similar for women and men while there were obviously many women with higher values than in men as shown by the higher mean and individual values over 0.50 l/MJ compared to a maximum observed value of 0.36 l/MJ in men (Table 2). The high reproducibil-

ity and large inter-individual differences in water loss warrant further research into relations with subject characteristics and lifestyle. Thus, it is difficult to define a general recommendation though, as can be seen from Table 3, the upper recommendation of 0.36 l/MJ (1.5 ml/kcal) seems to cover the requirements of all subjects.

In conclusion, determinants of water turnover in men are energy intake and physical activity, while seasonal effects only appear through energy expenditure. Water turnover in women appears to be higher and unrelated to these factors, possibly due to weight consciousness. Thus, only in men does water loss reflect a physiological water requirement.

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