Caffeine ingestion and fluid balance: a review

R. J. Maughan* & J. Griffin†

*School of Sport and Exercise Sciences, Loughborough University, Leicestershire, UK; †11 Loveday Road, Ealing, London, UK

Correspondence
Professor R. J. Maughan,
School of Sport and Exercise Sciences,
Loughborough University,
Leicestershire LE11 3TU,
UK.
Tel.: 01509 223279
E-mail: r.j.maughan@lboro.ac.uk

Keywords
body water, caffeine, diuresis, fluid balance, hydration.

Abstract

Background Caffeine and related methylxanthine compounds are recognized as having a diuretic action, and consumers are often advised to avoid beverages containing these compounds in situations where fluid balance may be compromised. The aim of this review is to evaluate the available literature concerning the effect of caffeine ingestion on fluid balance and to formulate targeted and evidence-based advice on caffeinated beverages in the context of optimum hydration.

Method A literature search was performed using the Medline database of articles published in the medical and scientific literature for the period of January 1966–March 2002. Subject headings and key words used in this search were: tea, coffee, caffeine, diuresis, fluid balance and water-electrolyte balance. A secondary search was performed using the bibliographies of publications identified in the initial search.

Results The available literature suggests that acute ingestion of caffeine in large doses (at least 250–300 mg, equivalent to the amount found in 2–3 cups of coffee or 5–8 cups of tea) results in a short-term stimulation of urine output in individuals who have been deprived of caffeine for a period of days or weeks. A profound tolerance to the diuretic and other effects of caffeine develops, however, and the actions are much diminished in individuals who regularly consume tea or coffee. Doses of caffeine equivalent to the amount normally found in standard servings of tea, coffee and carbonated soft drinks appear to have no diuretic action.

Conclusion The most ecologically valid of the published studies offers no support for the suggestion that consumption of caffeine-containing beverages as part of a normal lifestyle leads to fluid loss in excess of the volume ingested or is associated with poor hydration status. Therefore, there would appear to be no clear basis for refraining from caffeine containing drinks in situations where fluid balance might be compromised.

Introduction

Maintaining the body's fluid balance at an optimal – or at least an adequate – level is important for health and well-being in the general population (Hoffman, 1991; Kleiner, 1999). For some populations, the risk of dehydration is high and the consequences potentially serious. Individuals at particular risk include the elderly (Leaf, 1984), yet the importance of maintaining hydration status is often overlooked (Mentes *et al.*, 1998). Fluid balance will be compromised by failure to consume sufficient fluid to meet ongoing water losses or by ingestion of diuretic agents. Commonly ingested diuretics include alcohol and members of the methylxanthine family of compounds (caffeine, theophylline and theobromine) which are found in many popular foods and drinks, especially tea, coffee and cola drinks as well as chocolate products.

British Olympic teams travelling to compete in recent Games have been advised to avoid, or at least restrict, the intake of tea, coffee, cola drinks and alcohol. This was based on the belief that these drinks would result in the loss of a greater volume of urine than the volume of water they contained. Advice to travellers provided by British Airways in their in-flight magazine states: 'tea, coffee, cola and alcohol should be avoided as they are all diuretic – causing the body to lose even more water than normal' (Marlin, 2001).

Although there are recognized health benefits of maintaining an adequate hydration status, many health professionals discourage consumption of tea and coffee because of the belief that negative effects on fluid balance will ensue. This belief is widespread, but it is difficult to find a solid foundation of evidence on which it is based. Hence, this negative perception amongst health professionals may not be built upon a strong foundation of scientific evidence. The aims of this review are to summarize and evaluate the available literature concerning the effect of caffeine ingestion on fluid balance and to formulate targeted and evidence-based advice on caffeinated beverages in the context of promoting optimum hydration.

Methods

Information on which to base this review was sought from a number of sources. A literature search was performed using the Medline database of articles published in the medical and scientific literature for the period of January 1966–March 2002. Subject headings and key words used in this search were: tea, coffee, caffeine, diuresis, fluid balance, water-electrolyte balance. Searching the Allied and Complementary Medicine (AMED) database did not reveal any additional publications using the combined key words of caffeine and diuresis. A secondary search was performed using the bibliographies of publications identified in the initial search. Original research papers, reviews and textbooks not identified through the Medline search were also consulted. Much of the older literature was comprehensively reviewed by Spiller (1984), Arnaud (1987) and by Curatolo & Robertson (1983). Much anecdotal information was found in Braun (1996), and these reviews were also used as a source of references to the earlier articles. Finally, personal contact was made with a number of scientists working in the area of fluid balance in an effort to identify published or unpublished information that did not emerge from the search process.

Results

The effect of caffeine on fluid balance

The scientific and medical literature contains a limited number of studies on the effects of caffeine-containing beverages on fluid balance. Most of those studies have looked at the effects of caffeine itself rather than using tea, coffee or other beverages. Many studies have also used experimental models, including fluid and dietary restriction accompanied by relatively prolonged periods of caffeine withdrawal that cast doubt on the applicability of the results to the general population going about their daily activities. Subject numbers in these investigations have generally been small, and there has been a preponderance of healthy college-age males. Little is known about the effects of age and gender on sensitivity to the effects of caffeine, but there is evidence that circulating oestrogen levels can affect caffeine metabolism (Graham, 1997), suggesting that there may be some differences between men and women and between pre-and post-menopausal women.

The studies most commonly cited to support the idea that caffeine should be avoided on account of its diuretic action are those of Robertson *et al.* (1978), Passmore *et al.* (1987) and Neuhauser-Berthold *et al.* (1997), along with the earlier studies of Eddy & Downs (1928). In most textbooks of nutrition or medicine, however, no reference is provided to support statements about the effects of caffeine on fluid balance, although there is an almost uniform reference to the action of caffeine as a diuretic. The earliest report of the effects or caffeine on urine output seems to date from measurements made in St Petersburg in the early 1860s and published by Koschlakoff (1864). He reported a number of cardiovascular and respiratory effects of caffeine, including its successful use in the treatment of two patients suffering from urine retention. Subsequent studies, however, have cast doubt on the clinical usefulness of caffeine in such cases.

Direct comparisons of published studies are not always possible as limited experimental details are provided by some authors: a meta-analysis of these studies is certainly not possible. In some studies, purified caffeine was used, but others have used coffee. Some have compared the effects of caffeine using decaffeinated coffee as a control, which seems inappropriate as there may be other active components in coffee (Graham *et al.*, 1998), whereas others have used water as a control. Other possible confounding factors include the variable periods of caffeine deprivation imposed prior to the measurement period, the inclusion of both males and females in some studies, and a variable (from 3 to 24 h) post-administration urine collection period. The absence of body mass data in most trials makes comparisons of doses difficult, as a fixed dose was given in many studies and this might be expected to have a greater effect on subjects with a smaller body mass.

Eddy & Downs (1928) made measurements on only three subjects, although repeated measurements were made on all subjects, increasing to some extent the reliability of the findings, and these authors also used doses of caffeine adjusted for the body mass of their subjects, something that has rarely been carried out in more recent studies. Diuresis was assessed from urine output at various time intervals after administration of the test dose relative to each subject's 'normal' level of urine output. The minimum effective dose that promoted a diuretic response (i.e. a 'marked' increase in urine volume relative to the control condition) was established for each subject. The mean minimum effective dose was 1.12 mg kg^{-1} body mass when the subjects were habituated to caffeine use and was 0.48 mg kg^{-1} when subjects were measured after a period of abstention from caffeine use.

Neuhauser-Berthold *et al.* (1997) studied the responses of 12 young (28 ± 3 years, mean ± SD) subjects (six male, six female) and showed that ingestion of 642 mg of caffeine resulted in an increase ($P < 0.001$) in urine output of 753 (SD, 532) mL and a loss ($P < 0.001$) of body mass of 0.7 (SD, 0.4) kg over 24 h compared with a control trial where an equal volume of water was consumed. This study, however, does not offer strong evidence to support the notion that regular users of tea, coffee and cola should reduce their intake of these beverages in situations where they are at risk of dehydration. The subjects were habitual coffee drinkers (2–4 cups per day) who were deprived of coffee for 6 days prior to the measurement period, and the caffeine dosage was high, although this was spread over the day.

Robertson *et al.* (1978) studied nine young adult subjects, including three females. All were non-consumers of coffee, and subjects were instructed not to consume any tea, chocolate or cola in the 3 week period prior to the study. Caffeine (250 mg) and placebo were administered as a single dose after an overnight fast and urine collections carried out for 3 h. There was an increase in urine output from 366 ± 30 mL (mean ± SD) on the placebo trial to 469 ± 43 mL on the caffeine trial, accompanied by an increase in urinary sodium excretion. Given the large variability normally seen in urine output and in responsiveness to caffeine, the small variance in urine volume seems surprising.

Nussberger *et al.* (1990) also used a caffeine dose of 250 mg or placebo, administered in a crossover design to eight male volunteers who had abstained from caffeine for a period of 1 week. There is an inadequate description of the methodology used in this study and a number of key areas are uncertain. The authors state that they compared the effects of administration of 300 mL of water containing 250 mg of caffeine with a placebo trial where '100 g decaffeinated Mocafino coffee containing only 0.179 g caffeine' was given. If the placebo did indeed contain 179 mg of caffeine, it is hardly different from the intervention leg of the study, but it is hard to believe that 100 g of decaffeinated coffee was administered in a volume of 300 mL. It was stated that a single-blind randomization of treatment administration was used, but caffeine in water would yield a colourless solution whereas the coffee would inevitably be coloured, so the subjects would hardly be blind to the treatment. The subjects were on a methylxanthine-free diet for 1 week before the first trial, but there is no indication that this was applied between the two trials, which were separated by a period of 1 week. Subjects were followed for a period of 3 h after treatment, and the authors reported a higher ($P < 0.05$) urine output on the caffeine trial (362 ± 48 mL) than on the coffee trial (215 ± 60 mL) during the first hour after ingestion, with no differences thereafter. In view of the uncertainties over the methods and the poor experimental design, however, the results of this study must be treated with some caution.

Wemple *et al.* (1996) studied six subjects (four male, two female), three of whom were habitual caffeine users and three of whom were abstainers. All subjects abstained from caffeine use for at least 4 days prior to experimental trials. Subjects completed four trials, a resting trial and an exercise trial with and without caffeine. The caffeine dose was large (8.7 mg kg^{-1} body mass) amounting to 490–680 mg, and large volumes of fluid were administered at regular intervals throughout the trials (8 mL kg^{-1} at time 0, then a further 27 mL kg^{-1} at intervals during the trial). They found that urine output from 60 to 240 min after administration of caffeine or placebo was greater ($P < 0.01$) with caffeine (1843 ± 166 mL) than with placebo (1411 ± 181 mL) at rest but not during exercise, and that exercise reduced urine output (398 ± 32 mL on the caffeine trial and 490 ± 57 mL on the placebo trial).

In contrast to the results of these studies, Dorfman & Jarvik (1970) did not find evidence for a diuretic action of 300 mg of caffeine in 10 healthy young volunteers. Subjects took caffeine or placebo before retiring to bed and collected the overnight urine produced over the following 8 h. The mean volume of urine collected was 337 mL on the placebo trial and 386 mL on the caffeine trial, but this small difference between trials was not statistically significant. There was a higher urinary sodium output on the caffeine trial (54.9 meq) than on the placebo condition (34.8 meq). In this study, caffeine was administered prior to going to bed for the night and 8-h overnight urine collection period was used. A more significant difference in this study was that prior restriction of caffeine intake was applied only from noon on the day of the study. The caffeine dose was sufficient for some behavioural effects, including delayed sleep latency, to be observed.

Other studies have also shown that there is little diuretic action with small doses of caffeine. In one of the few studies to investigate the dose-response relationship, Passmore *et al.* (1987) examined the effects on urine output and a number of related physiological variables after administration of caffeine at doses of 45, 90, 180 and 360 mg. Subjects were eight healthy young men. All were habitual users of caffeine and caffeine intake was standardized at approximately 240 mg day^{-1} (four cups of coffee or six cups of tea: their data) for 5 days prior to each study day: complete abstinence from foods and drinks containing caffeine or other methylxanthines was then imposed for the last 24 h before the study day. Urine was collected for 4 h after treatment, during which time 100 mL of water was ingested at hourly intervals. At the highest dose of caffeine (360 mg), the cumulative urine output at the 3 h time point was higher than on the placebo trial, but no other significant differences were recorded.

Grandjean *et al.* (2000) adopted an experimental design intended to more closely resemble the conditions of daily living. On four separate occasions, 18 healthy adult males consumed either water or water plus a combination of different caffeine-containing drinks, with total fluid intake being prescribed for each individual according to accepted clinical guidelines. Urine was collected over the whole 24-h period of each trial. There was no difference in urine output between trials where water (1424 mL of urine over 24 h), a low dose (114 mg) of caffeine (1424 mL) or a higher dose (253 mg) of caffeine (1575 mL) was given. There was a slight decline in body mass, amounting to an average of 0.30%, over the measurement period on all trials with no difference between trials. The authors concluded that 'advising people to disregard caffeinated beverages as part of the daily intake is not substantiated by the results of this study'. They also concluded from the observed fall in body mass in all treatment conditions than the use of current guidelines to identify fluid needs may underestimate actual requirements.

The data summarized in Table 1 suggest that a diuretic response to caffeine-containing drinks is likely to occur in response to an acute dose of caffeine of about 300 mg or more, but is unlikely at doses of about 250 mg or less. There is some overlap in the results, but this can be ascribed to differences in experimental conditions, including the body mass of the subjects, their habituation to caffeine, and the period of withdrawal imposed prior to the measurement period. A caffeine dose of 300 mg amounts to a dose of 60 mg kg^{-1} for a subject with a body mass of 50 kg, but to a dose of only 38 mg kg^{-1} for an 80 kg subject. Data on the body mass of the subjects who participated were not reported in some of the studies cited above. There must also be questions about the reliability of assessments of habitual intake of methylxanthines, as these generally rely on subject recall, and about subject compliance with the instructions to abstain from caffeine prior to participation. In rather few studies has the baseline plasma or urine caffeine level been measured to assess compliance.

Hydration status of the individual at the time of caffeine ingestion may also affect the response, but this has not been controlled in many of the published studies. Alcohol is a well-recognized and relatively potent diuretic, but it has long been known that the diuretic effect is attenuated in individuals who are in fluid deficit. Eggleton (1941) showed that even mild fluid restriction (an overnight fast followed by a light breakfast 2–2 1/2 h before the test began) was enough to ensure that a significant part of the ingested fluid was retained when the alcohol dose was low. It is not known whether the diuretic effect of caffeine is reduced in subjects who are mildly dehydrated.

On the basis of the results of Neuhauser-Berthold *et al.* (1997), Stookey (1999) proposed that caffeine exerts a negative effect on fluid such that each milligram of caffeine consumed will stimulate the formation of 1.1 mL of urine. The evidence, however, suggests that the relationship between caffeine intake and urine output is not a linear one, but rather that there is a threshold level below which little or no effect on urine production is observed. The habituation to the actions of caffeine that occurs in regular users must also be taken into account.

Table 1 Impact of caffeine ingestion on urine flow*

Caffeine dose (mg)	Diuretic effect	Reference
642	Yes	Neuhauser-Berthold *et al.* (1997)
586	Yes	Wemple *et al.* (1996)
360	Yes	Passmore *et al.* (1987)
250	Yes	Nussberger *et al.* (1990)†
250	Yes	Robertson *et al.* (1978)
300	No	Dorfman & Jarvik (1970)
253	No	Grandjean *et al.* (2000)
180	No	Passmore *et al.* (1987)
114	No	Grandjean *et al.* (2000)
90	No	Passmore *et al.* (1987)
45	No	Passmore *et al.* (1987)

*The study of Eddy & Downs (1928) has been excluded on the grounds of an inadequate subject number ($n = 3$).
†There are some uncertainties (identified in the text) over the methodology used by Nussberger *et al.*, (1990) and these results should perhaps be ignored.

Caffeine levels of different drinks and relevance to the UK drinking patterns

Many commonly consumed foods and beverages contain caffeine or other methylxanthines, but there is considerable inter-individual variability in the habitual level of intake. About 70% of the UK population drink tea on a regular basis, and the average consumption is 2.5 cups per day; coffee is consumed by 48% of the population with an average consumption of one cup per day. There is a wide distribution around these average levels of consumption of caffeinated drinks and large differences in consumption between age groups. For example, on average 2–9-year-olds drink less than half a cup of tea daily whereas older people (45–64 years) drink more tea (average of 3.6 cups per day) (National Drinks Survey, 2002).

The caffeine content of most beverages varies considerably, as seen by the variability of the published data (Table 2). For instance, the caffeine content of a cup of tea will depend on many different factors including brewing time, whether the infusion is stirred, the leaf to water ratio, and the size of the serving. Published data for caffeine intake must therefore be treated with some degree of caution. It should also be recognized that many carbonated soft drinks other than the colas also contain substantial amounts of caffeine. So-called 'energy drinks' which rely on a high sugar concentration and a large (100–200 mg) dose of caffeine for their effect have also recently become popular, especially among young people.

In addition to caffeine, the other methylxanthines (theophylline and theobromine) present in tea and coffee may also contribute to a diuretic action, in which case, the results of studies that have investigated the response to administration of caffeine alone would not be applicable. Theobromine has a relatively weak diuretic action, but theophylline has a potency similar to that of caffeine (Fredholm, 1984). The effects of administration of tea, coffee or other beverages may therefore differ in some important respects from the response to the administration of an equivalent dose of caffeine. Graham *et al.* (1998) showed some important differences in the responses to the ingestion of caffeine and coffee.

Table 2 Caffeine content of various commonly consumed beverages

	Caffeine content (mg) per serving*			
Source	MAFF (1998)	Ziegler†	McArdle‡	Thomas§
Tea	40	59	12–67	15–75
Instant coffee	58	76	53–144	61–70
Filter coffee	61–125	105	85–200	97–125
Hot chocolate	–	21	8–13	–
Cola	23	70	36–59	43–65

*Serving size is corrected to 200 mL for tea, coffee and hot chocolate, and to 330 mL for cola. Note that an American grande size serving of coffee may contain as much as 600 mg of caffeine.
†Ziegler & Filer (1996).
‡McArdle *et al.* (1999).
§Thomas (1994).

Conclusions

Three broad conclusions can tentatively be drawn from the published literature on the effects of caffeine on fluid balance:

1 Large doses of caffeine (above 250 mg) have an acute diuretic action;

2 Single caffeine doses at the levels found in commonly consumed beverages have little or no diuretic action;

3 Regular caffeine users become habituated to the effects of caffeine, diminishing its actions.

These conclusions are based on the information presented above. There are several limitations to the review, and other information that was not identified by the review process may exist. It is also possible that the publication process itself may have prevented the publication of studies where no action of caffeine was seen. Against this, however, any well-designed study should have included a range of caffeine concentrations, including at least one where an effect was identified. In many of the published studies, it was not possible to evaluate the quality of the data. The repeatability of the measurements was not identified in any of the published papers. There is insufficient information available to establish how responses to caffeine might be affected by factors such as age, gender, hydration status or nutritional status. A large inter-individual variability in plasma caffeine levels in response to administration of a standard dose and in the physiological responses suggests that small differences as a result of changes in any of these variables are unlikely to be detectable. There is also a scarcity of information on the effects of administration of the complex mixtures of biologically active compounds present in beverages such as tea and coffee, as opposed to large doses of purified caffeine.

Practical recommendations for dietitians

In formulating advice on the role of caffeinated beverages in hydration, it is necessary to understand the fluid balance equation. The normal daily water balance for a sedentary healthy individual with a body mass of about 70–75 kg living in a temperate climate, based on McArdle *et al.* (1999), shows a daily water exchange of 2550 mL. Urine excretion accounts for 1250 mL. The remaining water is lost from the body through sweating, during respiration when water vapour is lost on expiration and in the elimination of faeces. Food accounts for 1000 mL of the daily water input, metabolism 350 mL and drinks from all sources account for 1200 mL. Within the healthy population, individual requirements for fluid can vary considerably. This is most noticeable when sweat losses rise because of increases in physical activity level, ambient temperature and humidity.

Fluid intake requirements should be met by drinking and enjoying a variety of different drinks. The validity of recommendations to limit the intake of caffeine-containing drinks on the grounds that they have a diuretic effect have been questioned in this review. From the results, it would appear that there is no scientific evidence to support advice to the general population to avoid consumption of caffeine containing drinks on the grounds of their diuretic effect, except when total daily consumption of caffeine from all sources is regularly in excess of 300 mg. In addition to the beverages listed in Table 2, chocolate, some 'energy drinks' and over the counter medicines are sources of dietary caffeine. In assessing total caffeine intake care should also be taken in determining the actual quantity of caffeinated drinks consumed. Although can or bottle sizes are easily identified, the volume of fluid in glasses, cups and mugs can be very variable (Nelson *et al.*, 1997). Daily intakes of caffeine should be assessed in relation to body mass. This is particularly relevant when an individual is at the lower end of the range of body mass in relation to height. If caffeine intakes above 300 mg day^{-1} are consumed on a regular basis, advice should be given to reduce the intake to acceptable levels. This should be achieved by limiting the intake of those drinks that provide little in the way of nutritional and health benefits.

Special considerations

Pregnancy

There appear to be no specific fluid requirements for pregnancy other than the advice to increase consumption of fluids and dietary fibre to help relieve constipation, a common problem in pregnancy. Certainly there is no justification for a restriction in fluid intake during pregnancy because of the inconvenience of more frequent urination. Pregnant women should be encouraged to drink at least as much as they normally drink and to choose drinks that are not only suitable but also enjoyable. Concerns have been raised about the appropriateness of caffeine containing drinks during pregnancy. Caffeine freely crosses the placenta and plasma caffeine concentrations in the neonate are similar to those in the maternal plasma. The Committee on Toxicity of Chemicals in Food recently reviewed the evidence linking caffeine to health in pregnancy (Committee on Toxicity of Chemicals in Foods, Consumer Products and the Environment, 2001). They concluded that it is prudent for pregnant women to limit total caffeine intake from all dietary sources to below 300 mg day^{-1} as caffeine intakes above this level may be associated with low birth weight and, in some cases, miscarriage. This equates to a daily intake of around four cups of tea, plus two cups of instant coffee and a bar of chocolate. As a consequence pregnant women can be advised to choose caffeine-containing drinks as a source of fluid provided that total daily caffeine intake does not exceed 300 mg.

Breast-feeding

Usually over 700 mL of breast milk is produced daily from 10 to 15 days after birth. The volume of breast milk produced is unaffected by the fluid intake of the mother but this extra fluid requirement must be met by an increase in fluid intake if the mother is to avoid dehydration. An increased fluid intake is also essential in the days immediately after the birth when breast-feeding is being established. Breast-feeding mothers should be encouraged to consume a greater fluid intake than usual, advised not to wait to feel thirsty before drinking and not to ignore feelings of thirst. Dusdieker *et al.* (1990) suggest that breast-feeding mothers need to consume about 2 L day^{-1} to protect themselves against dehydration. The increased requirement for fluid will be met more easily if breast-feeding mothers are advised to enjoy a variety of suitable drinks. Young children are able to metabolize caffeine more rapidly than older people. The clearance rate in infants at 6 months of age is twice that of adults (Aranda *et al.*, 1979). Although caffeine passes into breast milk, in the absence of published evidence to suggest otherwise, breast-feeding mothers may take caffeine containing-drinks, providing again that total daily intake does not exceed 300 mg.

Children

Fluid requirements for children are not clearly defined. The number of drinks children need varies from day to day depending on the weather, how active children are and what food they are eating. The Paediatric Group of the British Dietetic Association suggest that children should be offered a drink with each meal, at least once between meals and that extra drinks should be offered in hot weather and during sport and energetic activities. The best drinks for children are milk and water as they do not damage teeth. Caffeinated drinks are not advised as a main drink for preschool children, milk and water being the best choices to offer between meals. Data from the National Diet and Nutrition Survey of children aged 1 1/2–4 1/2 years (Gregory *et al.*, 1995) suggest this advice is being heeded. During the recording period just over one third of children had drunk tea (37%) but only 7% had drunk coffee, equivalent to about 2 1/2 cups of tea and 1 1/2 cups of coffee over 7 days. Diluted fruit juice is best offered with meals in order to reduce the risk of dental caries. Children are more susceptible to dental caries than adults as the tooth enamel is still being developed during the first 6 years of life and remains relatively soft. Frequent consumption of sugary drinks should therefore be avoided. The National Diet and Nutrition Survey (Gregory *et al.*, 2000) showed that calcium intakes were often insufficient to meet requirements. Between 2 and 5% of children aged 4–10 years old had calcium intakes below the Lower Reference Nutrient Intake. For older primary and secondary school children, rather than discouraging caffeinated drinks such as tea and coffee on the misinformed grounds that they cause dehydration, such drinks, when made with milk, could be positively encouraged within the total caffeine intake guidelines already suggested. Where the intake of caffeine is regularly in excess of 300 mg day^{-1} consideration should be given to reducing the intake of dietary sources with less health and nutritional benefits such as many of the soft drinks and high-caffeine energy drinks.

The elderly

A daily intake of 1500–2000 mL is considered necessary for this population group, made up of 1500 mL (6–8 cups) as drinks and the rest obtained from foods. However, ageing is associated with a reduced sensation of thirst and failure to drink enough to replace obligatory fluids losses will lead to dehydration. Those who habitually drink caffeine-containing drinks such as tea and coffee should not be encouraged to restrict their intake of these drinks on the grounds that it will lead to dehydration. Such advice could compromise fluid intake at a time when efforts should be directed towards increasing fluid intake.

The physically active

Sports people and those with physically demanding occupations need to ensure adequate hydration before, during and after exercise to minimize loss in performance and to reduce the risk of thermal stress. The rate of sweat loss depends on a number of factors, including work intensity, environmental temperature, humidity, body surface area, existing hydration status, acclimatization and clothing. Sweat rates of 1–2 L h^{-1} during moderately intense exercise are typical but when the temperature is high these losses can exceed 2 L h^{-1} (Rehrer & Burke, 1996). In extreme conditions, daily fluid intake and loss may exceed 10 L (Maughan & Lindinger, 1995). Individuals need to estimate likely fluid losses and ensure that sufficient fluids are consumed to maintain hydration. Fluids that are palatable are more likely to be drunk in adequate amounts. The fluid intake of children during exercise is particularly influenced by the palatability of the drink (Bar-Or & Wilk, 1996). Those who take part in regular exercise can often benefit from using a sports drink containing carbohydrate and some sodium (Maughan, 1998). It is also important that an adequate fluid intake is achieved throughout the day. Individuals who habitually consume caffeine-containing drinks can be reassured that intakes of less than 300 mg day^{-1} caffeine will not compromise hydration status.

Acknowledgment

This review was supported by PG Tips tea from Brooke Bond, part of Unilever Bestfoods, UK.

References

Aranda, J.V., Collinge, J.P., Zinman, R. & Watters, G. (1979) Maturation of caffeine elimination in infancy. *Arch. Dis. Child.* **54**, 946–949.

Arnaud, M.J. (1987) The pharmacology of caffeine. *Prog. Drug Res.* **31**, 73–313.

Bar-Or, O. & Wilk, B. (1996) Water and electrolyte replenishment in the exercising child. *Int. J. Sport Nutr.* **6**, 93–99.

Braun, S. (1996) *Buzz*. New York: Oxford University Press.

Committee on Toxicity of Chemicals in Foods, Consumer Products and the Environment (2001) *COT Statement 2001/06. Statement on the Reproductive Effects of Caffeine*. London: Food Standards Agency.

Curatolo, P.W. & Robertson, D. (1983) The health consequences of caffeine. *Ann. Int. Med.* **98**, 641–653.

Dorfman, L.J. & Jarvik, M.E. (1970) Comparative stimulant and diuretic actions of caffeine and theobromine in man. *Clin. Pharmacol. Ther.* **11**, 869–872.

Dusdieker, L.B., Stumbo, P.J. & Booth, B.M. (1990) Prolonged maternal fluid supplementation in breast-feeding. *Pediatrics* **86**, 737–740.

Eddy, N.M. & Downs, A.W. (1928) Tolerance and cross-tolerance in the human subject to the diuretic effect of caffeine, theobromine and theophylline. *J. Pharmacol. Exp. Therap.* **33**, 167–174.

Eggleton, G. (1941) The diuretic action of alcohol in man. *J. Physiol.* **101**, 172–191.

Fredholm, B.B. (1984) Cardiovascular and renal actions of methylxanthines. In *The Methylxanthine Beverages and Foods: Chemistry, Consumption and Health Effects*. ed. G. A. Spiller, *Prog. Clin. Biol. Res.* **158**, 303–330.

Graham, T.E. (1997) The possible actions of methylxanthines on various tissues. In *The Clinical Pharmacology of Sports and Exercise*, eds T. Reilly & M. Orme, pp. 257–270. Amsterdam: Elsevier Science.

Graham, T.E., Hibbert, E. & Sathasivam, P. (1998) The metabolic and endurance exercise effects of coffee and caffeine ingestion. *J. Appl. Physiol.* **85**, 883–889.

Grandjean, A.C., Reimers, K.J., Bannick, K.E. & Haven, M.C. (2000) The effect of caffeinated, non-caffeinated, caloric and non-caloric beverages on hydration. *J. Am. Coll. Nut.* **19**, 591–600.

Gregory, J., Collins, D.L., Davies, P.S.W., Hughes, J.M. & Clarke, P.C. (1995) *National Diet and Nutrition Survey. Children Aged 1 1/2 to 4 1/2 years*. Vol 1. Report of the Diet and Nutrition Survey. London: The Stationery Office.

Gregory, J., Lowe, S., Bates, C.J., Prentice, A., Jackson, L.V., Smithers, G., Wenlock, R. & Farron, M. (2000) *National Diet and Nutrition Survey: Young People Aged 4 to 18 years*. Vol 1. Report of the National Diet and Nutrition Survey. London: The Stationery Office.

Hoffman, N.B. (1991) Dehydration in the elderly: insidious and manageable. *Geriatrics* **46**, 35–38.

Kleiner, S.M. (1999) Water: an essential but overlooked nutrient. *J. Am. Diet. Ass.* **99**, 200–206.

Koschlakoff (1864) Beobachtungen uber die wirkung des citronensauren coffein's. *Virchow's Archiv.* **31**, 436–445.

Leaf, A. (1984) Dehydration in the elderly. *N. Engl. J. Med.* **311**, 791–792.

McArdle, W.D., Katch, F.I. & Katch, V.L. (1999) *Sports and Exercise Nutrition*. Philadelphia: Lipincott Williams & Wilkins.

MAFF (1998) *Updated Food Surveillance Information Sheet: Caffeine on Energy Drinks and other Caffeine Containing Products*. London: HMSO.

Marlin, E. (2001) Gut instincts. *British Airways High Life Magazine* July, 92.

Maughan, R.J. (1998) The sports drink as a functional food: formulations for successful performance. *Proc. Nut. Soc.* **57**, 15–23.

Maughan, R.J. & Lindinger, M.I. (1995) Preparing for and competing in the heat: the human perspective. *Equine Vet. J.* **20**, 8–15.

Mentes, J., Culp, K., Wakefield, B., Gaspar, P., Rapp, C.G., Mobly, P. & Tripp-Reimer, T. (1998) Dehydration as a precipitating factor in the development of acute confusion in the frail elderly. In *Hydration and Aging*, eds M. J. Arnaud, R. Baumgartner, J. E. Morley, I. Rosenberg & S. Toshikazu, pp. 83–100. New York: Springer.

National Drinks Survey. January 2002.

Nelson, M., Atkinson, M. & Meyer, J. (1997) *A Photographic Atlas of Food Portion Sizes*. London: MAFF.

Neuhauser-Berthold, B.S., Verwied, S.C. & Luhrmann, P.M. (1997) Coffee consumption and total body water homeostasis as measured by fluid balance and bioelectrical impedance analysis. *Ann. Nutr. Metab.* **41**, 29–36.

Nussberger, J., Mooser, V., Maridor, G., Juillerat, L., Waeber, B. & Brunner, H.R. (1990) Caffeine-induced diuresis and atrial natriuretic peptides. *J. Cardiovascular. Pharmacol.* **15**, 685–691.

Passmore, A.P., Kondowe, G.P. & Johnston, G.D. (1987) Renal and cardiovascular effects of caffeine: a dose-response study. *Clin. Sci.* **72**, 749–756.

Rehrer, N.J. & Burke, L.M. (1996) Sweat losses during various sports. *Aust. J. Nutr. Diet.* **53**, 13–16.

Robertson, D., Froelich, J.C., Carr, R.K., Watson, J.T., Hollifield, J.W., Shand, D.G. & Oates, J.A. (1978) Effects of caffeine on plasma renin activity, catecholamines and blood pressure. *NEJM* **298**, 181–186.

Spiller, G.A. (1984) Overview of the methylxanthine beverages and foods and their effect on health. *Prog. Clin. Biol. Res.* **158**, 1–7.

Stookey, J.D. (1999) The diuretic effects of alcohol and caffeine and total water intake misclassification. *Eur. J. Epidemiol.* **15**, 181–188.

Thomas, B. (ed.) (1994) *Manual of Dietetic Practice*, 2nd edn. Oxford: Blackwell Science.

Wemple, R.D., Lamb, D.R. & McKeever, K.H. (1996) Caffeine versus caffeine-free sports drinks: effects on urine production at rest and during prolonged exercise. *Int. J. Sports Med.* **18**, 40–46.

Ziegler, E.E. & Filer, L.J. (1996) *Present Knowledge in Nutrition*, 7th edn. Washington: ILSI Press.