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Voluntary dehydration among elementary school children residing in a hot arid environment

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Abstract

Background: Voluntary dehydration is a condition where humans do not drink appropriately in the presence of an adequate fluid supply. This may adversely affect their physical and intellectual performance. The present study aimed to describe the prevalence of voluntary dehydration among elementary school children of different ethnicities and countries of birth.
Methods: Four hundred and twenty-nine elementary school children, aged 8–10 years, from four subpopulations (Israeli-born Jewish and Bedouin-Arab children, and immigrant children who recently arrived to Israel from Eastern Europe and from Ethiopia) were studied. The level of dehydration was determined by noontime urine osmolality, from samples taken over 1 week in mid-summer. Urine osmolality <500 mOsmol kg^{-1} H_2O was considered to be an appropriate level of hydration.
Results: Mean urine osmolality was 862 ± 211 mOsmol kg^{-1} H_2O. Osmolality above 800 mOsmol kg^{-1} H_2O was detected in 67.5% of the urine samples; among these, 25% were above 1000 mOsmol kg^{-1} H_2O. The most dehydrated group was that of Israeli-born Jewish children, whereas the Bedouin-Arab children were the least dehydrated.
Conclusions: A high proportion of children who reside in a hot and arid environment were found to be in a state of moderate to severe dehydration. Bedouin ethnicity was associated with better hydration, whereas Israeli-born Jews were most severely dehydrated. Educational intervention programmes promoting water intake should start in early childhood and continue throughout life.

Introduction

Voluntary dehydration is a condition in which humans, who are oblivious to excessive water loss as a result of environmental conditions, do not drink appropriately in the presence of adequate fluid supply (Greenleaf & Sargent, 1965). The state of dehydration is reflected by excretion of urine of high osmolality. On the basis of a study by Katz *et al.* (1965), an appropriate level of hydration is reflected by urine osmolality of less than 500 mOsmol kg^{-1} H_2O. A moderate level of dehydration is reflected by urine osmolality of 501–800 mOsmol kg^{-1} H_2O. High and maximal levels of dehydration are reflected by urine osmolalities of 801–1000 and above 1000 mOsmol kg^{-1} H_2O, respectively. Dehydration may affect the general sense of well-being and adversely affect physiological and intellectual functions (Gopinathan *et al.*, 1988; Borghi *et al.*, 1996; Kleiner, 1999).

The adverse effects of acute induction of dehydration on physical performance and exercise have been demonstrated in many studies on adult athletes and outdoor workers (Barr, 1999; Kleiner, 1999). In adults, a 2% loss in body fluids was estimated to result in a decrease of 20% in physical performance (Sawka & Pandolf, 1990). Cognitive and intellectual performances are also impaired by dehydration (Liberman, 2007). Gopinathan *et al.* (1988) established that soldiers who exercise in hot weather demonstrate a reduction in arithmetic ability, short-term memory, and visual-motor tracking after a 2% loss of body fluids. Sharma *et al.* (1986) examined the effects of various levels of dehydration on mental functions in soldiers in a laboratory-controlled environment. They demonstrated a decline in the mean score of coordination that parallels the degree of dehydration. Cian *et al.* (2001) demonstrated that acute dehydration, either secondary to exposure to heat or exercise-induced, causes a significant reduction in cognitive performance in decision-making and perceptual tasks in adults. They also reported a significant improvement in short-term memory following rehydration. A study by Petri *et al.* (2006) demonstrated that 24 h of voluntary fluid intake deprivation, in soldiers, led to deterioration in objective parameters of psychological processing.

We were unable to identify a formal definition for the term 'chronic dehydration'.

In adults, prolonged dehydration is associated with an increased risk of developing certain types of malignancies (Bar-David *et al.*, 2004), especially of the urinary tract, colon, and breast (Michaud *et al.*, 1999), mitral-valve prolapse (Lox *et al.*, 1992), salivary dysfunction (Ship & Fischer, 1997), chronic constipation (Arnaud, 2003), and obesity (Lappalainen *et al.*, 1993).

Very few studies on voluntary dehydration have been conducted in children. Bar-David *et al.* (2005) demonstrated a correlation between hydration state and cognitive achievements in visual attention, immediate memory span, semantic flexibility, and automatic application of arithmetic operations in school-aged children residing in a hot climate. Their study was conducted under normal daily activity, unlike other studies where dehydration was induced and controlled. Other adverse effects of chronic dehydration in children include urinary stone formation (Landau *et al.*, 2000).

Children are more prone to develop voluntary dehydration as a result of their high proportion of body surface area to body mass, especially when residing in hot climates. They are also less likely to restrict their physical activities during the hot hours of the day and are more exposed to solar radiation, which contributes to the heat stress index (Epstein *et al.*, 1983; Committee on Sport Medicine and Fitness, 2000).

The present study was conducted in the 'Negev' (southern) region of Israel, which comprises an arid area, characterised by low precipitation, hot dry days, and cold nights. It is populated by over 500 000 inhabitants, of whom 50% are Jews who came to this area in the last 60 years, mainly from Eastern Europe and North Africa. Approximately 25% of the Negev population are Bedouin-Arab Muslims, with the majority residing in permanent settlements, and a small percentage of these still practice a nomadic lifestyle. The other 25% of the population is composed of recent immigrants from Eastern Europe (i.e. the former Soviet Union) and Ethiopia, of whom a large proportion arrived in the 5 years before the study was conducted.

Phillip *et al.* (1993) conducted a study on 200 Jewish kindergarten children (aged 2–6 years) residing in the same 'Negev' area. They revealed that the average urine osmolality increased with age, from 608 mOsmol kg^{-1} H_2O at 2 years to 832 mOsmol kg^{-1} H_2O at 6 years. In the same geographic area, a study by Bar-David *et al.* (2005) reported that 63% of 51 Jewish school children aged 10–12 years had a morning urine osmolality of 800 mOsmol kg^{-1} H_2O and above.

As a result of global worming, large populations that reside in temperate climate zones are at risk of voluntary dehydration. In addition, the European open borders policy has encouraged the mass movement of populations of various ethnic backgrounds and their settlement in Western Europe and the UK. They may have different water drinking habits and a predisposition to dehydration. The present study aimed to describe the prevalence of voluntary dehydration among elementary school children from different ethnicities and countries of birth.

Materials and methods

The study protocol was approved by the research review board of the Soroka University Medical Center, Beer-Sheva, Israel. Informed consent was requested from parents of the participating children. Confidentiality was maintained by using coded study numbers for each child, which concealed the identity of the participants. Refusal to take part in the study was fully honoured with no consequences.

Subjects

Four hundred and forty-one elementary school children, aged 8–10 years, were recruited from five different schools. Three of the schools are located in a Jewish town: one in a rural Jewish community, and one in a

Bedouin town. This reflects the proportion of the Jewish population by settlement (town versus rural) and the proportion between the ethnicities. The gender and place of birth of the children were recorded. Because of the small number of participants, nine children born in North and South America and Western Europe were excluded from the study. Three Israeli-born Jewish children were excluded for technical reasons. Thus, 429 children were evetually recruited in the study.

Procedure

One urine sample for osmolality measurement was collected from each participant at noontime, during 1 week in June 2000. Children received no instructions regarding drinking. The range of ambient temperature was 35–37 °C during this week. Classrooms were not air-conditioned. The urine samples were sealed and placed in a freezer (−20 °C) within 1 h, until analysis. Samples were thawed at room temperature. Analysis was conducted the same day. This method is based on a previous study demonstrating that freezing urine samples does not affect the results of their eventual analysis (Phillip *et al.*, 1993).

Statistical analysis

Osmolality was measured using the Vogel Osmometer (OM-801, Gissen, Germany) calibrated with standard solutions of 0, 300, and 1000 mOsmol kg H_2O.

Statistical analysis was performed using SPSS for Windows, version 10.0 (SPSS Inc., Chicago, IL, USA). A chi-squared test was used for nominal variables and an independent *t*-test was used for normally distributed continuous variables. $P \leq 0.05$ was considered statistically significant.

Results

Participants' demographic data are described in Table 1. The mean urine osmolality of the study population was 862 ± 211 mOsmol kg^{-1} H_2O. High osmolality (above 800 mOsmol kg^{-1} H_2O) was detected in 67.5% of the urine samples. Among these, 25% were above 1000 mOsmol kg^{-1} H_2O, indicating maximal dehydration. Only 6.8% of the children excreted urine of 500 mOsmol kg^{-1} H_2O or less; thus, more than 93% of children were at some level of dehydration. The mean urine osmolality was 883 ± 201 mOsmol kg^{-1} H_2O among boys and 844 ± 218 mOsmol kg^{-1} H_2O among girls (P = 0.057).

Urine osmolality by study group is also presented in Table 1. The group that demonstrated the highest rate of dehydration was that of Israeli-born Jewish children. The mean urine osmolality of the two groups of immigrant children combined indictated a lower level of dehydration (845 ± 266 mOsmol kg^{-1} H_2O). The Israeli-born Bedouin children were the least dehydrated ($P < 0.001$ versus Israeli-born Jewish children).

Table 1 Study population by place of birth, gender and mean urine osmolality (SD)

Place of birth	Male	Female	Total	Urine osmolality* (mOsmol kg^{-1} H_2O)
Israel–Jewish	128	136	264	905.8 (183.5)
Israel–Bedouin	52	38	90	771.3 (196.0)
Ethiopia	17	26	43	856.3 (256.2)
Eastern Europe	10	22	32	830.3 (271.6)
Total	207	222	429	

*$P < 0.05$.

The percentage of children in each of the dehydration categories is presented in Table 2. Eighty percent of the Israeli-born Jewish children excreted urine of 800 mOsmol kg^{-1} H_2O or greater, as did 64% of the children born in Ethiopia and 60% of the children born in Eastern Europe. In the three Jewish groups, approximately 30% excreted urine of more than 1000 mOsmol kg^{-1} H_2O. In the Israeli-born Bedouin group, only 50% of the urine samples were 800 mOsmol kg^{-1} H_2O and above; with 7% above 1000 mOsmol kg^{-1} H_2O ($P < 0.05$).

Discussion

Normal water balance is a function of two mechanisms: the secretion of antidiuretic hormone (ADH) by the neurohypophysis and the sense of thirst. The stimuli for ADH release include an increased plasma osmolality perceived by osmoreceptors in the hypothalamus and a decreased blood volume as detected by baroreceptors in the carotid sinus of the aortic arch. ADH changes the permeability of the renal tubular cell membrane for water

Table 2 Distribution of level of urine osmolality (in mOsmol kg^{-1} H_2O) by percentage of children per origin

Origin	<500*	501–800†	801–1000‡	>1000§
Israeli Jews	5	15	50	30
East Europe	9	31	32	28
Ethiopia	14	22	35	29
Bedouin	8	42	43	7

$P < 0.05$.
Based on Katz *et al.* (1965):
*Mildly concentrated urine.
†Moderately concentrated urine.
‡Highly concentrated urine.
§Maximally concentrated urine.

through cyclic AMP-activated water channels (aquaporins).

At a plasma osmolality below 280 mOsmol kg^{-1} H_2O, the concentration of ADH is essentially zero, the plasma is maximally diluted, and the urine osmolality can drop to 50 mOsmol kg^{-1} H_2O. At a plasma osmolality above 280 mOsmol kg^{-1} H_2O, ADH is secreted in linear proportion to the rise of plasma osmolality, until the urine osmolality reaches a maximum of 1200 mOsmol kg^{-1} H_2O. The threshold for thirst occurs at plasma osmolality values of 290–295 mOsmol kg^{-1} H_2O, corresponding to an urine osmolality of approximately 800 mOsmol kg^{-1} H_2O. An appropriate level of hydration is reflected by an urine osmolality of less than 500 mOsmol kg^{-1} H_2O (Katz *et al.*, 1965). This corresponds to the fact that humans begin to feel thirsty at a high level of dehydration. The clinical relevance is that a significant proportion of the population who live in a hot climate are at risk of having highly concentrated urine during the summer months, and thus chronic dehydration.

In the present study, for the first time, four groups of elementary school children were studied to determine their vulnerability to a state of chronic voluntary dehydration. Despite of living under the same climatic conditions, the group of Israeli-born Jewish children had the highest mean urine osmolality, whereas the Israeli-born Bedouin-Arab children had the lowest. There are two possible explanations for these differences. First, the Bedouin children originate from a population that has lived in the desert for many generations and have developed a mechanism that lowers the threshold of thirst. Second, Bedouin children may have better drinking habits (Bar-David *et al.*, 1998).

The results of the two groups of immigrant children, from Eastern Europe and Ethiopia, are surprisingly similar. This may reflect their gradual adoption of drinking habits as well as the levels of activity of the Israeli-born Jewish children.

Phillip *et al.* (1993) conducted a study of 200 kindergarten children (aged 2–6 years) in southern Israel and found that urine osmolality exceeding 800 mOsmol kg^{-1} H_2O was excreted by 60.5% of the children. In that study, the average urine osmolality increased with age. This could be explained by the physiological increase in the kidneys' ability to concentrate urine as age increases, combined with the increased outdoor activity of children as they become older (Rapoport, 1993).

In a study by Bar-David *et al.* (2005), 63% of 51 Jewish school children aged 10–12 years had a morning urine osmolality of 800 mOsmol kg^{-1} H_2O and above, and 25% had a morning urine osmolality of more than 1000 mOsmol kg^{-1} H_2O. Similar results were found at noontime, demonstrating that approximately two-thirds of the children were in a state of chronic voluntary dehydration during many hours of the day. The present study reports very similar results in a larger sample from the same population. Therefore, it appears that many children in this area are in a state of prolonged dehydration.

Recovery from a state of dehydration is dependent on the induced intake of fluids. (Bar-Or & Wilk, 1996; Wilk *et al.*, 1998). Spontaneous voluntary drinking is usually not enough. Bar-Or and Wilk demonstrated, in a number of studies, that the temperature, flavour, and composition of drinking fluids are important determinants with respect to the willingness of people to drink (Rivera-Brown *et al.* 1999). Educational programmes aimed at encouraging people to drink more water have been successful in reducing the prevalence of urinary stone formation in desert dwellers (Frank & De Vries, 1966). Schools in the UK are becoming increasingly aware of the importance of the frequent intake of water by the pupils, thus encouraging good water drinking habits.

The present study did not undertake a drinking-diary. It is assumed that the appropriate fluid intake for elementary school children of average level of activity is approximately 2.5 L day^{-1}.

Because similar studies on voluntary dehydration on different ethnic groups and in other climatic areas are scarce, the generalisation of our results is limited. However, their implications might be of importance to other places. As a result of global worming, large populations who reside in temperate climate zones are at risk of voluntary dehydration. People who reside in countries of cold winters are exposed to heating systems that may imitate a dry hot climate and thus are prone to the same risk. In addition, the European open borders policy encourages the mass movement of populations of various ethnic backgrounds and their settlement in west Europe and the UK. They may have different water drinking habits and a predisposition to dehydration.

During the last 10–15 years, in Western Europe, there has been increased awareness regarding water drinking habits in school-aged children as well as the importance of the availability of and easy access to water in schools.

Leading on that issue are the UK and Germany. Sichert-Hellert *et al.* (2001), in a group of studies known as the DONALD Study, noted a low total water intake, especially a low tap water intake, in German children and adolescents. On the other hand, they found an increase in beverage consumption together with its implications for obesity trends and dental caries.

In the UK, the promotion of good hydration is included within the Government's Food in Schools programme, which supports the National Healthy School

Standard. It advises that good quality drinking water should be available to pupils throughout the day and should not be restricted to taps or drinking fountains located in toilet areas.

A survey in Northumbrian adolescents aged 12–14 years (Rugg-Gunn *et al*., 1987) found that many children do not drink adequately for their age and activity level, and some drink significantly less during the school days than at the weekends.

Petter *et al*. (1995), in a survey on the drinking habits of young children with reference to the consumption of plain water, in and around Southampton, UK, found that 72.5% of the preschool group and 50% of the infant school group never drank plain water. Squash was by far the most frequently consumed drink.

Recent studies support these ideas. Kaushik *et al*. (2007), in a study conducted in Southampton, UK, on the association between children's access to drinking water and their fluid intake, revealed that most children had an inadequate fluid intake. Free access to drinking water in class was associated with better total fluid intake. Their conclusion was that primary schools should promote water drinking in classrooms.

Molloy *et al*. (2008) demonstrated that teachers had poor knowledge of pupils' hydration requirements as well as the adverse effects of inadequate hydration on learning.

Conclusions

A high proportion of children who reside in a hot and arid environment were found to be in a state of moderate to severe dehydration, as reflected by their urine osmolality. Bedouin ethnicity was associated with better hydration, whereas Israeli-born Jews were the most severely dehydrated.

Because dehydrated children are at risk of suffering the adverse effects of dehydration with respect to their physiological and intellectual functions, good drinking habits and maintaining an appropriate fluid balance should be an essential part of a healthy lifestyle. Educational intervention programmes promoting water intake should start in early childhood and continue throughout life. Further studies are needed to determine differences in vulnerability to dehydration in other ethnic groups.

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Conflict of interests, source of funding and authorship

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YB-D designed the study, collected data, and wrote the manuscript. JU designed the study, interpretated data, and edited the manuscript. DL acted as the nephrology consultant, interpretated data and reviewed the manuscript. ZB-D coordinated the study, analysed samples, and drafted the manuscript. DP designed the study and performed the statistical analysis. All authors critically reviewed the manuscript and approved the final version submitted for publication.

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