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Should children drink more water? The effects of drinking water on cognition in children

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Abstract

While dehydration has well-documented negative effects on adult cognition, there is little research on hydration and cognitive performance in children. We investigated whether having a drink of water improved children's performance on cognitive tasks. Fifty-eight children aged 7-9 years old were randomly allocated to a group that received additional water or a group that did not. Results showed that children who drank additional water rated themselves as significantly less thirsty than the comparison group ($p = 0.002$), and they performed better on visual attention tasks (letter cancellation, $p = 0.02$; spot the difference memory tasks, p 's = 0.019 and 0.014).

Keywords: hydration, children, drinking water, cognition

Introduction

This paper addresses a gap in the literature examining the effect of drinking water on cognition in children. There has been extensive research on the effect of hydration on cognitive performance in adults. This has been studied by examining dehydration induced by physical activity, heat exposure or fluid restriction, or a combination of these factors. When dehydration is induced, cognitive performance is commonly negatively affected (for a review see Ritz & Berrut, 2005). Gopinathan, Pichan, & Sharma (1998) found that dehydration induced by heat exposure and fluid restriction resulted in impaired performance on short term memory tasks, visuomotor tracking tasks and arithmetic efficiency. They reported a dose-response effect, with cognitive performance related to the degree of dehydration. Heat stress and/or exercise induced dehydration has been found to negatively affect perceptual discrimination, psychomotor skills and short term

memory (Cian et al, 2000). Studies that induce dehydration through fluid restriction have found conflicting results, with some showing no effect on attention or memory (Neave et al., 2001), while others report hydration status positively relating to attention, memory and psychomotor skills (Suhr, Hall, Patterson, & Niinistö, 2004). Thus, in adults, the majority of studies find that dehydration is related to poorer performance.

Children are at particular risk of dehydration. They may not replace lost fluids sufficiently (Bar-Or, Dotan, Inbar, Rothstein, & Zonder, 1978) and are dependent on caregivers for access to drinks. A larger surface area to volume ratio makes them more susceptible to changes in skin temperature as a result of fluctuations in environmental temperature (Bar-Or, 1989). Finally, water accounts for a larger proportion of children's bodies compared to adults (D'Anci, Constant, & Rosenberg, 2006), making water depletion more likely in children. However, there has been little research on the effect of dehydration on cognition in children. In children, ethical issues surrounding consent mean that it may be undesirable to induce dehydration through fluid restriction, heat exposure or exercise. Instead, studies have examined voluntary dehydration. Bar-David, Urkin, & Kozminsky (2005) studied children in a hot climate (southern Israel) and, using their naturally occurring hydration status, divided them into hydrated and dehydrated groups using urine osmality results. Those in the dehydrated group performed significantly worse than the hydrated group on auditory digit span, and there were trends in the data towards poorer performance on measures of semantic flexibility (making groups and verbal analogies) and pattern identification (hidden figures), but not on simple addition problems. Thus, Bar-David et al.'s study suggests that children's cognitive performance is at risk from dehydration in a manner similar to that found in adults.

In climates with less extreme temperatures, or indeed countries in which children are educated in cool, perhaps air conditioned buildings, a pertinent question is whether even mild dehydration affects cognition. In adults, there is evidence to suggest that this is the case. In a review of the literature on hydration and cognition, Lieberman (2007) suggested that cognitive abilities show a dose response effect with the degree of dehydration. Even at 1% dehydration, performance on a serial addition task was negatively affected (Gopinathan et al., 1988).

A further question is whether drinking water can aid cognition under normal conditions (i.e. no or mild dehydration, rather than severe). Recent research in adults suggests that this is the case. Rogers, Kainth, & Smit (2001) reported that drinking water improved cognitive performance in thirsty individuals. In children, however, there is a paucity of research in this area. The present study sought to address this gap in the literature. We sought to examine whether providing children with additional water and encouragement to drink would result in improvements in performance on cognitive tasks. We chose to test 7-8 year old children because children of this age have not been the focus of much research in this area, despite there being many anecdotal reports of schools encouraging children to drink more with reported positive effects on cognition and behavior (e.g. BBC news online, 2000). Rather than adopting a quasi-experimental design by taking naturally occurring hydration status and observing the effects of this on cognition in children, we randomly assigned children to either a group who were given additional water and encouraged to drink up to 250ml of water or a group who were not. Levels of subjective thirst and performance on a range of cognitive tasks were then assessed. We anticipated that the consumption of additional water would result in better

cognitive performance.

Method

Participants

Fifty eight children participated in the study (26 boys). They were aged between 7 years 7 months to 9 years 8 months (mean age 8 years 7 months). Children from two classes in the same school were asked to participate and all of the children from these classes who attended school on the testing day took part. In each class, half of the children were randomly assigned to the additional water group and the remainder to the no additional water group. There were 28 children in the group that received additional water (additional water group; 11 boys) and 30 children in the group that did not receive additional water (no additional water group; 15 boys). One child in the additional water group did not consume any water in the test session and thus data from this child are removed from further analyses (new group $n = 27$). The study was approved by the University of East London, School of Psychology ethics board.

Although we did not formally collect data on ethnicity or socio-economic status, the majority ethnic group in the school is Black African and Caribbean (Ofsted Inspection Report, 2006). Recent census data reported the largest (33%) local socio-economic group to be C1 (supervisory, clerical, junior managerial, administrative or professional (Office for National Statistics, 2001).

Materials

Previous research has indicated that perceptual discrimination, psychomotor skills, short term memory, and attention are affected by dehydration. The selected tasks

were designed to measure these cognitive processes and were based on subtests found in published test batteries such as IQ tests. Letter cancellation and spot the difference tasks were used to assess perceptual discrimination; a visuomotor tracking task to assess psychomotor skills; and a story recall task to assess short term memory. All tasks require attention.

Thirst Scale. Measures of subjective thirst have been argued to provide a good indication of hydration status (Rogers et al, 2001). Our thirst scale asked children "how thirsty are you?" Children had to mark a 16 cm horizontal line with the words "very thirsty" and a pictorial representation of a thirsty face on the far left, and "not at all thirsty" and a photo of pouring water on the far right. Subjective thirst ratings were calculated by expressing the distance along the line (from right to left), as a proportion of the whole line. Thus, higher ratings equate to higher subjective thirst.

Story Memory. A short story taken from Oakhill (1984) was read to the children. They were then asked four questions about the story. Children wrote their answers in an answer booklet and the score was the number of correct answers out of four.

Letter Cancellation Task. Children were instructed to cross through all target letters in a grid. The target letter "U" ($n = 38$) was embedded in a 20x20 matrix of non-target letters ("O", $n = 323$; "V", $n = 28$; "C", $n = 11$). The score was calculated by calculating the number of target letters (U) identified in 1 minute, minus the number of incorrectly identified letters (O, V, C). The maximum score was 38; a higher score indicated better performance.

Spot the Difference Task (Easy and Hard). To assess visual attention and memory, children completed a spot the difference task. They were first shown a cartoon

picture and told that they should study the picture because they would have to look at a second, similar picture and identify any differences. After the original cartoon they were shown a blank sheet of paper in order to avoid change blindness (Pashler, 1988), and then immediately turned the page to view the second, different cartoon. These differences had to be identified by marking the cartoon. They could not refer back to the original image.

There were two conditions to this task; easy and hard. The easy condition had 3 differences between the original and second image; the hard condition had 10 differences. In the easy condition they were shown the original cartoon for 45 seconds, and given 1 minute to identify these differences. In the hard version, the original image was viewed for 1 minute and 1.5 minutes were allowed to identify the differences.

In both conditions, scores were calculated by subtracting the number of incorrectly identified differences (if any), from the number of correctly identified differences. Thus, there was a maximum score of 3 in the easy version and 10 in the hard version.

Visuo-motor tracking task. This tracking task was used to assess visuo-motor skills and required children to draw a line within tracklines, as fast as they could, without crossing or touching the lines. The tracklines were 0.5 cm apart, 38 cm from start to finish, and formed a curving pattern. They had 20 seconds to complete as much of the task as possible and the score was calculated by measuring the completed length in cm, minus the number of times their line touched or crossed the tracklines. The maximum score was 38.

Water bottles and scales. Individual drinking bottles were filled with 250 ml of water. Scales were used to weigh water remaining after drinking.

Procedure

Children were tested in groups. Children in the additional water group were encouraged to drink as much as they could; children in the no additional water group were not present during water consumption, nor were they aware that the other group was drinking. There was an interval of approximately 20 minutes between water consumption and test. This interval duration was selected as it was comparable to other studies examining the effect of water consumption on performance (Neave et al., 2001; Rogers et al., 2001). The additional water group and the no additional water group completed the thirst scale and cognitive tasks separately. Children completed the tasks in the following order: thirst scale, story memory, letter cancellation; spot the difference (easy followed by hard), visuomotor tracking. Children were given a printed booklet that contained the thirst scale and cognitive tasks. They recorded their answers in this booklet. The experimenter instructed them from the front of the classroom: a classroom assistant assisted where necessary. Because the sequence of tasks was the same for both groups, task order was considered unlikely to affect group differences. After completing all the tasks, children returned their task booklets to the experimenter and collected a sticker to thank them for their participation.

Results

The study took place on March 5th and 6th 2008 in a school in London, UK. Although we did not measure the classroom air temperature, historical records suggest that the mean outdoor temperature in London on the 5th March was 5.6°C (range .9 to 10.3) and 9.9°C (range 7.9 to 12.6) on 6th March (TuTiempo.net, 2008).

Water consumption and subjective thirst ratings. The additional water group drank

between 57 ml and 250 ml, with a mean of 211.7 ml ($SD = 62.97$ ml). Four children in the additional water group did not complete the thirst scale. Subjective thirst ratings taken just before cognitive tasks (and approximately 20 minutes after water consumption) revealed that children in the additional water group reported that they felt significantly less thirsty than children in the no additional water group (see Table 1 for details). These results suggest that drinking water affected thirst levels in the expected direction.

Cognitive Tasks. Children performed well on all tasks; they were neither at ceiling nor floor on any task (see Table 1). The data indicate that children in the additional water group scored higher than children in the no additional water group on the letter cancellation task and both spot the difference tasks (easy and hard; see Table 1). T-tests confirmed these initial impressions.

As it might be expected that the amount of water drunk may result in different effects on performance, some exploratory post hoc analyses were conducted to investigate this further. These analyses include data only from children in the additional water group. We compared those who drank 250 ml ($n = 16$) with those who drank less than 250 ml ($n = 11$, $M = 156$ ml, $SD = 67$ ml). The only measure on which there was a difference in these analyses was the story memory task, $t(25) = 2.20$, $p = 0.038$ (250 ml group, $M = 3.5$, $SD = .73$; less than 250 ml group, $M = 2.73$, $SD = 1.10$). Group differences on this measure did not reach significance in the main analysis. Thus, these results offer some preliminary evidence that drinking 250 ml of water 20 minutes before performing a story memory task improved performance more than if less than 250 mls

were consumed. Correlations between the amount of water drunk and performance on the cognitive tasks were not significant.

In order to examine whether the subjective feeling of thirst measured at test accounted for group differences, a series of ANCOVAs were conducted that compared groups on each measures and covaried thirst scale scores. Subjective thirst was not found to covary with any of the measures of cognitive performance. The group effect remained significant in the case of both spot the difference tests (easy, $F(1,50) = 8.191$, $p = 0.006$; hard, $F(1,49) = 5.893$, $p = 0.019$), but the effect was weakened in the case of letter cancellation ($F(1,50) = 2.948$, $p = 0.092$). Group differences remained non-significant in the cases of story memory ($F(1,50) = .895$, *ns*) and visuomotor tracking ($F(1,44) = 1.873$, *ns*)

Discussion

Our findings suggest that consuming water benefits cognitive performance in children. The interpretation of these results leads to several additional questions and a number of avenues for further research. Children who had a drink of water during the test session performed significantly better on the letter cancellation task and both spot the difference tasks (easy and hard), but performance on the story memory and visuomotor tracking tasks was not affected by water consumption.

The finding that consuming water improved children's performance on tasks that require visual processing supports results reported by Bar-David et al. (2005) who reported trends in 10-12 year old children towards better hydration being associated with better performance on tasks involving processing of complex visual patterns. Previous research examining the relationship between dehydration in adults and cognitive

performance has found that the areas of perceptual discrimination, psychomotor skills, short term memory, and attention are affected by dehydration. In our study, perceptual discrimination and attention (letter cancellation and spot the difference tasks) were improved by having a drink of water, but the tasks that we used to assess psychomotor skills and short term memory were not affected. It may be that such areas are not affected by hydration status in children. Alternatively, it could be that while dehydration negatively affects performance, drinking water does not improve it.

It is also possible that the amount of water drunk may affect performance on tasks differently. In the sub-group analysis in which those children who drank 250 ml water were compared with those who drank less than 250 ml, the only significant effect was on short term story memory in which those who drank more performed better. Finding a statistically significant difference on the story memory task in these post hoc analyses was unexpected, because group differences between those in the additional water group and the no additional water group did not reach significance in the main analysis. Thus, these results require replication.

Some caution should be exercised when interpreting non-significant findings. It would be inappropriate to draw too strong an inference about the effect of water consumption on task performance from non-significant findings, such as story memory and visuomotor tracking, because the sample size may have been too small to detect real but weaker effects, or the measures may not have been the optimal measure of the cognitive process assessed. Comparing findings across studies can be difficult when different tasks are employed because "pure" tasks that assess only one cognitive function are extremely rare (if they exist at all). We plan to address these questions in future

research by further examining the specific cognitive processes affected by water consumption in children.

A further factor to be considered in future research is the interaction of thirst and water consumption on cognitive performance. Rogers et al. (2001) found that with no additional water, thirsty subjects performed worse than subjects with low thirst; a small amount of water (120 ml) resulted in no group differences; while a larger drink (330 ml) resulted in a drop in performance for non-thirsty subjects and an improvement in performance for those who were initially thirsty. The present study did not assess thirst levels both before and after water consumption (an omission that we plan to rectify in future studies), although we did explore whether the subjective feeling of thirst measured at test (approximately 20 minutes after water consumption) accounted for group differences. In our sample, we found that subjective thirst at test did not account for the group differences and group differences on both spot the difference tasks remained significant with thirst covaried. These findings suggest that some factor over and above thirst affected performance, and we suggest that it was water consumption. If, as Rogers et al.'s study suggests, thirst affects cognition, a further consideration is whether the mechanism is one of diverting attention from task performance or a result of a physiological effect of thirst on performance. Our data suggest that the principal mechanism is unlikely to be attentional because some group differences remained significant even when subjective thirst at test was accounted for. However, it should be noted that we did not measure thirst at baseline in this study. In future studies we plan to explore further the effect of thirst on cognition and the mechanisms underlying this effect.

A further factor that deserves consideration is whether these results may have been affected by the demand characteristics of the experiment. To put this more simply, did the children in the water condition think they were special and try harder? The finding that the effect of additional water had selective effects on cognitive ability suggests that this is unlikely, but we plan to address this in future research.

As discussed above, the cognitive tasks used in this study were selected because previous research has shown them to be affected by dehydration. A recent study that reported certain brain areas associated with subjective ratings of thirst may suggest other areas of cognition to explore further. McKinley et al.(2007) reported, in elderly participants, that thirst ratings were related to blood flow changes observed under positron emission tomography in particular brain areas. The identification of neuropsychological functions associated with these brain areas suggests areas for future research. Brain activation was related to thirst in the following areas (neuropsychological functions associated with these brain areas follow in parentheses): primary somatosensory (sense of touch); motor cortices (motor control and behaviour); prefrontal cortex (Executive Functions, including planning and inhibitory control); anterior cingulate cortex (emotions and decision making) and the superior temporal gyrus (auditory processing). It is possible that not all of these brain areas may be similarly activated in children under conditions of thirst, but this study does suggest some interesting new research directions.

In conclusion, the results of the present study suggest that even children in a state of mild dehydration, not induced by intentional water deprivation or by heat stress and living in a cold climate, can benefit from drinking more water and improve their

cognitive performance. More research is necessary both to confirm these findings and to further explore the relationship between drinking water and cognition in children.

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Table 1. Means (*M*), standard deviations (*SD*), and significance levels (*t*-tests) of scores on cognitive tasks by water group

Cognitive Task	No Additional water group		Additional water group		Independent t-test results
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Thirst Scale (max =1)	0.61	0.35	0.32	0.26	$t(39.8) = 2.26, p = .002$
Story Memory (max = 4)	2.83	1.29	3.19	0.96	<i>ns</i>
Letter Cancellation (max = 38)	29.27	5.9	32.44	4.55	$t(55) = 2.26, p = .028$
Spot the Difference - Easy (max = 3)	1.8	1.06	2.41	0.8	$t(55) = 2.42, p = .019$
Spot the Difference - Hard (max = 10)	3.83	1.05	4.73	1.49	$t(44.2) = 2.6, p = .014$
Visuo-motor tracking task (max = 38)	30.07	6.99	31.57	7.37	<i>ns</i>