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Drinking water enhances cognitive performance: positive effects on working memory but not long-term memory

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Abstract

Previous studies suggest that acute water drinking interventions enhance working memory, particularly digit span. The aims of the present study were two-fold. Firstly, to investigate whether the working memory enhancements extend to different components of working memory. Secondly, to evaluate whether drinking water would improve long term memory task performance. Seventy-four adult participants completed baseline tests and then either drank 300 ml water or nothing. They completed a thirst scale, two working memory tests (digit span and Corsi blocks) and two long term memory tests (picture recall and word recall). After this the water group was offered 300 ml water and the control group did not have a drink. Following a 20 minute interval the measures were repeated. The results showed that both working memory tests were improved by drinking water, but long term memory assessments were not affected. This study adds to the body of evidence that suggests that acute drinking interventions in adults enhance working memory, but not long term memory, and that it may not be restricted to particular components of working memory.

Keywords: water, memory, drinking, adults

Introduction

Previous work has demonstrated that acute water drinking interventions can enhance cognitive performance, for both children and adults, and in a range of different tasks (Benton & Young, 2015; Masento, Golightly, Field, Butler, & van Reekum, 2014). For example, visual attention - as measured by letter cancellation performance - has reliably been shown to improve after drinking amounts of water ranging between 25 ml and 500 ml (Booth, Taylor, & Edmonds, 2012; Edmonds, Crombie, & Gardner, 2013; Edmonds et al., 2017; Edmonds & Jeffes, 2009). Acute drinking interventions have also been shown to reduce subjective feelings of thirst (Edmonds & Burford, 2009; Edmonds, Crombie, Ballieux, Gardner, & Dawkins, 2013; Edmonds et al., 2017; Edmonds & Jeffes, 2009; Rogers, Kainth, & Smit, 2001). Such reductions in subjective thirst ratings after drinking have been linked to changes in cognitive performance. Adults' digit span has been reported to increase only after drinking an amount of water sufficient to also reduce subjective thirst (Edmonds et al., 2017). In contrast, visual attention improves after a very small drink, or mouth rinsing water, and these changes were not linked to subjective thirst changes (Edmonds et al., 2017; Edmonds, Harte, & Gardner, 2018; Edmonds, Skeete, Klamerus, & Gardner, 2021).

Many studies investigating cognitive enhancement after drinking water have focused on memory. Studies in children report that visual memory (Edmonds & Burford, 2009) and object recall (Benton & Burgess, 2009) improves approximately 20 to 30 minutes after drinking water ranging from 250 ml to 300 ml, but that memory for stories does not (Edmonds & Burford, 2009). Adults' word recall in participants who fasted overnight was unaffected by drinking either 150 ml water, or after a second 150 ml water drink (Neave et al., 2001), nor did it improve after drinking 300 ml water (150 ml on two occasions) during a dehydration protocol (Cousins, Young, Thomas, & Benton, 2019). Digit span is the most frequently studied memory task in the field of acute water drinking interventions. The task involves remembering lists of digit sequences that increase in length, and verbally repeating the digit sequence back, until the individual's maximum "span" is reached. In adults, digit span increases after drinking water (Edmonds et al., 2017), but only after a large drink (300 ml), and not a small drink (25 ml). In keeping with the claim that a larger volume of water is necessary to improve digit span, mouth rinsing (swilling and spitting water) does not improve span in either adults (Edmonds, Skeete, Klamerus, & Gardner, 2019) or children (Edmonds et al., 2018). Furthermore, drinking interventions that take place over longer periods of time have shown enhanced digit span. For example, increasing water drunk over a whole school day resulted in positive associations between the amount drunk and digit span performance in children (Fadda et al., 2012). Moreover, drinking that resulted in changes in hydration status over two hours improved digit span (Perry, Rapinett, Glaser, & Ghetti, 2015). Taken together, these findings suggest that adults' short term verbal span is enhanced by drinking water. Yet, the potential enhancement of different aspects of memory by drinking water has yet to be systematically explored in adults.

In the present study, the aims were two-fold. Firstly, we sought to evaluate whether the effect is observed in comparable working memory tasks in which different material is included. Thus, we included both digit span and working memory assessment, using visuospatial, rather than verbal material - the Corsi blocks task. This spatial span task requires participants to remember the positions of blocks that are identified in a particular sequence that increases in length until the spatial span is identified. Participants completed the span tests at baseline, and then either drank 300 ml water or no drink, and were reassessed 20 minutes later. Secondly, we assessed the impact of drinking on two comparable long term memory tasks that contain different material; a word recall and a picture recall task. Both involved recall after a filled interval. We hypothesised that drinking water would enhance performance in both memory span tasks (digit span and Corsi blocks). There is limited evidence to allow predictions about the effect on the recall tasks (word recall and picture recall). In line with previous studies, it was expected that drinking water would reduce feelings of thirst.

Material and Methods

Participants

The sample comprised 74 adults aged 18-65 years (26 males, 48 females). Participants were randomly assigned to either the water group (n=37, 27 female; mean age 39 years 3 months) or the control (n=37, 21 female; mean age 39 years 11 months). This sample size was chosen to be match and slightly exceed those used in similar previous work (Edmonds et al., 2017, 2018, 2021).

Measures

Thirst Scale

The thirst visual analogue scale comprised a horizontal line with anchors labelled as “Not thirsty at all” and “Very thirsty”. Participants marked the line at a point that indicated their level of thirst and scores were converted to percentages. A higher score indicated higher subjective thirst.

Digit Span

A series of digits were read aloud at the rate of one digit per second and participants were asked to repeat them in the same order. Sequences increased in length by one digit; two sequences of each length were presented, up to a maximum of ten, until the participant was unsuccessful in recalling both trials of the same length. The maximum score was ten and a higher score indicates a longer span.

Corsi Blocks

The Corsi blocks test uses a wooden board (20 x 25 cm) with nine 2 cm square wooden blocks glued on top (De Renzi & Nichelli, 1975). Numbers were positioned on the back of the blocks only visible to the experimenter. Pre-determined sequences are tapped out on top of the blocks at a rate of one block per second and the participant repeats the sequence. The sequence length increased successively by one block, up to a maximum of 10 blocks; two sequences at each length were tested, until the participant was unsuccessful in reproducing both sequences of the same length. The maximum score was ten.

Word Recall

A pre-recorded list of 15 unrelated words was played to participants. The word lists were obtained from Rey's Auditory Verbal Learning Test (Rey, 1964). Words were presented at a rate of one word every two seconds. For recall, participants were asked to say out loud as many words as they could remember. The maximum score was 15.

Picture Recall

An A4 sheet with 20 images was presented to the participant; these included common items such as sunglasses and modes of transport. Participants were given one minute to study them and told they would subsequently be removed and they would be asked questions about the images. For example, one image was a pair of sunglasses with purple frames, and the question associated with that image was "What colour were the frames of the sunglasses?". At recall, there were ten questions about the images and answers were scored as correct or incorrect. The maximum score was 10.

Procedure

Ethical approval was obtained by University of Westminster Psychology Ethics Committee. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Participants were told that the study was about effects of drinking water on memory. They completed the scales and tests in the following order: thirst scales, word recall, digit span, corsi blocks and picture recall. They were then offered either 300 ml water (water group) by the researcher administering the tests, or nothing (control). All those assigned to the water group drank all of the 300 ml, within one or two minutes. A 20 minute interval followed, after which the thirst scales were repeated, followed by parallel forms of the memory tests. Parallel forms were used and the order of these was counterbalanced. After completing the study, participants were debriefed.

Statistical Analysis

A series of mixed model 2x2 ANOVAs (TIME x GROUP) was conducted on each outcome variable. Planned follow up tests comparing baseline and test scores in each group were carried out after a significant interaction. The Bonferroni correction for multiple tests was employed and the alpha level set at 0.025 (0.05/2 comparisons).

Results

All of the participants in the water group drank all of the water offered. All participants completed each test and no cases were excluded. There were no significant group differences at baseline on any measure (Thirst, $t(72) = 1.19$, $p = 0.239$; Digit Span, $t(72) = 1.24$, $p =$

0.218; Corsi blocks, *t*(72) = 0.12, *p* = 0.909; Picture recall, *t*(72) = 0.83, *p* = 0.407; Word recall, *t*(72) = 1.41, *p* = 0.163).

Data presented in Table 1 show mean scores and standard deviations for all outcome measures by group and time of test.

Table 1. Means and standard deviations for all outcome measures by group and time of test

Outcome measure	Water Group (n=37)				Control group (n=37)				Direction of effect
	Baseline		Test		Baseline		Test		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Thirst	58.49	20.02	35.22	18.56	53.11	18.95	58.08	24.27	-
Digit Span	7.00	1.03	7.54	0.96	7.35	1.38	7.35	1.16	+
Corsi Blocks	6.19	1.08	6.86	1.13	6.22	0.95	6.05	0.88	+
Word Recall	5.14	2.12	5.05	2.30	5.89	2.48	5.12	2.04	ns
Picture Recall	5.16	1.86	6.11	1.98	4.81	1.76	5.32	1.45	ns

Thirst

Subjective thirst scores show a main effect of time of test, $F(1,72) = 18.76$, $p < 0.001$, $\eta_p^2 = 0.207$, and a significant interaction between time of test and group, $F(1,72) = 44.69$, $p < 0.001$, $\eta_p^2 = 0.383$. Planned follow up test showed that this was a result of a significant decrease in subjective thirst for those who drank water, $t(36) = 6.03$, $p < 0.001$, and a significant increase in thirst for those in the control group, $t(36) = 2.88$, $p = 0.007$. The main effect of group was not significant, $F(1,72) = 4.15$, $p = 0.054$, $\eta_p^2 = 0.054$.

Digit Span

Digit span scores were significantly higher at test than baseline, $F(1,72) = 8.61$, $p = .004$, $\eta_p^2 = 0.107$, but this increase was moderated by the intervention, with a significant interaction, $F(1,72) = 8.61$, $p = 0.004$, $\eta_p^2 = 0.107$. Those who drank water had an increase in digit span after drinking $t(36) = 4.50$, $p < 0.001$, but scores for those in the control group did not change $t(36) = 0.00$, $p = 1.00$. The main effect of group was not significant, $F(1,72) = 0.11$, $p = 0.746$, $\eta_p^2 = 0.001$.

Corsi Blocks

Performance on the Corsi blocks task also showed a main effect of time, $F(1,72) = 5.32$, $p = 0.025$, $\eta_p^2 = 0.068$, with an increase in scores from baseline to test. This should be interpreted in the light of the significant interaction, $F (1,72) = 13.93$, $p < 0.001$, $\eta_p^2 = 0.162$. The water group showed an improvement in spatial span over time, $t(36) = 4.10$, $p < 0.001$, but the control group did not, $t(36) = 1.06$, $p = 0.295$. The main effect of group was not significant, $F(1,72) = 3.57$, $p = 0.063$, $\eta_p^2 = 0.047$.

Picture Recall

Picture recall scores were lower at test compared to baseline, $F(1,72) = 11.30$, $p < .001$, $\eta_p^2 = 0.136$. Neither the main effect of group, $F(1,72) = 2.61$, $p = 0.111$, $\eta_p^2 = 0.035$, nor 0the interaction were significant, $F(1,72) = 0.99$, $p = 0.323$, $\eta_p^2 = 0.014$.

Word Recall

For word recall, there was no significant effect of time of test, $F(1,72) = 2.86$, $p = 0.095$, $\eta_p^2 = 0.038$, nor group, $F(1,72) = 0.80$, $p = 0.375$, $\eta_p^2 = 0.011$, nor was the interaction significant, $F(1,72) = 1.88$, $p = 0.174$, $\eta_p^2 = 0.026$.

Discussion

Our results show, in line with other studies, that digit span is improved after drinking water (Edmonds et al., 2017, 2019; Fadda et al., 2012; Perry et al., 2015). Our other memory span test, the Corsi blocks spatial span, showed the same pattern of findings as that observed for digit span. Practice was ruled out as an explanation for these effects because improved performance was restricted to those drinking water, and not to the control group. In contrast, our other two memory assessments - picture recall and word recall - were not affected by drinking water. In addition, as expected, subjective thirst ratings decreased in those who drank water and increased in those who did not. These findings are summarised in Table 1. Our findings support the interpretation that, in adults, working memory is enhanced by drinking water over a short time period, while long term memory is not. The present study provides novel evidence that this finding extends to spatial working memory.

Working memory performance is known to be affected in two broad ways – by pre-occupying thoughts and by biological processes (Blasiman & Was, 2018) – either of which may potentially offer an account for the current enhancement effects. Preoccupying thoughts has been proposed as an explanation for effects on working memory caused by a range of acute emotional and motivational stressors such as anxiety (Elliman, Green, Rogers, & Finch, 1997), dieting (Green et al., 2003), and cravings (Greenstein & Kassel, 2009). According to this account, preoccupying thoughts about the stressor compete for limited capacity working memory resources during testing, thus disrupting performance on tasks measuring working memory. In the current study, consuming water reduced subjective thirst, so one might speculate that this also may have alleviated for the Water group any preoccupying thoughts about feeling thirsty that may have suppressed working memory performance. However, the enhancement found for spatial working memory is incompatible with this account because preoccupying thoughts have consistently been found to disrupt selectively the phonological loop rather than visuospatial sketchpad, presumably due to subvocal rehearsal of the thoughts (Elliman et al., 1997; Green et al., 2003; Greenstein & Kassel, 2009).

Our results may be better explained by physiological responses to drinking that modulate performance dependent upon cognitive load. Along these lines, it is well established that consuming glucose has fast, time limited enhancement effects, that are more pronounced under high load (Scholey, Harper, & Kennedy, 2001), with positive effects on both verbal and spatial tasks (Owen, Scholey, Finnegan, Hu, & Sünram-Lea, 2012). While glucose metabolism clearly provides cells with fuel, the physiological responses to water ingestion that facilitate cognitive performance under load are less obvious. A recent proposal suggests these could be indirect consequences of normal homeostatic mechanisms (Benton & Young, 2019). Drinking a large glass of water (500ml) affects cardiovascular function, specifically an increase in heart rate variability (HRV) that peaks 20 – 25 minutes after drinking, coupled with an increase in sympathetic vasoconstrictor activity (Routledge, Chowdhary, Coote, & Townend, 2002). Crucially, regions of the prefrontal cortex implicated in working memory function (Brunoni & Vanderhasselt, 2014) are part of the central autonomic network mediating changes in HRV (Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012). Recent research has shown that drinking water leads to corresponding changes in cardiovascular and autonomic function measured by heart rate variability, and brain activity measured by fMRI during a demanding task (Young, Cousins, Johnston, Fletcher, & Benton, 2019). However, similar effects have yet to be examined for working memory.

In contrast to the effects of drinking on working memory, performance on two long term recall tasks was not improved after drinking water. There are limited published data on the effects of drinking on long term memory, with one study in children showing an acute effect of drinking on picture recall (Benton & Burgess, 2009), but two showing no effect on adults' word recall (Cousins et al., 2019; Neave et al., 2001). Firm conclusions about the question of whether acute drinking water interventions enhances long term memory cannot be made on the basis of just three studies (and only two in adults), but here we consider why there may be conflicting findings. Firstly, it is possible that the parameters of the procedures used are not optimal to enhance long term memory in adults. For example, 300 mls water may not be sufficient, or that the interval between drinking and test was too short, or too long. While children's long term picture recall improved between 20 to 35 minutes after drinking 300 ml water (Benton & Burgess, 2009), it is possible that 300 ml may be insufficient to enhance performance in adults, given their larger body size and associated increased water demands (European Food Safety Authority (EFSA), 2010). Finding that there was no effect on adults' word recall after drinking 150 ml water following an overnight fast (Neave et al., 2001) might suggest that this amount is not sufficient for thirsty adults. Secondly, it is possible that drinking water does not reliably enhance long term memory. These alternatives can be teased apart by further empirical work that systematically manipulates task design parameters.

There are some strengths and some limitations of the present study. The tasks employed in the present study were pencil and paper tests. There are advantages to this method of administration; For example, it is easy to assess participants in different locations and these tasks are well reported in the literature. However, pencil and paper tests do not allow for speed of response to be measured, and reaction time has previously been reported to improve after drinking water (Edmonds, Crombie, & Gardner, 2013; Ganio et al., 2011).

Studies that offer water as an intervention are not able to offer a placebo as control and it is thus difficult to blind participants to the study aims. When examining performance effects of a drink such as coffee, blinding is relatively straightforward because the active ingredient of interest (caffeine) can be isolated, and caffeinated or decaffeinated versions offered (Fillmore & Vogel-Sprott, 1992; Lotshaw, Bradley, & Brooks, 1996). This is difficult with water, but one study has tried to address this by independently manipulating water ingestion, and expectancy about the effects of drinking water (Edmonds, Crombie, Ballieux, et al., 2013). This revealed that drinking water impacted positively on cognitive performance, but the expectancy did not. While blinding would be good practice, these findings imply that expectancy effects are not a serious issue.

Moreover, the physiological response of males and females to water ingestion may be different. There are different water demands by sex, some of which is related to differences in body size (Jéquier & Constant, 2010). Some suggest that studies assessing the effect of changes in hydration status on performance use single sex samples (Claybaugh, Sato, Crosswhite, & Hassell, 2000; Stachenfeld et al., 2001). However, the amount of water offered to participants in our study is unlikely to cause large differences in hydration status, and thus our results are unlikely to have been affected by sex differences in hydration.

Finally, we consider what the real world applications of these findings might be. If a small drink of 300 ml water - approximately a large cup - can improve working memory, then water ingestion may result in enhancement of various abilities drawing on working memory. This could include tests at school, given links between working memory and scholastic attainment in English, Maths and Science (St Clair-Thompson & Gathercole, 2006), and evidence that working memory plays a role in various aspects of mental arithmetic (DeStefano & LeFevre, 2004; Raghubar, Barnes, & Hecht, 2010) and language comprehension (Daneman & Merikle, 1996). Working memory has also been shown to be crucial for situation awareness during driving (Johannsdottir & Herdman, 2010), and the control of focused attention enabling the ability to ignore distractions (de Fockert, Rees, Frith, & Lavie, 2001). In conclusion, this study adds to the body of evidence that suggests that acute drinking interventions in adults enhance working memory, but not long term memory, and that it may not be restricted to particular materials to be remembered.

Declarations

Ethics Approval

Ethical approval was obtained by University of Westminster Psychology Ethics Committee. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Funding

No funding was received for conducting this study.

Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Consent for publication

Informed written consent was obtained for each participant.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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