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Research report

Water consumption, not expectancies about water consumption, affects cognitive performance in adults ☆

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ABSTRACT

Research has shown that water supplementation positively affects cognitive performance in children and adults. The present study considered whether this could be a result of expectancies that individuals have about the effects of water on cognition. Forty-seven participants were recruited and told the study was examining the effects of repeated testing on cognitive performance. They were assigned either to a condition in which positive expectancies about the effects of drinking water were induced, or a control condition in which no expectancies were induced. Within these groups, approximately half were given a drink of water, while the remainder were not. Performance on a thirst scale, letter cancellation, digit span forwards and backwards and a simple reaction time task was assessed at baseline (before the drink) and 20 min and 40 min after water consumption. Effects of water, but not expectancy, were found on subjective thirst ratings and letter cancellation task performance, but not on digit span or reaction time. This suggests that water consumption effects on letter cancellation are due to the physiological effects of water, rather than expectancies about the effects of drinking water.

Introduction

This paper contributes to the growing literature on the effects of hydration on cognitive performance. The aims of this study were twofold. Firstly, we examined an alternative explanation for the reported positive effects of water supplementation on cognition, namely that individuals may perform better after having a drink of water because they expect to do so. Secondly, we investigated the time-course of the effect, by exploring whether the positive effects are observed at both 20 and 40 min post water consumption.

Hydration status has been shown to affect cognitive performance. For instance, dehydration has well established negative effects on cognitive performance (see Edmonds, 2012, for a - review). In adults, dehydration to a loss of more than 2% body weight, induced by heat exposure or exercise, results in poor performance on tasks assessing memory and psychomotor performance (Gopinathan, Pichan, & Sharma, 1988; Sharma, Sridharan, Pichan, & Panwar, 1986); although see Secher and Ritz (2012) for a discussion of methodological limitations. Subjective feelings of concentration and alertness are also negatively affected (Armstrong et al., 2012; Shirrefs, Merson, Fraser, & Archer, 2004; Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005). Similarly, in children, dehydration negatively affects performance on memory tasks (Bar-David, Urkin, & Kozminsky, 2005; Fadda et al., 2012). Furthermore, there is a growing body of evidence that water supplementation has positive effects on cognition. In children, supplementing with water results in improved performance on tests of memory and attention (Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). In adults, it has been shown that thirsty individuals perform better on a rapid visual information processing task after having a drink (Rogers, Kainth, & Smit, 2001; although see Neave et al., 2001). An unresolved interpretative issue is that either water consumption and/or the participant expectations about water consumption could contribute to the water supplementation effects. Thus, water consumption could potentially have a psychological effect on performance, instead of an influence mediated by hydration status. One aim of the present study was to assess this alternative explanation.

Indeed, many studies have demonstrated that expectancies about the effects of a substance influence an individual's behaviour or cognition. This is the case in the literature on alcohol (Leigh & Stacy, 1991), nicotine (Keleman, 2008) and caffeine (Dawkins, Shahzad, Ahmed, & Edmonds, 2011; Fillmore & Vogel-Sprott, 1992; Lotshaw, Bradley, & Brooks, 1996). For example, in the case of caffeine, consuming caffeine and having the expectation of having consumed caffeine, both improved attention and psychomotor speed (Dawkins et al., 2011). Given that the placebo or

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'expectancy' effect can be observed with many other substances, it is therefore possible that similar phenomena may occur with respect to water consumption.

In the case of water consumption, participants' knowledge of the aims of the study might elicit demand characteristics or a response expectancy because those consuming water may expect to do better and inadvertently try harder. Our main aim therefore is to explore the effects of water and expectancy using the balanced placebo design in which half of the participants are given water and half are not, and their expectancies about its effects are manipulated. Unlike other psychoactive ingested substances such as caffeine, it is not possible to give water and mislead participants about some crucial aspect of that substance (there are no hydrating and non-hydrating waters). Therefore, within the two study groups (water and no water), half were provided with verbal information about the beneficial effects of water on cognitive performance (expectancy group), while the remainder were given no such information (no expectancy group). A secondary aim was to evaluate the length of the water supplementation effect, and to that end, participants were tested at baseline, 20 and 40 min post consumption.

Methods

Participants

Forty-seven participants aged 18–57 years (15 male) were recruited from staff and students at the University of East London and friends of the researchers. Three participants from the WATER condition did not consume water (one from the EXPECTANCY condition and two from the NO EXPECTANCY condition). Data from these participants were excluded from all of the following analyses. Therefore, the total N for analyses was 44 and they were distributed in the following way: 9 in the no water, no expectancy condition (3 male; Age: $M = 30.7$ years, range 19–53 years); 11 in the no water, expectancy condition (6 male; Age: $M = 30.9$ years, range 19–51 years); 14 in the water, no expectancy condition (5 male; Age: $M = 29.1$ years, range 18–54 years) and 10 in the water and expectancy condition (1 male; Age: $M = 27.0$ years, range 18–57 years).

Tasks

Tests of cognitive performance were selected that have been shown to be sensitive to the effects of water supplementation in previous studies (Booth & Edmonds, 2012; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009; Fadda et al., 2012).

Thirst

Participants were presented with a horizontal line with the label 'not thirsty at all' at the far right and 'very thirsty' at the far left with appropriate illustrations at either end (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). They were required to mark the line to indicate how thirsty they were feeling. A higher score indicated higher subjective thirst.

Memory – digit span forward

Participants were read a list of numbers and were asked to repeat them in the same order. The to-be-remembered list of numbers increased by one digit every second sequence until the participant failed to accurately recall them on two consecutive trials of the same length. A higher score represented a larger span.

Memory – Digit span backward

The same procedure was followed as described for digit span forwards but in this version, participants were asked to recall the digits in reverse order. A higher score represented a longer backwards span.

Visual attention – Letter cancellation

Participants were required to cross through target letters (e.g. U) in a 20×20 grid containing non-target letters (e.g. C, D, O and V), as fast as they could. They were stopped at 20 s and the score was the number of correctly identified letters.

Simple reaction time

A simple reaction time task from the Cambridge Neuropsychological Test Automated Battery (CANTAB) was administered. In this task, participants press a button using their dominant hand to respond rapidly to a square presented on the screen. The interval between the squares varied so as to be unpredictable.

Mood

Mood was measured using the Visual Analog Mood Scales (VAMS) (Stern, 1997). This is a self report rating of eight moods: Afraid, Confused, Sad, Angry, Energetic, Tired, Happy and Tense.

Procedure

The study design and procedure is shown in Fig. 1. Participants were told that the study was about the effects of repeated testing on cognitive performance. After consent had been taken and background information collected, the expectancy manipulation was introduced. Participants in the EXPECTANCY condition, were told the following:

> "It is commonly believed that water aids cognitive performance in all areas. Our previous research has certainly showed that this is the case. We tested students twice on two separate occasions on a number of different cognitive tasks, once where they had a drink of water beforehand and once when they did not. We found that participants always did better on the occasion when they had drunk water before starting the tasks. Our research adds to the findings in the literature that also report the beneficial effects of drinking water on cognitive performance. We are therefore also interested to look at the effects of drinking water on cognitive performance over time to see how long the effects are sustained."

If they were in the WATER condition, they were then told, "Today you are in the water condition and will be invited to have a drink of water shortly."

If they were in the NO WATER condition, they were told, "Today you are in the no water condition."

Participants in the NO EXPECTANCY + WATER condition were given a drink of water without being alerted to its connection with the study. For these participants, the researcher said, "I just need to get something from my office" and returned with two cups of water. The researcher drank the water, with the aim that the participant would do the same. For both WATER conditions, participants were given 200 ml water; any remaining fluid was measured after debriefing in order to calculate how much the participant consumed. The experimenter ran through the procedure in the order outlined in Fig. 1. Participants were tested at baseline, 20 min post water consumption (Test 1) and 40 min post water

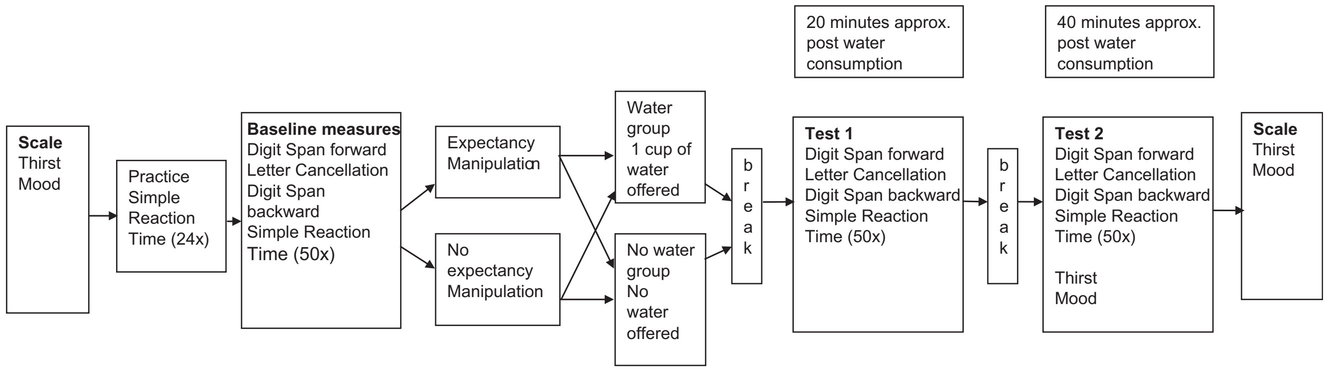

Fig. 1. Visual representation of study procedure.

consumption (Test 2); previous research has shown positive effects on cognition at these durations post consumption (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). The majority of the participants were tested in the afternoon and they were all tested in the same room (although they were tested individually). At the end of the study, participants were debriefed, told the real aims of the study, and given the opportunity to ask questions.

The study was approved by the University of East London's ethics board. All participants consented prior to taking part in the study. After completion, all of the participants were told of the real aims of the study, given the opportunity to ask questions, and were given a debriefing sheet.

Statistical analysis

The primary aim was to investigate the relative contribution of expectations about water and water consumption on changes in cognitive performance from baseline to Test 1 and Test 2. A series of mixed model ANOVAs (TIME × EXPECTANCY × WATER) were conducted for each outcome variable. If WATER or EXPECTANCY showed a change over TIME, then these analyses were followed up by analyses of change scores. These follow up analyses used ANOVA to examine change scores from Baseline to Test 1 and Baseline to Test 2 (Test 1 minus Baseline and Test 2 minus baseline), by water and expectancy conditions. Thirst and mood scores were measured only at Baseline and Test 2, so the analyses for these variables was a mixed model ANOVA (TIME × EXPECTANCY × WATER).

Results

Water consumption

Participants in the WATER condition consumed a mean 167 ml water ($SD = 82.72$). Those in the EXPECTANCY condition consumed a *mean* 165 ml ($SD = 24.15$); a similar amount to those in the NO EXPECTANCY condition, who consumed a *mean* of 167.86 ml ($SD = 108.16$). There was no statistically significant difference in the amount drunk between expectancy groups, $t(14.77) = .096$, $p = .925$.

Rating of subjective thirst

Data presented in Table 1 show mean and standard deviations for subjective ratings of thirst at baseline and Test 2 (thirst was only measured at these two time points). These data appear to show that, for those individuals in the WATER condition, there was a reduction in thirst from Baseline to Test 2, but those who were not supplemented showed an increase in ratings of subjective thirst. These impressions were supported by a significant TIME × WATER interaction, $F(1, 40) = 16.79$, $p < .001$. There were no other main effects or interactions. Follow up paired *t*-tests showed that thirst ratings increased significantly over time for those who did not receive any water, $t(22) = 3.22$, $p = .005$, and decreased significantly for those who did have a drink, $t(19) = 3.86$, $p = .001$.

Cognitive tests

Data presented in Table 2 show mean and standard deviations for each cognitive test at each time point and by condition. Visual inspection of these data suggests that letter cancellation scores appear to show a greater increase in the water condition compared to the no water condition. Forward digit span scores show little improvement over time and backward digit span scores and reaction time show an inconsistent pattern over time and conditions.

For letter cancellation, there was a significant main effect of TIME, $F(1, 39) = 41.72$, $p < .001$, with overall scores increasing at each time point. There was also a significant TIME × WATER interaction, $F(1, 39) = 5.49$, $p = .024$. To follow up the significant TIME × WATER interactions, difference scores analyses were conducted. Fig. 2 shows letter cancellation Test 1-baseline and Test 2-baseline difference scores for EXPECTANCY and WATER variables. The data presented suggest greater improvement if water was consumed, and that this was the case at both time points, regardless of EXPECTANCY condition. These impressions were supported by the analyses. The Test 1-baseline analyses showed that the difference score was greater in the WATER condition compared to the NO WATER condition, $F(1, 40) = 4.78$, $p = .035$. There was no effect of EXPECTANCY and no interaction; in both cases $F < 1$. In the Test 2-baseline analysis, there was a main effect of WATER, $F(1, 40) = 6.20$, $p = .017$, and no other main effects or interactions. These results suggest that the water consumption effect lasted until Test 2, approximately 40 min post water consumption.

The analysis of Digit Span Backwards showed a significant main effect of TIME, $F(1, 39) = 26.29$, $p < .001$, with scores generally increasing over the time points, and this interacted with water, TIME × WATER, $F(1, 39) = 6.86$, $p = .012$. Follow up analyses of the TIME × WATER interaction examined difference scores. In the case of Test 1-Baseline scores, neither the main effect of WATER, $F(1, 42) = 1.47$, $p = .233$, nor EXPECTANCY, $F(1, 40) = .025$, $p = .88$, nor the interaction, $F(1, 42) = 1.054$, $p = .311$, were statistically significant. The TIME main effect and interactions observed in the raw score analysis were due to an effect at Test 2; difference score analysis showed a main effect of WATER, $F(1, 40) = 6.38$, $p = .016$, counter-intuitively, with a larger improvement in scores for those who had NO WATER.

Digit span forwards scores showed a significant WATER × EXPECTANCY interaction, $F(1, 39) = 41.72$, $p < .001$, indicating that, overall, scores were higher for those in the Water & No

Table 1
Means and standard deviations for subjective ratings of thirst at baseline and Test 2 for expectancy and water groups.

Water condition	Expectancy condition									
	Expectancy					No Expectancy				
		Baseline		Test 2			Baseline		Test 2	
	n	*M*	*SD*	*M*	*SD*	*n*	*M*	*SD*	*M*	*SD*
Water	10	**9.93**	5.14	**7.63**	5.45	14	**10.37**	3.75	**6.56**	4.73
No water	11	**8.39**	4.81	**10.70**	4.06	9	**9.68**	4.68	**11.40**	3.76

Note: Thirst ratings decreased significantly from baseline to test for those in the water condition ($n = 24$), and increased significantly for those in the No water condition ($n = 20$). For further details see the results section.

Table 2
Means and standard deviations for all cognitive tests at baseline, Test 1 and Test 2 for expectancy and water groups.

Task	Water condition	Expectancy condition													
		Expectancy							No Expectancy						
			Baseline		Test 1		Test 2			Baseline		Test 1		Test 2	
		n	*M*	*SD*	*M*	*SD*	*M*	*SD*	*n*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Letter cancellation	Water	10	**16.6**	3.34	**20.80**	4.16	**20.20**	5.31	14	**16.92**	3.88	**22.00**	3.24	**24.08**	4.19
	No water	11	**20.73**	4.54	**22.64**	3.83	**23.09**	5.30	9	**20.22**	7.14	**23.22**	6.82	**22.89**	7.01
Forward digit span	Water	10	**5.90**	1.10	**5.70**	1.16	**5.70**	.95	14	**6.43**	.94	**6.71**	1.38	**6.50**	1.35
	No water	11	**6.27**	1.01	**6.36**	.81	**6.45**	9.3	9	**5.44**	.73	**6.33**	.87	**5.78**	.67
Backward digit span	Water	10	**4.30**	.82	**4.30**	.68	**4.80**	1.40	14	**4.40**	.96	**4.77**	1.56	**4.54**	1.05
	No water	11	**4.09**	.83	**4.82**	1.99	**5.00**	.71	9	**3.89**	.60	**4.33**	1.10	**5.00**	1.10
Simple reaction time mean	Water	10	**228.12**	28.55	**248.88**	35.59	**243.92**	27.85	14	**228.12**	28.55	**236.24**	32.84	**231.78**	36.00
	No water	11	**211.56**	14.86	**217.99**	23.36	**222.89**	19.77	9	**226.66**	52.99	**222.42**	22.44	**231.70**	47.83

Note: When analysing changes in scores over time, there were two findings of note. Letter cancellation difference scores (Test 2 – baseline and Test 1 – baseline) were significantly larger in the group that consumed water compared to those who did not; there were no effects of expectancy. Digit Span Backwards difference scores (Test 2-baseline) were significantly larger in those who did not consume water, compared to those who did; there were no effects of expectancy. For further details see the Results section.

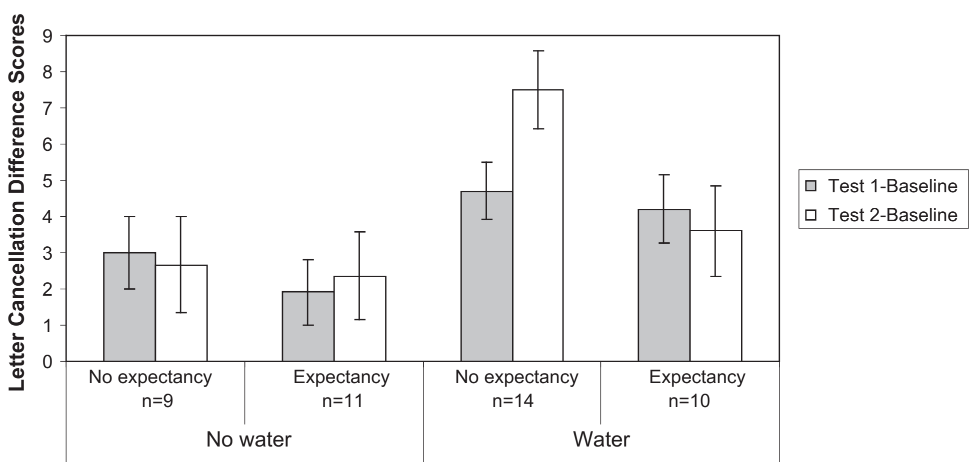

Fig. 2. Mean letter cancellation difference scores (±SE) from baseline to Test 1 and baseline to Test 2 by WATER and EXPECTANCY.

Expectancy and No Water and Expectancy conditions, than in the other two conditions. There were no significant main effects or interactions for reaction time. This was the case when either median or mean RTs were analysed.

Analyses including age as a covariate

Our sample had a wide age range and in order to investigate whether age influenced the results, we repeated the difference score analyses and included age as a covariate. In no case was age a statistically significant covariate. For thirst scores, the main effect of WATER remained significant, $F(1, 39) = 15.469$, $p < .001$, with those who were supplemented with water showing the greatest difference in thirst ratings from baseline to test (Age, $F(1, 39) = .002$, $p = .963$). The results for Backward Digit Span were also replicated; in the analysis of Test 2-baseline difference scores, there was a main effect of WATER, $F(1, 39) = 5.66$, $p = .022$ (Age, $F(1, 39) = .930$, $p = .341$) and in this analysis also, the bigger difference was in the group who were not supplemented. In the analyses of letter cancellation difference scores, the effects of WATER were replicated: Test 1 – baseline, $F(1, 39) = 5.04$, $p = .031$ (Age, $F(1, 39) = .49$, $p = .490$); Test 2 – baseline, $F(1, 39) = 5.81$, $p = .021$ (Age, $F(1, 39) = .052$, $p = .822$). In both cases, those participants who were supplemented with water showed the bigger difference in scores over time.

Mood scores

Mood scores by WATER, EXPECTANCY and TIME (baseline and Test 2) are shown in Table 3. The analysis revealed that

Table 3
Means and standard deviations for mood scores at baseline and Test 2 for expectancy and water groups.

Mood	Water condition	Expectancy condition									
		Expectancy					No expectancy				
			Baseline		Test 2			Baseline		Test 2	
		n	*M*	*SD*	*M*	*SD*	*n*	*M*	*SD*	*M*	*SD*
Afraid	Water	10	**1.82**	2.41	**1.06**	1.44	14	**1.43**	1.75	**.88**	.94
	No water	11	**1.04**	1.61	**.82**	1.28	9	**2.32**	2.59	**1.89**	3.06
Confused	Water	10	**2.07**	2.49	**1.09**	1.03	14	**2.10**	2.18	**1.25**	1.20
	No water	11	**.95**	1.38	**1.06**	1.45	9	**2.38**	2.08	**1.70**	2.09
Sad	Water	10	**1.63**	2.96	**.68**	.68	14	**1.12**	1.28	**.74**	1.12
	No water	11	**.72**	1.44	**.81**	1.42	9	**1.36**	2.13	**1.40**	3.05
Angry	Water	10	**.72**	.85	**.41**	.60	14	**.69**	.90	**.84**	1.77
	No water	11	**.53**	.95	**.61**	.88	9	**1.51**	2.59	**1.17**	3.09
Energetic	Water	10	**4.76**	3.19	**3.96**	3.34	14	**4.27**	2.42	**3.78**	2.52
	No water	11	**4.68**	2.74	**3.67**	3.40	9	**3.69**	2.60	**3.14**	2.38
Tired	Water	10	**5.43**	2.29	**5.80**	3.09	14	**3.87**	2.75	**3.46**	2.99
	No water	11	**3.42**	2.42	**4.29**	2.50	9	**3.89**	3.53	**4.02**	3.99
Happy	Water	10	**5.77**	3.33	**6.15**	3.62	14	**5.44**	3.02	**6.02**	2.99
	No water	11	**6.86**	3.54	**6.62**	3.44	9	**6.04**	3013	**6.42**	3.16
Tense	Water	10	**3.03**	3.73	**1.34**	1.50	14	**1.34**	1.34	**2.28**	2.56
	No water	11	**.79**	.82	**1.55**	1.50	9	**1.72**	1.72	**.93**	1.39

Note: Participants rated themselves as significantly less Confused and Energetic at Test 2 compared to baseline; there were no effects of expectancy. For ratings of Tense, there was a three way interaction (TIME × WATER × EXPECTANCY). For further details see the Results section.

participants rated themselves as less confused, $F(1, 39) = 4.84$, $p = .034$, and less energetic, $F(1, 39) = 5.87$, $p = .020$, at Test 2 compared to baseline. In the case of Afraid, Sad, Angry, Tired and Happy, there were no significant main effects or interactions. There was a significant three-way TIME × WATER × EXPECTANCY interaction for Tense, $F(1, 39) = 9.23$, $p = .004$; this is difficult to interpret because all four conditions have different baseline ratings.

Discussion

This study is the first to examine alternative explanations for the effects of water supplementation on thirst and cognition. We found positive effects of water consumption on both ratings of subjective thirst and performance on a visual attention task (letter cancellation). In the case of subjective ratings of thirst, those who received water showed a greater decrease in thirst ratings from Baseline to Test 2 compared to those who did not receive water. In the case of visual attention, the results show that the water group showed greater elevation from baseline to Test 1 and to Test 2 than those in the no water group. Positive effects of water consumption were not found for any of the other variables and, importantly, in no case did the analyses show that the expectancy manipulation about the effect of water consumption on cognition moderated the effect of water consumption on performance.

Visual attention appears particularly sensitive to water supplementation. Previous studies have shown that water supplementation leads to improved letter cancellation performance in children (Booth & Edmonds, 2012; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). This is the first study to show effects of water supplementation on letter cancellation performance in adults. Letter cancellation is not a process-pure task and involves visual attention, speeded processing and speeded responding. The present study did not find an effect of water supplementation on reaction time performance. Thus, this may suggest that speeded *responding* is not the component of letter cancellation task performance affected by water consumption. Instead, it is possible that the speeded *processing* or the attention required by this task is hydration–sensitive. This could be formally tested by examining the effect on a processing speed task such as inspection time (Deary, 1994; Edmonds et al., 2008) or by including other visual attention tasks.

Furthermore, this study found that water supplementation improved performance on our visual attention task at both 20 and 40 min post consumption. Previous studies have found that water supplementation improves children's performance on a visual attention task at 20 min (Edmonds & Burford, 2009) or 40 min (Edmonds & Jeffes, 2009) post-supplementation. This is the first study to test at more than one time point post-supplementation, and suggests that the positive effect is maintained over the whole 40 min. There is no evidence from the current study that performance improves further, or diminishes, between 20 and 40 min. Further research should extend the interval between supplementation and test in order to test the boundaries of the effect. This is particularly important for the applied nature of this research, for example, in order to make recommendations about how far in advance of an exam or important meeting water should be consumed to influence performance optimally.

There was an unexpected result observed in the scores on backwards digit span indicating that the no water group showed a greater elevation in performance from baseline to Test 2 than the supplemented group. This could be an idiosyncrasy of the current group, and should be a focus for replication. However, D'Anci, Constant and Rosenberg (2006) suggest that some of the counter-intuitive effects of hydration status on cognition may be expected because physiological processes can have either excitatory or inhibitory effects on cognition (see Edmonds, 2012 for a discussion). According to this account, one would predict that some processes may be impeded by water consumption, while others are aided.

In the present study, water supplementation was not found to impact on subjective ratings of mood. This is surprising because previously mood has been reported to be affected by hydration status. For example D'Anci et al. (2009) found that dehydration was associated with higher ratings of anger, fatigue, depression, tension and confusion, and lower levels of vigour. It is possible that the measure chosen is not sensitive to hydration status. It is reassuring however, that in our study, ratings of confusion decreased over the test period.

It could be argued that the relatively small sample size is a limitation of the present study. However, statistically significant group differences were found on some measures, suggesting that the sample size was adequate in those cases. For example, performance on the letter cancellation task would appear to be particularly sensitive to water supplementation (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). It is possible, however, that statistically significant group differences may have been observed in performance on other tasks if the sample size were larger; this can be addressed in future studies. Future studies should also include a different, more sensitive measure of mood. Furthermore, the effects of water supplementation on different age groups is something that should be addressed. Children, adults and older adults have different bodily water demands (Jéquier & Constant, 2010), so it is plausible that effects of supplementation on cognitive performance may not be the same in different groups (although age did not affect the analyses in this study).

While there is an established literature exploring the effect of expectancy on performance in the case of caffeine (Dawkins et al., 2011; Fillmore & Vogel-Sprott, 1992; Lotshaw et al., 1996) and alcohol (Leigh & Stacy, 1991), to our knowledge, this is the first study that has explored the effects of expectancies about water consumption on cognition. These results suggest that the positive effects of water supplementation that have been observed in this and other studies are not a result of prior expectations that individuals may have about the potential effects of water. This lends support to the argument that it is the physiological effects of water consumption that lead to improved performance. If physiological measures of hydration, such as urinary, plasma or salivary osmolality, were also shown to be related to changes in cognition, stronger conclusions could be reached about the physiological effects of water supplementation on cognition. In terms of implications for practice, the interpretation of these data suggests that drinking water may be beneficial for cognitive performance.

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