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Abstract

Water supplementation has been found to facilitate visual attention and short-term memory, but the dose required to improve performance is not yet known. We assessed the dose response effect of water on thirst, mood and cognitive performance in both adults and children. Participants were offered either no water, 25 ml or 300 ml water to drink. Study 1 assessed 96 adults and in Study 2, data are presented from 60 children aged 7-9 years. In both studies, performance was assessed at baseline and 20 minutes after drinking (or no drink); on thirst and mood scales, letter cancellation and a digit span test. For both children and adults, a large drink (300 ml) was necessary to reduce thirst, while a small drink (25 ml) was sufficient to improve visual attention (letter cancellation). In adults, a large drink improved digit span, but there was no such effect in children. In children, but not adults, a small drink resulted in increased thirst ratings. Both children and adults show dose-response effects of drinking on visual attention. Visual attention is enhanced by small amounts of fluid and appears not to be contingent on thirst reduction. Memory performance may be related to thirst, but differently for children and adults. These contrasting dose-response characteristics could imply cognitive enhancement by different mechanisms for these two domains.

Keywords

Water, cognition, drinking, performance, mood

Introduction

While there is agreement that certain cognitive processes and mood states are facilitated by drinking water (Benton, Braun, Cobo, Edmonds, Elmadfa, El-Sharkawy, Feehally, Gellert, Holdsworth, Kapsokefalou, Kenney, Leiper, Macdonald, Maffeis, Maughan, Shirrefs, Toth-Heyn, Watson, 2015; Masento, Golightly, Field, Butler & van Reekum, 2016), there are conflicting findings in the literature. This may be a result of differences in the amount of water offered across studies with resulting differential dose response effects on performance. This paper reports two studies that investigate the dose response effect of water consumption on cognitive performance and mood in both adults and children.

Studies in children have reported that visual attention, measured by performance on a letter cancellation task, is improved by drinking 250 ml (Booth, Taylor & Edmonds, 2012; Edmonds & Burford, 2009) or 500 ml water (Edmonds & Jeffes, 2009). Drinking 250 ml or 300 ml water has been found to improve children's performance on tasks assessing visual memory (Edmonds & Burford, 2009; Benton & Burgess, 2009) and an increase in water consumption over a whole day has been associated with better digit span (Fadda, Rappinett, Grathwohl, Parisi, Fanari, Calo & Schmitt, 2012; an average of 624 ml over a school day). In contrast, children's memory for stories (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009), visuomotor tracking (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009), or sustained attention tasks (Benton & Burgess, 2009) have not been found to be affected by water consumption.

In the case of adults, 200 ml water has been found to improve visual attention (Edmonds, Crombie, Ballieux, Gardner, Dawkins, 2013) (measured by letter cancellation) and 500 ml has been shown to shorten reaction time (Edmonds, Crombie, Gardner, 2013). However, studies have also reported that water did not improve performance on tasks assessing memory (Edmonds, Crombie, Gardner, 2013; Neave, Scholey, Emmett, Moss, Kennedy, Wesnes, 2001), set shifting (Edmonds, Crombie, Gardner, 2013), or attention (Edmonds, Crombie, Gardner, 2013; Neave, et al, 2001). Moreover, one study suggested that performance on a set shifting task was not affected by drinking water, and was better if participants reported themselves to be thirsty (Edmonds, Crombie, & Gardner, 2013). Other studies have also reported that the effect of drinking water is influenced by participants' thirst. For example, adults' performance on a rapid visual information processing task was improved after drinking either 120 ml or 330 ml water, but only if they initially rated themselves as thirsty (Rogers, Kainth, Smit, 2001); if they initially rated themselves as not thirsty, consuming water resulted in poorer performance. Similarly, reaction times of adults who rate themselves as less thirsty, were not found to be affected by water supplementation, while the reaction time of thirsty individuals sped up after drinking water (Edmonds, Crombie, Gardner, 2013.

In the case of mood, inconsistent effects of water supplementation have been reported. Subjective feelings of alertness and concentration have been found to be higher in adults who have free access to water compared to a group on a restricted drinking regime (Shirrefs, Merson, Fraser, Archer, 2004). Moreover, adults have rated themselves as more alert after acute water ingestion (Rogers et al, 2001). Other studies have reported no effect of water on adults' subjective ratings of mood (Edmonds, Crombie, Ballieux, Gardner, Dawkins, 2013). In the case of children, there is some evidence to suggest that those who drank water rated themselves as happier compared to those who drank nothing (Edmonds & Jeffes, 2009), although it is possible that this is due to diminishing the discomfort associated with thirst.

The studies reviewed above show somewhat inconsistent findings with regards to the effect of water consumption on cognition and mood, but they also offer inconsistent amounts of water. A dose response effect, that has yet to be investigated, could potentially explain disparities. However, without systematically surveying the literature, we do not yet have the evidence to claim that the literature support this. Our review of the literature is suggestive that performance on a visual attention task (letter cancellation) seems to occur irrespective of dose, while improvements on a memory task (digit span) seem to require a larger dose of water; thus, different systems may be sensitive to different doses of water. Here, we report an investigation of the dose response characteristics of the effects of acute water supplementation on cognitive performance and mood. We seek to test the generality of the phenomenon by assessing both adults (Study 1) and children (Study 2) given that these are the two populations commonly used in these studies. We explored this systematically in adults and children, using visual attention (letter cancellation) and memory (digit span) tasks that have been employed in previous studies.

Study 1: Adults

The aim of Study 1 was to evaluate the dose response effect of water on cognitive performance and mood in adults. We manipulated the volume of water offered to participants, offering either a large drink (300 ml) a small drink (25 ml) or no drink, and examined the effect on performance on measures of visual attention and memory, and subjective ratings of thirst and mood.

Methods

Participants. Ninety-six participants were recruited from the student population at the University of Westminster. There was no monetary or other incentive to take part. Each of the three groups consisted of 32 participants. The mean age of participants was 21.0 years in each group (300 ml, *SD* = 2.5 years; 25 ml, *SD* = 3.6 years; no water, *SD* = 2.8 years). There were more females than males overall, but the ratio of males to females was similar in each group (300 ml, F = 22; 25 ml, F = 25; no water, F = 21).

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving adult participants were approved by the ethics committee of the Department of Psychology, University of Westminster. Written informed consent was obtained from all participants.

Measures.

Thirst Scales. To indicate subjective thirst, participants marked a horizontal line with anchors stating "not thirsty at all" and "very thirsty". Scores were calculated by measuring the line starting from "not at all thirsty". Scores were expressed as percentages and a higher score indicates a higher level of subjective thirst.

Mood Scale. To assess mood, participants marked a horizontal line with anchors stating, “very sad” and “very happy” to indicate their current subjective happiness. Scores were expressed as percentages and higher scores were associated with a more positive mood.

Letter Cancellation. This was a pencil and paper test. Participants had to cross through examples of a target letter ("U") in a 20 x 20 grid as quickly as possible, within 20 seconds. The grid was filled with targets (n= 38) and distractor letters (“O”, n=323; “V”, n=28; “C”, n=11). The score was the number of correctly identified letters minus incorrectly checked letters and the maximum score was 38. A higher score indicated better performance.

Digit Span. A series of digits were read aloud by the researcher at a rate of 1 digit every two seconds. Participants were required to repeat the sequence in the order that it was presented. Sequences were initially three digits in length, and increased by one digit until a maximum of ten digits was reached.

Adults were required to repeat the sequence back to the experimenter out loud. There were two trials at each sequence length, and the test proceeded if at least one were answered correctly; the task was stopped when participants failed to correctly repeat two consecutive sequences

Procedure. All participants completed the thirst and mood scale, followed by baseline cognitive tests. They were then offered either 25 ml, 300 ml, or no water and were encouraged to drink the full amount, which all of them did. After water consumption there was an interval of approximately 20 minutes, which is the interval commonly reported in the literature reviewed above, during which the participants spent time quietly. Following the interval, participants completed the second set of scales and cognitive tests. Parallel forms of the cognitive tests were used and the order of these was counterbalanced. Upon completion participants were thanked and debriefed. Adult participants were tested individually in a quiet room.

Statistical Analysis. For both studies, a mixed model ANOVA (TIME x VOLUME) were conducted for each outcome variable. Analyses comparing baseline and test scores were carried out at each volume level in accordance with the hypotheses. The Bonferroni correction for multiple tests was employed and the alpha level was set at 0.017 (0.05 / 3 comparisons).

Results and Discussion

Thirst and Mood. Data presented in Table 1 show mean scores and standard deviations for ratings on the thirst and mood scale by volume group and time of test

Thirst Scales. There were significant main effects of TIME (F (1,93) = 6.89, p = 0.010) and VOLUME (F (1,93) = 5.23, p = 0.007). These should be interpreted in the light of the significant interaction between TIME and VOLUME (F (1,93) = 27.34, p < 0.001). Follow up tests showed that there was a significant reduction in thirst ratings for those who drank 300 ml (t (31) = 6.71, p < 0.001), but the ratings did not alter significantly over time for those who drank 25 ml (t (31) = 1.49, p = .146), or no water (t (31) = 1.72, p = 0.095).

Mood Scale. The main effect of TIME was statistically significant (F (1,93) = 34.49, p < 0.001), but VOLUME was not (F (1,93) = 0.54, p = 0.583). The interaction between TIME and VOLUME approached significance (F (1,93) = 2.91, p = 0.059). Exploratory post hoc tests comparing ratings at baseline and test were conducted for each VOLUME group (no water, 25 ml, 300 ml), which showed significant increases in ratings over time for those who drank 300 ml (t (31) = 4.18, p < 0.001) or 25 ml (t (31) = 4.54, p < 0.001), but no significant difference in ratings at baseline and test for those who drank nothing (t (31) = 1.50, p = 0.144). These t-tests should be interpreted cautiously because the interaction was not statistically significant.

Cognitive Tests. Table 2 presents mean scores and standard deviations for performance on each of the cognitive tests by volume of water at the two test points.

Letter Cancellation. Main effects of TIME ($F (1,93) = 38.39$, $p < 0.001$) and VOLUME ($F (2,93) = 5.50$, $p = 0.006$) were significant. The significant interaction ($F (2,93) = 8.42$, $p < 0.001$) indicated that there was a significant increase in number of targets correctly identified at baseline compared to test for those who drank 25 ml ($t (31) = 3.62$, $p < 0.001$) and 300 ml water ($t (31) = 7.47$, $p < 0.001$); the improvement was greater in the case of those who drank 300 ml (mean difference = 5.48) compared to those who drank 25 ml (mean difference = 2.72). There was no significant difference in scores over time for those who drank nothing ($t (31) = 0.70$, ns).

Digit Span. Performance on the Digit Span test showed a main effect of TIME ($F (1,93) = 4.2$, $p = 0.042$), but not VOLUME ($F (2,93) = 1.13$, $p = 0.328$). There was a significant interaction between TIME and VOLUME ($F (2,93) = 3.60$, $p = 0.031$), with no change in digit span in the no water ($t (31) = 0.70$, ns) or 25 ml ($t (31) = 0.74$, ns) groups, but a significant increase in span in the group that drank 300 ml ($t (31) = 3.36$, $p = 0.002$).

The results of Study 1 show that, in adults, a large drink of water is necessary to reduce subjective feelings of thirst and to improve short term memory, as assessed by digit span. In contrast, even a small drink is sufficient to improve adults' visual attention, as assessed by letter cancellation. Drinking did not affect adults' mood ratings. These results suggest that, for adults, there are dose response effects of drinking on cognitive performance.

Study 2: Children

The aim of Study 2 was to examine whether similar dose response effects of water are observed in children to those reported above in adults. A similar design and procedure to that employed in Study 1 was adopted in Study 2.

Methods

Participants. Children were recruited from three schools east of London, UK and were offered no monetary or other incentive to participate. All schools were in a similar geographical area, and if the proportion of children receiving free school meals (FSM) were used as a proxy of socioeconomic status, all were similar with a low proportion receiving FSM (GOV.UK, 2016). The whole sample consisted of 86 children. However, not all participant data were included in the analysis. Initially, 79 participants were randomly assigned to one of the three drink groups (0 ml, 25 ml or 300 ml). However, 11 out of the 27 children in the 300 ml group did not consume the full amount of water, drinking between 30 ml and 180 ml. Therefore, we recruited an additional 7 children in this group in order to try to increase the sample size to that of the other drink groups. Four of these seven drank the full 300 ml; thus, there were a total of 20 children in this group who consumed all of the water that they were offered. In order that each VOLUME group had comparable numbers, we used a random number generator to randomly exclude children in the 0 ml and 25ml groups in order to reduce the sample sizes to 20 in each group.

In the sample that were included in the analyses, there were 60 children aged 7 to 10 years. The no water group comprised 10 males and 10 females (range, 7 years to 10 years), the 25 ml group comprised 10 males and 10 females (range, 7 years to 10 years) and the 300 ml group comprised 5 males and 15 females (range, 8 years to 10 years).

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving child participants were approved by the ethics committee of the School of Psychology, University of East London. Written informed consent was obtained from the parent or guardian of all participants, and written informed assent was obtained from each child.

Measures. The same letter cancellation task, thirst and mood scale as those used in Study 1 were employed here. The digit span task used the same number sequences, but because participants were tested in groups, they wrote down their responses rather than reporting them orally.

Procedure. The same procedure used for adult participants was also used for child participants, with the exception that children were tested in small groups in a quiet room away from the classroom. They were tested in groups comprised of children in the same experimental condition; thus they would not have seen other children having, or not having, drinks. They were tested at a similar time of day.

Results

Data presented in Table 3 show mean scores and standard deviations for ratings on the thirst and mood scale by volume group and time of test

Thirst Scales. Self-rated thirst scores showed a main effect of VOLUME ($F(2,52) = 9.22$, $p < 0.001$) with thirst scores decreasing as children drank a greater volume of water. The main effect of TIME was not significant ($F(1,52) = 0.57$, $p = 0.455$). The main effect of VOLUME should be interpreted in light of the significant interaction ($F(2,52) = 13.03$, $p < 0.001$). Follow up t-tests examined whether there was a change in scores from baseline to test in each of the three volume groups. Interestingly, while the thirst ratings of the 300 ml group decreased significantly from baseline to test ($t(10) = 3.25$, $p = 0.005$), the ratings of the 25 ml group showed an increase in self rated thirst over time ($t(17) = 2.96$, $p = 0.008$). The no water group's ratings also decreased, but not significantly so ($t(19) = 1.19$, $p = 0.249$).

Mood Scale. There was no effect of VOLUME ($F(2,52) = 0.40$, $p = 0.673$), nor TIME ($F(1,52) = 0.74$, $p = 0.395$), nor was the interaction significant ($F(2,52) = 1.73$, $p = 0.188$).

Cognitive Tests. Table 4 presents mean scores and standard deviations for performance on each of the cognitive tests by volume of water at the two test points.

Letter Cancellation. The main effect of TIME ($F(1,57) = 37.73$, $p < 0.001$), was significant, but VOLUME was not significant ($F(2,57) = 1.27$, $p = 0.289$). The interaction was not significant ($F(2,57) = 1.26$, $p = 0.292$). We were interested in the performance of each VOLUME group and conducted t-tests comparing performance at baseline and test. There was a significant increase in number of targets correctly identified at test compared to baseline for those who drank 25 ml ($t(19) = 6.89$, $p < 0.001$) and those who drank 300 ml ($t(19) = 4.31$, $p < 0.001$). There was no significant difference in performance over time for those who drank no water ($t(19) = 1.72$, $p = 0.101$). While these t-tests should be interpreted cautiously because the interaction was not statistically significant, the absence of group differences at baseline, F (2,57) = 1.36, p = .264, would tend to discount regression to the mean as an explanation.

Digit Span. For performance on the Digit Span task, neither main effect, nor the interaction were significant (VOLUME, F (2,56) = 0.10, p = 0.907; TIME, F (1,56) = 0.12, p = 0.729; VOLUME x TIME, F(2,56) = 0.35, p = 0.710).

These results replicate in children our finding that a large drink is necessary to reduce ratings of subjective thirst. Indeed, a small drink was found to increase thirst ratings in our sample, perhaps because it made children desire more water. By contrast, a small drink was sufficient to improve children's performance on our visual attention task, in line with our findings for adults in Study 1. Although the interaction between volume drunk and time of test was not statistically significant, the pattern of mean scores and t-test results are the same for children and adults. In contrast to the adult results, children's memory was not improved by drinking. In line with the results in adults, mood was not affected.

General Discussion

Our results show that children and adults exhibit dose-response effects of drinking on visual attention and memory; these findings are summarised in Figure 1. In our study in adults, only a large drink affected thirst and memory, while a small drink was sufficient to improve performance on the attention task. This association lends support to the view that, in adults, memory is contingent on thirst reduction, while attention is not for either children or adults. Memory performance may be related to thirst, but differently for children and adults. In adults, a large drink improved digit span, but there was no such effect in children. In children, but not adults, a small drink resulted in increased thirst ratings. These contrasting dose-response characteristics for visual attention and memory could imply cognitive enhancement by different mechanisms for these two domains.

Effects of water on performance on visual attention tasks were present even for small quantities of fluid consumption, and in both adults and children. They also appear not to be contingent on thirst reduction; performance on the visual attention task was affected by a small drink, while thirst ratings were decreased only after consuming a larger drink. These results may help to explain the cross-study consistency of findings of the effect of water supplementation on visual attention tasks. Performance on these tasks has reliably been improved by water supplementation across studies that administered differing amounts of water (Booth et al, 2012; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009; Edmonds et al, 2013; Edmonds et al, 2013). Here, we found that even a small amount of water was sufficient to improve performance in this domain, in line with the view that visual attention, measured by letter cancellation, is particularly sensitive to water supplementation.

The positive effect on letter cancellation performance a short while after consuming a small amount of water is unlikely to have resulted from a meaningful change in hydration status. A larger bolus of fluid (and a longer interval) would be required to substantially change the body's hydration level (Cheuvront & Kenefick, 2014). Instead, we speculate that the mechanism could be a result of a hedonic shift in the unpleasant symptoms of mouth dryness, rather than changes in hydration status related to thirst, thus rendering the individual more comfortable, and less distracted. Alternatively, it could be that stimulation of oropharyngeal receptors, which are specialised to react to small quantities of water (Rolls and Rolls, 1982), elicit physiological changes that may result in improved performance (as proposed by

Edmonds et al, 2013). These arguments might help to explain the somewhat equivocal effects of drinking a small amount of water on happiness ratings in adults (shown only in the simple effects analysis) - in which case, happiness may act as a proxy for mouth-comfort. In support of this interpretation are our findings in the present studies that consuming a small drink seems not to be sufficient to relieve all of the sensation of thirst. It could be that thirst ratings are sensitive to the effect of drinking not solely in the mouth, but in the throat or further down the gastro-intestinal tract; sensations that may be relieved only by a larger drink. In support of this is the finding that a larger drink (400 ml) is more effective at reducing thirst and mouth dryness than a smaller drink (150 ml) (Brunstrom and MacRae, 1997). Other properties of drinks such as temperature and acidity also influence their ability to quench thirst and affect drinking behaviour (Brunstrom, 2002; Rolls and Rolls, 1982). Therefore, the effect of these on cognition, either via thirst or directly could be a fruitful area for future research. The cognitive systems affected by drinking should also be investigated. For example, it is possible that drinking water increases general arousal and facilitates performance.

Drinking affected memory differently to visual attention performance, which might suggest that there are different mechanisms underlying the effects for these two domains of cognition. In adults, but not children, performance on the memory task did not improve unless a larger drink was consumed, which was also associated with decreased thirst ratings. This suggests that thirst reduction may be important for positive effects of water consumption on memory in adults, but not in children. Our results are consistent with a recent study that found that memory performance was related to thirst, but focused attention was less so (Benton, Jenkins, Watkins, & Young 2016). However, it should be noted that the administration of the digit span test was different for adults and children - adults were tested individually and repeated the number strings to the researcher, while children were tested in groups and wrote the number strings in a test booklet. It might be that effects of drinking on memory are sensitive to mode of testing. Thus, it is important that mode of presentation is formally evaluated before firm conclusions about age differences can be made. It is also possible that there are fundamental differences in the thirst response and ability to accurately report the thirst response between adults and children, and/or that there are age-related differences in memory ability. These alternatives could be explored in future.

Previous work has reported that memory is not always improved by water supplementation, with some studies reporting better memory after drinking (Edmonds & Burford, 2009; Benton & Burgess, 2009; Fadda et al, 2012) and some reporting no improvement (Edmonds & Jeffes, 2009; Edmonds et al, 2013; Neave et al, 2001). These inconsistencies are unlikely to be a result solely of inconsistent volumes of water in this and other studies; the 300 ml that we asked participants to consume is comparable to the amounts offered by others. Alternatively, it may be that not all types of memory are similarly affected by water supplementation. In the current study, in common with others (Fadda et al, 2012), we tested memory by assessing short term memory for auditorially presented digits, while further studies that have reported positive effects of water consumption on memory have assessed memory for pictures of objects (Edmonds & Burford, 2009; Benton & Burgess, 2009) or memory for orally presented story information (Edmonds & Burford, 2009). Those that have reported no effects of water have assessed spatial working memory (Edmonds, Crombie, Gardner, 2013; Neave et al, 2001) and memory for visually presented words (Edmonds, Crombie, Gardner, 2013). These cross study differences in results might be a result of procedural differences that affect task demands, with some tasks requiring quick responding similar to that required in the visual attention tasks, while others do not. Or, it could be that some memory tasks have greater attentional demands than others; the evidence presented here suggests that attention is particularly affected by water consumption and thus, a memory task with a high attentional load may be more susceptible to drinking water. Furthermore, task difficulty could play a role. Alternatively, they may occur because different memory systems are selectively affected by water supplementation. It could also be that inconsistent effects across studies are linked to different levels of baseline thirst or hydration status. These alternatives should be explored by further work.

The protocol of tests used in these studies was kept relatively short in order to be in line with that used in other studies. To further the literature, future studies should extend the type of assessments used to further ascertain which cognitive processes are affected by drinking water. In addition, it would be reassuring to confirm the effects of drinking water on particular cognitive processes by examining performance on more than one test designed to assess the same cognitive domain. However, when considering the number of tests employed in a single study, one should consider the possibility that effects are time sensitive and increasing the test battery could mask potential effects by extending the interval between test at baseline and at re-test, after intervention. One study has examined the effects of drinking water on performance at multiple timepoints; Edmonds et al (2013) reported that letter cancellation performance was improved after drinking (compared to those who drank nothing) at both 20 and 40 minutes post intervention.

There were some differences in the gender distribution across groups in our child study. We suggest that it is unlikely that these would impact on factors related to hydration because pre-pubertal participants are unlikely to have sufficient difference in body size to influence hydration status and thus be gender-sensitive to the effects of drinking water. However, it is possible that there are some gender differences that may have an impact on performance, such as temperament (Else-Quest, Shibley-Hyde, Goldsmith, Van Hulle, 2006) or impulsivity (Cross, Copping, Campbell, 2011); although it should be noted that the presence of gender differences is controversial (Fine, 2011) and it is also possible that there are individual differences in these constructs (John & Gross, 2004).

Thirst is a well-studied phenomenon (Rolls and Rolls, 1982); although the relation of thirst to cognition is less well examined. However, relatively little is known about the thirst mechanism in children (Kenney and Chiu, 2001). Children are at particular risk of dehydration for a variety of physiological (e.g. higher total body water content, poor acclimatisation to heat, higher respiratory and metabolic rate) and social (depended on caregivers for access to drinks) reasons (Edmonds, 2012). Furthermore, children are susceptible to voluntary dehydration - defined as the failure to rehydrate after a dehydration event (such as exercise) due to inadequate or lack of thirst (Kenney and Chiu, 2001); although it is suggested that children rarely dehydrate when the dehydration event is short (less than 45 minutes, Kenney and Chiu, 2001). Data from our study could suggest that children's perception of thirst operates differently from that of adults; we report that both adults’ and children's thirst ratings were decreased by a drink of 300 ml water, but children's ratings increased after consuming just 25 ml water. However, these data should be replicated before strong conclusions about whether children's ability to perceive and report on the interoceptive signal of thirst is the same as that in adults. We suggest that thirst in children - their perception of it, susceptibility, relation to hydration status and to performance and mood - should be the subject of future scrutiny.

In conclusion, our results suggest that different domains of cognition are affected by drinking varying amounts of water in distinct ways. We propose a link between performance on a speeded visual attention task and either a hedonic shift in mouth comfort, or oropharyngeal factors; therefore, a focus of future acute drinking research should be on which explanation is best supported by evidence and which systems play a role in this process. For example, it may be mediated by changes in the haemodynamic response in the brain, but this link has yet to be investigated. The impact of mouth rinsing could be utilised as a manipulation that stimulates oral receptors without swallowing fluid: there is a growing body of research examining the effect of carbohydrate mouth rinsing on cognitive performance (Sanders, Shirk, Burgin, Martin, 2012; Turner, Byblow, Stinear, Gant, 2014), analogous to work examining the effect of small amounts of fluid on performance. Future research could also examine the promising relation between larger drinks of water and memory, perhaps related to hydration status and not just to acute episodes of drinking; Perry Rapinett, Glaser and Ghetti (2015) have reported associations between hydration status assessed by urinary osmolality, drinking and cognitive performance. In the case of research examining the effect of hydration status on cognition, we do not yet know whether speeded visual attention is affected by hydration. It may be of particular interest to examine the question of hydration status and cognition in groups that are at specific risk of dehydration, such as children and older adults.

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Figure Captions Figure 1. Graphical summary of statistically significant increases and decreases (indicated by arrows) in performance and rating scales by measure and study.

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Measure	Adult Study	Child Study
Thirst	300 ml ↓	300 ml ↓ 25 ml ↑
Mood	-	-
Letter Cancellation	25 & 300 ml ↑	25 & 300 ml ↑
Digit Span	300 ml ↑	-

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Study 1

Table 1. Adult study: Means and standard deviations on thirst and mood scale by volume of water consumed and time of test.

	No drink				25 ml				300 ml			
	Baseline		Test		Baseline		Test		Baseline		Test	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Thirst	57.08	22.29	60.31	21.91	45.17	21.29	50.10	27.24	57.08	22.29	25.23	21.41
Mood	64.65	16.76	68.17	12.08	63.63	15.28	73.29	16.18	64.33	15.76	75.67	16.09

Table 2. Adult Study: Means and standard deviations on cognitive tests by volume of water consumed and time of test.

Test	No drink				25 ml				300 ml			
	Baseline		Test		Baseline		Test		Baseline		Test	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Letter Cancellation	22.64	5.45	22.34	5.45	22.91	5.59	25.63	6.30	23.34	4.76	28.81	4.43
Digit Span	8.66	1.41	8.56	1.13	8.53	1.39	8.69	1.42	8.75	1.44	9.31	1.51

Table 3. Child Study: Means and standard deviations on thirst and mood scale by volume of water consumed and time of test.

	No drink				25 ml				300 ml			
	Baseline		Test		Baseline		Test		Baseline		Test	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Thirst	68.55	16.25	73.55	19.65	65.16	26.42	78.84	26.64	61.06	11.39	35.00	29.09
Mood	81.80	15.19	80.30	16.10	81.61	15.34	71.67	31.54	75.53	17.28	79.29	18.18

Note, there were some missing data as a result of some children not completing all of the tests.

For thirst scales the no drink group, n=20; the 25 ml group, n=19; and the 300 ml group, n=17.

For Happy, the no drink group, n=20; the 25 ml group, n=18; and 300 ml group, n = 17.

Table 4. Child study: Means and standard deviations on cognitive tests by volume of water consumed and time of test.

Test	No drink				25 ml				300 ml			
	Baseline		Test		Baseline		Test		Baseline		Test	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Letter Cancellation	14.75	3.81	16.85	5.88	13.05	4.78	17.05	5.38	15.60	6.07	19.40	6.11
Digit Span	4.43	1.02	4.74	1.12	4.25	1.62	3.75	1.65	4.70	1.29	4.40	1.14

Note, there were some missing data as a result of some children not completing all of the tests.

For letter cancellation, all group n's were 20.

For Digit Span, the no drink group, n = 19; the 25 ml group, n = 20; and the 300 ml group, n = 20.