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At what stage in the drinking process does drinking water affect attention and memory? Effects of mouth rinsing and mouth drying in adults.

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Abstract

Drinking water is important for health and there is agreement that drinking water facilitates certain cognitive processes. However, the mechanism underlying the effect of drinking water on cognition is unknown. While attention performance is improved by even a very small drink, memory performance seems to require larger drinks for performance enhancement. This suggests that attention could be affected earlier in the drinking process than memory. We aimed to elucidate further the mechanism involved, by investigating the stage during the drinking process influencing performance on cognitive tasks. To this end, we compared mouth rinsing and mouth drying. Mouth rinsing was expected to result in improved attention performance and would suggest that the mechanism responsible is located in the mouth and occurs early in the drinking process, before swallowing. Eighty-seven adults participated in either a treatment (mouth rinsing or mouth drying) or control (no intervention) condition. They were assessed at baseline and 20 minutes later after intervention on measures of visual attention, short-term memory, subjective thirst and mood. Our results showed that mouth rinsing improved visual attention, but not short-term memory, mood or subjective thirst. Mouth drying did not affect performance. Our results support the hypothesis that different mechanisms underlie the effect of drinking water on different cognitive processes. They suggest that merely sipping water, as opposed to having a large drink, can improve attention.

Introduction

Maintaining healthy hydration is crucial for both health (Benelam and Wyness 2010; Benton et al. 2015), cognitive performance (D'Anci et al. 2006; Masento et al. 2014) and mood (Neave et al. 2001). In contrast to more long term, chronic, changes in hydration status, short term, acute, water drinking interventions also positively affect cognition (Benton et al. 2015; Masento et al. 2014). While the underlying mechanism behind the positive effects of drinking water on cognition is not yet known, there are a number of physiological and psychological candidate explanations. Physiological explanations include a haemodynamic response to drinking that promotes cerebral blood flow (May and Jordan 2011) and a hormonal response associated with dehydration, in which cortisol rises with increasing dehydration (Francesconi et al. 1987; Greendale et al. 2000; Kirschbaum et al. 1996). Psychological explanations include reducing distraction associated with thirst (Cohen 1983) and arousal being increased by drinking water, which improves cognitive performance (Edmonds et al. 2018). Physiological accounts based upon hydration changes assume ingestion of an adequate volume of water to affect a change in hydration status, and at a long enough duration that allows for gastrointestinal and blood volume changes to occur (minutes or hours) (Zimmerman et al. 2016). By contrast, psychological explanations make no such assumptions about volume or timecourse. The aim of the present study is to establish at which stage of drinking cognition is affected, and thus help to identify the mechanism responsible.

Studies examining the effect of drinking water on cognition show dose response effects specific to certain cognitive processes. For example, visual attention is facilitated after drinking water, seemingly irrespective of volume – with improvements in letter cancellation 20 to 30 minutes after drinking amounts of water ranging between 25 ml and 500 ml. This is observed in both children (Booth et al. 2012; Edmonds et al. 2017; Edmonds and Jeffes 2009) and adults (Edmonds et al. 2017; Edmonds, Crombie, and Gardner 2013). In contrast, short-term memory improves only after consuming larger amounts of water. For example, some studies have shown that children's digit spans lengthen after drinking an average of an additional 600 ml water over a school day (Fadda et al. 2012), and after drinking sufficient fluid over a two and a half hour period to result in changes in hydration status (children were offered 750 ml and hydration status was assessed by urinary osmolality) (Perry et al. 2015). Drinking smaller amounts of water (300 ml) improved adults' digit span 20 to 30 minutes later, but not children's (Edmonds et al. 2017), and drinking very small amounts of water (25 ml) did not result in improved digit spans in either children or adults after 20 minutes (Edmonds et al. 2017). Therefore, the majority of the research on memory suggests that memory processes may be affected only when water is consumed in amounts large enough, and over a time period long enough, to result in changes in hydration status - changes that would not occur after consuming a small drink. In contrast, all of the studies examining visual attention, find that both adults and children's performance is improved by a small drink and over a short time period. Taken together, these findings suggest that the mechanisms involved in the observed effect of drinking water on cognitive performance may operate at different stages of the drinking process, perhaps early on for visual attention (before swallowing) and later for short-term memory (once water has been absorbed).

One manner by which the drinking stage at which cognition is affected could be identified, and thus shed light on the mechanism involved, is to examine how mouth rinsing water affects performance. Mouth rinsing, in which liquid is rinsed around the mouth and expelled, is commonly used to examine the effect of carbohydrate drinks on sports performance, a research area that evolved partly because drinking carbohydrate while exercising is not always well tolerated by the stomach. Carbohydrate mouth rinsing often results in sports performance enhancement (Jeukendrup et al. 2013; Rollo et al. 2015; Sinclair et al. 2013). This methodological approach could be employed, but substituting water, in order to examine at what point in the drinking process cognition is affected by drinking water (Edmonds et al. 2018). Improved performance after mouth rinsing water would imply a mechanism operating within the mouth, since the fluid does not progress further. This could be due to stimulation of oropharyngeal receptors, a hedonic shift in mouth comfort, or related to changes in alertness (Edmonds et al. 2017). In contrast, for processes that are observed to be affected by drinking (and swallowing) larger volumes of water, a change in hydration status may be a more likely mechanism, given the need for gastrointestinal detection of osmolarity and/or blood volume changes to have occurred (Zimmerman et al., 2016).

One study has evaluated the effect of mouth rinsing water on cognition in children and reported that visual attention improved, thus suggesting the timing of the effect, and the mechanism involved, is related to processes occurring within the mouth (Edmonds et al. 2018). In contrast, Edmonds et al reported that short-term memory was not affected by mouth rinsing water, which is consistent with the explanation that memory is affected by hydration status, or at least by processes that operate after the mouth. There are compelling reasons to replicate this mouth rinsing study in adults. For example, adults' cognitive performance shows similar dose response effects when drinking water to those observed in children. Thus, in the present study, we assess whether a similar mechanism can also explain the positive effect of drinking water on visual attention in adults. In addition, while Edmonds el al (2018) did not employ full counterbalancing, here we employed a between subjects methodology and full counterbalancing.

Moreover, we consider the effect of drinking, mouth rinsing and drying the mouth on subjective thirst. Studies have reported that the effect of drinking water on cognitive performance interacts with ratings of subjective thirst, with performance on a sustained attention task improving after drinking water in adults who rated themselves as thirsty, but decrements in performance in adults who were asked to consume additional water when they reported low initial ratings of subjective thirst (Rogers et al. 2001). In contrast, others have reported that improvements in attention performance after drinking were not contingent on associated thirst reduction and occurred after a small drink of water (25 ml) (Edmonds et al. 2017), while memory improvements were only observed alongside reductions in subjective thirst ratings and after a larger drink (300 ml) (Edmonds et al. 2017). Similar findings have been reported in children, with mouth rinsing resulting in improvements in visual attention performance, which were not accompanied by significant reductions in subjective thirst (Edmonds et al. 2018). Taken together, these findings suggest that small amounts of water can increase attention performance, but may not affect thirst ratings. Thus, in the present study, we expected mouth rinsing to affect attention, but not to decrease thirst.

As a contrast to mouth rinsing, Edmonds et al. (2018) also examined the effect of mouth drying, which was achieved by inserting dental rolls into the mouth at the intervention stage. While one might expect that mouth drying could have opposing effects to mouth rinsing, with performance decrements for processes for which improvements were observed after mouth rinsing, this was not the case in children: we predict similar outcomes in adults.

In the present study, we assessed whether adults' performance changes under conditions of mouth rinsing, mouth drying and a control (no intervention). Intervention timings were based on those adopted previously (Edmonds et al. 2018). Performance on a visual attention task (letter cancellation) and a short-term memory task (digit span), and subjective measures of thirst, mood and perceived effort, were assessed at baseline and test (20 minutes after intervention). In line with previous studies, we predicted that visual attention, which is hypothesised to be affected by processes occurring early in the drinking process, would improve after mouth rinsing and would be unaffected by mouth drying. In contrast, we hypothesised that short-term memory, which may be affected by improved hydration, or an effect on the body occurring after the mouth, would be unaffected by either mouth rinsing or mouth drying. We did not expect the manipulations to affect subjective thirst and mood ratings. Effort scales were included to exclude the possibility that participants expended more effort in certain conditions.

Methods

Participants

89 participants took part in the study; 30 in the control condition, 29 in mouth drying and 30 in mouth rinsing. However, two participants were excluded from the analyses because they did not follow the instructions correctly for all of the tasks. In addition, there are occasional missing data for the cognitive tasks – numbers in the analysis are included in Table 1. The final sample size was 87, with 30 in the control condition (4 male; mean age 21.77 years, range 19 to 27 years), 29 in mouth drying (6 male; mean age 22.62 years, range 19 to 47 years) and 28 in mouth rinsing (7 male; 21.73 years, range 19 to 28 years).

Materials

Cognitive Tests

Letter Cancellation

This was a pencil and paper test. Participants had to cross through target letters as quickly as possible. The target (U, n=38) was presented in a 20 x 20 grid with distractor letters (O, V, C; n=362) in upper case, Calibri size 11 font. Thirty seconds were allowed. The score was the number of correctly identified letters and thus the maximum score was 38. Parallel forms were used at baseline and test, and counterbalanced.

Forwards Digit Span

A series of digits were read aloud by the experimenter at a rate of 1 digit every two seconds and participants had to repeat the string in the order in which it was presented. Sequences started at 3 digits in length and increased by 1 digit, until a maximum of ten digits was reached. There were two trials at each sequence length and participants progressed if they responded correctly to at least one of the two trials. The test stopped when participants incorrectly recalled both examples of a given sequence length. The score was the length of the longest sequence correctly recalled. Parallel forms were used at baseline and test, and counterbalanced. The maximum score was 10.

Rating Scales

Thirst Scale

To indicate subjective thirst, participants marked a 10cm horizontal line with anchors stating "not thirsty at all" on the left and "very thirsty” on the right. Scores were calculated as percentages; measuring the line from the negative anchor to the positive anchor. A higher score indicates a higher subjective thirst rating.

Mood Scale

Mood scales assessed subjective ratings of Alertness and Happiness. These were visually represented using horizontal lines (10 cm long), which were set between antonyms ('alert'-'drowsy' and 'happy' - 'sad'). The mark was measured from sad to happy, and from drowsy to alert. Thus, higher score indicates a higher subjective rating of Alertness and Happiness.

Perceived Effort

The NASA Task Load Index (NASA-TLX) (Hart 1988) was used for participants to rate the Mental, Physical and Temporal demand of the study and the amount of Effort they felt they had to exert. Each scale comprised of a 10cm horizontal lines and participants had to mark the line to indicate whether they rated themselves a 'Low' or High' on each scale. Scores were calculated by measuring from the negative end of the scale and are presented as a percentage. A higher score indicates a greater perceived load.

Procedure

Participants completed baseline tests in the following order: thirst scale, mood scale, letter cancellation, digit span, perceived effort. After this, they were randomly allocated to one of the following three conditions.

Control Condition. After baseline testing, adults were instructed to sit quietly for 20 minutes until treatment test.

Mouth Rinsing Condition. After baseline testing, participants were given a plastic cup containing 25ml water and were asked to swill the contents around their mouths for 5 s, and then to spit the water out into the cup. This was then poured away. Participants then sat quietly for 20 min.

Mouth Drying Condition. After baseline testing, participants were given a small plastic bag containing 4 cotton-wool dental rolls (10mm). They were asked to place them in their mouths, between their upper and lower teeth and gums, and close their mouths. Dental rolls remained in place for 8 minutes, removed by the participant and placed back in the bag for disposal. Participants then sat quietly for 20 min.

The test took place 20 minutes after the condition treatment and included thirst, mood and perceived effort scales, and parallel forms of letter cancellation and digit span, in the same order as baseline testing. The parallel forms were counterbalanced across participants. On completion, participants were thanked and debriefed.

Participants were told that the study aims were concerned with links between drinking water, mood and cognitive performance. No training was given on any task prior to baseline testing. All participants were tested individually in the morning, in a quiet room in London, UK. We did not control for food and drink consumed prior to testing because the aims of the study did not seek to change hydration status.

Statistical Analysis

A series of Analyses of Covariance (ANCOVA) were conducted on each outcome variable, in which performance at test was examined across condition, with score at baseline included as the covariate. The alpha level was set at 0.05. To follow up any significant effects of treatment, ANCOVAs were conducted that compared performance at test for each pair of treatments (or control), whilst covarying baseline score. LSD tests were reported in the event of a significant main effect.

Results

Data presented in Table 1 shows mean and standard deviations of scores at baseline and test for the rating scales and cognitive tests over the three conditions.

Letter Cancellation

Data presented in Table 1 shows that the largest increase in letter cancellation performance from baseline to treatment was in the mouth rinsing condition. Overall, the ANCOVA showed an effect of CONDITION, $F(2,82) = 4.71$, $p = 0.012$. Baseline letter cancellation score was a significant covariate, $F(1, 82) = 69.90$, $p < 0.001$. LSD tests revealed a significant difference between the mouth drying and mouth rinsing conditions, $p = 0.050$, and control and mouth rinsing, $p = 0.003$. There was no difference between the control and mouth drying condition, $p = 0.318$.

Digit Span

Inspection of the mean scores reveals very little change in performance over time in any condition and the ANCOVA supported these impressions, $F\ (2,82) = 1.73$, $p = 0.184$. Baseline digit span was a significant covariate, $F(1,83) = 21.90$, $p < 0.001$. Importantly, participants were not performing at ceiling; while the maximum span was 10 digits, the overall mean baseline digit span was 6.49 (SD = 1.32) and the mean test span was 6.80 (SD = 1.29).

Thirst Scale

Mean baseline thirst ratings were very similar over conditions (see Table 1) and there was no significant different over the three conditions, $F(2,83) = 0.18$, $p = 0.838$.

Although visual inspection of the data suggests that the change in thirst scores is different over the three conditions, with the highest difference in the mouth drying condition, this was not statistically significant, $F(2,82) = 2.11$, $p = 0.128$. Baseline thirst was a significant covariate, $F(1,82) = 23.80$, $p<0.001$.

Mood Scale

Mean alertness ratings appear to show a small decrease from baseline to test in all three conditions. There were no statistically significant differences between conditions, $F\ (2,83) = 0.55$, $p = 0.578$. Baseline alertness rating was a significant covariate, $F(1,83) = 19.99$, $p < 0.001$.

While visual inspection of happiness ratings suggests a small increase over time in mean scores in the mouth rinsing condition, a small decrease in the mouth drying condition and a slightly larger increase in the control condition, none of these differences were statistically significant $F(2,83) = 1.04$, $p = 0.358$. Baseline happiness rating was a significant covariate, $F(1,83) = 25.13$, $p < 0.001$.

Perceived Effort

The mean difference scores show an inconsistent pattern of change from baseline to test in each condition over the four rating scales, and there were no statistically significant differences: Mental Demand, $F(2,82) = 0.03$, $p = 0.975$ (Baseline mental demand was a significant covariate, $F(1,82) = 98.74$, $p < 0.001$); Physical Demand, $F(2,82) = 0.175$, $p = 0.840$ (Baseline physical demand was a significant covariate, $F(1,82) = 59.24$, $p < 0.001$; Temporal Demand, $F(2,82) = 1.44$, $p = 0.244$ (Baseline temporal demand was a significant covariate, $F(1,82) = 27.93$, $p < 0.001$); Effort, $F(2, 82) = 0.70$, $p = 0.497$ (Baseline effort was a significant covariate, $F(1,82) = 80.47$, $p < 0.001$)

Discussion

Our results showed that adults' performance on visual attention and short-term memory tasks was affected by mouth rinsing and mouth drying in different ways. Visual attention was improved by mouth rinsing, while short-term memory was unaffected. An absence of improvement in a control condition that did not perform mouth rinsing indicated that this was not a practice or training effect. There was no effect of mouth drying on either visual attention or short-term memory performance. Subjective ratings of thirst, mood and perceived effort were also unaffected by the experimental manipulations.

These data support our hypothesis that different mechanisms may underlie the effect of drinking water on attention and memory. Finding that mouth rinsing improves visual attention performance is in line with previous research showing that visual attention improves after even a very small drink of water (25 ml) (Edmonds et al. 2017) and that mouth rinsing water improved children's visual attention (Edmonds et al. 2018). Finding that swilling and spitting water, and not swallowing, improves visual attention performance supports the argument that these improvements occur early in the drinking process. Moreover, these changes in visual attention were neither accompanied by changes in subjective thirst, nor subjective effort. With changes in visual attention performance associated with rinsing, but not swallowing, water our data imply that the effect of drinking water on attention is not contingent upon changing hydration status. More work is necessary to elucidate further the mechanism underlying the beneficial effect of mouth rinsing. An absence of corresponding effects for subjective alertness ratings casts doubt on this effect being mediated by changes in alertness. However, further work using more objective measures of alertness (Posner 2008) would be valuable. Of the other alternatives outlined in the Introduction, a hedonic shift in mouth comfort and stimulation of oropharyngeal receptors remain plausible explanations.

Our finding that neither mouth rinsing, nor mouth drying affected short-term memory offers indirect support to the suggestion that changes in memory performance occur after changes in hydration status, although it should be noted that we did not directly examine this question. Previous research in support of this hypothesis includes findings that that large amounts of water are necessary to improve memory performance (Benton and Burgess 2009; Edmonds et al. 2017; Edmonds and Burford 2009; Edmonds and Jeffes 2009; Fadda et al. 2012). Furthermore, previous work has reported direct links between hydration status and memory, with dehydration resulting in poorer working memory (Young and Benton 2016). This should be explored in future work, as well as examining the types of memory affected. Much of the work on the effects of drinking on memory has relied upon digit span as a test of short-term memory. It would be informative to assess the extent to which facilitation effects extend to other domains of short term and long-term memory.

Subjective ratings of thirst were unaffected by either manipulation, in line with previous work that reported on the effects of mouth rinsing and drying in children (Edmonds et al. 2018). The absence of any group differences in baseline thirst ratings suggest that our results were not confounded by any group differences in food and drink consumed prior to study participation (unmeasured). Although rinsing the mouth with water can temporarily reduce thirst sensations (Brunstrom 2002), a longer rinse may be necessary than that employed here (Obika et al. 2009). Given that the sensation of a dry mouth is associated with feeling thirsty (Brunstrom and Macrae 1997), it may seem counterintuitive that our results showed that wetting the mouth does not decrease the subjective sensation of thirst. However, theories of thirst suggest that thirst is influenced by changes in osmoreceptors and neural control of drinking, rather than being caused by a dry mouth (Rolls and Rolls 1982).

It is possible that expectancy effects may have contributed to the results of the present study. While expectancy effects can be controlled for in studies of substances for which there is an active and inactive version, for example caffeinated and decaffeinated coffee (Dawkins et al. 2011; Fillmore and Vogel-Sprott 1992; Lotshaw et al. 1996), there are no such active and inactive versions of water. However, one previous study that examined the effects of drinking water on cognitive performance and formally examined the question of whether expectancy effects influence performance reported that they such effect were not observed (Edmonds, Crombie, Ballieux, et al. 2013). Thus, while this remains a potential issue, we are reassured by previous work that found no such expectancy effects when examining the effect of drinking water on cognitive performance.

It may be premature to conclude from our study that memory is not affected by drinking water via a mechanism occurring early in the drinking process, before swallowing. It is possible that the digit span task used to measure short-term memory in the present study was less sensitive to change than the letter cancellation test used to measure visual attention. Digit span has been widely used in prior work, and evidence that water consumption affects digit span, particularly after drinking a larger drink of water, indicates that changes in short-term memory may be detected when measured by this task (Edmonds et al. 2017; Fadda et al. 2012; Perry et al. 2015). Nonetheless, it remains possible that mouth rinsing results in measurable changes in performance only for the most sensitive tasks, and the absence of an effect for digit span is because this task is not as sensitive to change as letter cancellation. Therefore, further work could address this issue by employing more sensitive measures of short term memory, perhaps by using computerised tasks.

We note that, in the mouth rinsing condition, if participants were to swallow water, that would have the potential to influence the outcome of the study. While we did not observe participants swallowing any water in the mouth rinsing condition, we did not formally assess this. Future studies could address this by measuring the volume of expelled water.

There were two factors that were not completely consistent across conditions; the gender of participants and the timing of the interventions. Firstly, our study included both male and female participants, the proportions of which were slightly different over the three conditions. Some studies examining the effect of hydration or drinking use single sex samples. This is motivated by the presence of effects of gender on hydration status, with women more likely to be dehydrated (Ritz et al. 2008), and different water demands by gender (Jéquier and Constant 2010). However, the manipulations used in the present study will not change hydration status, so gender is unlikely to affect the results via changes in hydration that may be gender-linked. Of course, potential effects of gender on these manipulations could be explored by future work. In relation to the present study, given findings from the literature and the small difference in numbers of males and females across conditions, it seems unlikely that gender contributed to between condition differences.

Secondly, the duration of the interventions was different in the mouth rinsing and mouth drying conditions, with rinsing lasting 5 seconds and drying lasting 8 minutes. The duration of these interventions was selected based on previous occurrences in the literature in which an effect was observed, with effects of mouth rinsing reported after 5-10 seconds (Jeukendrup et al. 2013; Sinclair et al. 2013) and drying after significantly longer (2 minutes) (Brunstrom et al. 1997). The durations were further selected based on the timings used in a previous study on which the present study was based (Edmonds et al. 2018). The duration of mouth rinsing (5 seconds) is not dissimilar to the amount of time taken to swallow water and thus it seems unlikely that the duration of mouth rinsing might have unduly affect the results in a manner different to studies in which water is drunk. The duration of mouth drying is longer, and may have impacted on the results; while mouth drying did not affect any of the outcome measures in our study, it is possible that it may have done so had a shorter duration been adopted. It would be useful if future work were to systematically evaluate the duration required for mouth drying and rinsing to affect cognitive performance and subjective experience, perhaps via ratings of thirst and mouth comfort.

Our paper adds to the body of work on drinking water, hydration and cognitive performance, by focusing on the mechanisms involved in the effect of drinking water on cognition. There are ways in which schools and workplaces can play an important role in helping children and employees to maintain water balance, termed euhydration, and prevent dehydration. In schools, the provision of drinking water is mandated by law in England (“The Education (Nutritional Standards and Requirements for School Food) (England) Regulations” 2007) and the USA (United States Department of Agriculture 2016). In the UK, the law does not specify the frequency of access; a factor that is likely to impact the volume drunk. Research suggests that a high proportion of children are dehydrated, with over 60% of schoolchildren found to be dehydrated on arrival at school in France (Bonnet et al. 2012), the UK (Barker et al. 2012), Italy (Assael et al. 2012) and 55% in the USA (Kenney et al. 2015). Policies on the availability of drinking water in the classroom impact on the amount of water that children drink during the school day (Kaushik et al. 2007). Interventions have shown that it is possible to increase the amount drunk by children at school (Fadda et al. 2012), and teachers can play a pivotal role in encouraging children to drink water throughout the school day (Edmonds et al. 2019). In UK workplaces, drinking water must be provided by law and be “readily accessible”(Health and Safety Executive 2013). However, while there may be a drive towards water bottles in UK classrooms, UK employers do not have to allow bottles of water in the workplace (Health and Safety Executive 2019). Daily water requirements will vary according to the type of work in which individuals are engaged, and the climate. For example, manual workers may have higher water requirements, and in a hot climate, these will be higher still (Grandjean and Campbell 2004). The water demands of desk-bound workers will be lower, but an office based working environment may encourage ease of access to drinks. Thus, while workplace and school policies on drinking water availability can impact on the amount drunk and employees' and children's hydration status, this may also impact on job and school performance via the types of effects on cognitive performance reported here and elsewhere, as well as acting on the myriad of outcomes improved with healthy hydration (Benelam and Wyness 2010). Drinking water, or other fluids, in small amounts throughout the day may be optimal to improve hydration status (Gandy 2017). This type of drinking regime may be optimal for short-term memory, visual attention performance and health outcomes.

In conclusion, in our study, performance on a visual attention task was improved by mouth rinsing water, which suggests that effects of drinking water on visual attention performance occurs at the pre-ingestive phase, while the water is in the mouth. In order to explore which factors might enhance the pre-ingestive effects of water, future research could explore the properties of the water that is rinsed, for example temperature and volume. Future work on potential mechanisms underlying the mouth rinsing effect could use brain imaging to identify the brain regions activated by mouth rinsing, thus paralleling work undertaken in studies of carbohydrate mouth rinsing (Chambers et al. 2009). In contrast to the effects on visual attention, short-term memory performance was not improved by mouth rinsing water. As argued above, our findings add indirect support to the argument that short-term memory is improved by water post-ingestively. Our results can be interpreted in the light of a body of evidence suggesting that memory performance is improved by drinking water and that dehydration has negative effects on memory. Many studies have examined the effect of hydration status and drinking on short term memory using the digit span test and future work should focus on the specific domains of memory affected.

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All procedures were approved by the Department of Psychology ethics committee, University of

Westminster (ETH1617-0099) and the University of East London ethics committee (UREC 1516 74). Written informed consent was obtained from all participants prior to participation.

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Table 1. Means, standard deviations and n for the rating scales and cognitive tests over the three conditions at baseline and test

	Mouth Rinsing						Mouth Drying						Control					
Measure	Baseline			Test			Baseline			Test			Baseline			Test		
	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
Letter Cancellation	28.79	5.69	28	33.54	4.09	28	29.07	7.03	28	31.64	6.30	28	29.70	6.73	30	30.97	5.03	30
Forwards Digit Span	6.64	1.19	28	6.79	1.37	28	6.82	1.19	28	7.25	1.35	28	6.17	1.37	30	6.40	1.04	30
Thirst Scale	54.93	21.88	28	62.39	25.97	28	56.93	21.76	29	74.32	20.86	29	58.36	22.07	29	70.72	21.42	29
Happiness Scale	65.61	24.98	28	67.38	19.65	28	67.36	24.68	29	63.79	19.58	29	70.10	20.06	30	62.67	20.16	30
Alertness Scale	62.41	24.34	28	55.16	25.14	28	63.60	23.07	29	58.10	25.00	29	52.73	20.83	30	46.83	23.29	30

Perceived Effort – Mental Demand	67.96	23.24	28	70.50	24.61	28	57.21	25.85	28	61.38	26.58	28	51.60	28.89	30	57.08	29.19	30
Perceived Effort – Physical Demand	14.39	18.64	28	24.30	25.91	28	18.21	22.83	28	28.46	29.86	28	16.93	17.50	30	24.27	24.74	30
Perceived Effort – Temporal Demand	53.82	26.05	28	60.79	29.49	28	57.59	29.96	28	51.20	31.74	28	57.43	25.02	30	57.55	27.82	30

Perceived Effort – Effort Scale	69.27	18.61	28	68.89	25.43	28	51.66	28.06	28	61.16	29.61	28	51.92	24.91	30	57.02	26.07	30