Water Consumption Increases Handwriting Speed and Volume Consumed Relates to Increased Finger Tapping Speed in Schoolchildren.

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Consent to participate (include appropriate statements)

All participants gave their consent for their data to be included and analysed.

Consent for publication (include appropriate statements)

All participants gave their consent for publication.

Abstract

Evidence shows that having a drink of water can improve cognitive performance in schoolchildren. This study investigated whether water consumption would improve a range of tasks requiring both cognitive and fine motor skills. Participants were 85 children (37 boys, 48 girls, mean age 10.1 years, SD = 0.6) attending a primary school in the UK. Children completed finger-tapping, bead-threading and handwriting tasks at baseline and test. They were divided into two groups; one group was offered a 500ml bottle of water after baseline tasks were completed and the other group was not. The drink group were given five minutes to consume the water and they could choose how much to drink. We also recorded the volume of water consumed in order to consider dose response relationships. Participants in both groups were given a 25 minute break, during which they could read quietly, before repeating the tasks at test. Results showed that the participants who were given a drink, regardless of volume, had faster handwriting speed at test than those who did not. Correlations between volume drunk and changes in performance from baseline to test showed there was a positive relationship between volume drunk and improvement in finger tapping speed. These results show that the simple intervention of giving children a drink of water has a beneficial effect on fine motor skills, and handwriting, which is an integral activity in school.

Keywords

Hydration, water consumption, handwriting, children, cognition, motor skills

Introduction

There are a growing number of studies that show that drinking water can enhance some aspects of cognitive performance in both adults and children (Liska et al., 2019). Consistently, studies have shown that drinking water improves performance in tasks requiring visual attention in both adults and children (Edmonds et al., 2017; Liska et al., 2019; Miljkovic Krecar et al., 2014; Rogers et al., 2001). Positive effects of water consumption have also been found in tasks which measure simple reaction time (Edmonds et al., 2013) and short-term memory in adults (Edmonds et al., 2017) and children (Benton & Burgess, 2009; Fadda et al., 2012).

Furthermore, there is some evidence that the enhancing effect of drinking water on cognitive tasks can be moderated by subjective thirst (Edmonds, Crombie & Gardner, 2013; Rogers, Kainth & Smit, 2001) and the amount of water drunk (Edmonds et al., 2017). Previous studies in adults showed that drinking water only improved cognitive performance in participants who rated themselves as having high thirst at baseline (Edmonds, Crombie & Gardner, 2013; Rogers, Kainth & Smit, 2001). Performance may also be affected by the volume of water drunk, for example, Edmonds et al (2017) found that a minimum of 300ml of water had to be drunk to improve memory. It is also of note that one may not need to ingest water to improve cognition - mouth rinsing alone has been shown to improve performance in a visual attention task (Edmonds, Harte, & Gardner, 2018; Edmonds, Skeete, Gardner, 2021).

Less research has been carried out to determine the effect of water consumption on psychomotor tasks, which require both a cognitive and motor response. To date, studies show that water consumption increases motor speed in adults in the trail making test (Benefer et al., 2013) and improves performance in children playing a "Wii" console game which requires a motor response in the form of the press of a button and a simultaneous downward sweep of the hand (Booth, Taylor, & Edmonds, 2012). However, no impact of drinking water was found on children's performance on a simple paper and pencil manual line tracing task which requires visuomotor skills (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009; Chard, Trinies, Edmonds,Sogore,Freeman,2019) There is little consistency in the type and complexity of motor tasks included in such intervention studies to date. Tasks assessing cognition and fine motor skills involve both a variety of cognitive skills and motor response. For example, the “Wii” console game task involves cognitive components such as visual sustained and selective attention (Brucki & Nitrini, 2008) as well as motor skills such as motor coordination and speed. In contrast, the manual line tracking task has simpler demands, requiring hand-eye coordination (Gowen & Miall, 2007).

In this study we have used a range of psychomotor tasks to assess the impact of drinking water on tasks requiring fine motor skills with varying cognitive demands. To assess the effect of drinking water on psychomotor skills with low cognitive demands, we included a finger-tapping task to assess motor speed without a requirement for visual processing (Christianson & Leathem, 2004; Henderson & Pehoski, 2006). To assess the effect of drinking water on a task which requires a measure of hand-eye coordination skills that are not required for finger-tapping task performance , we used a bead threading task. The bead threading task requires visual processing, feedback of tactile information and finger movement control (Henderson & Pehoski, 2006) .

In addition to considering the impact of drinking water on experimental psychomotor tasks, we considered the impact on a psychomotor activity employed everyday by children in schools – handwriting. It is easy to underestimate the impact of handwriting for children’s academic attainment. However, handwriting is linked to academic performance (Dinehart, 2015), to better spelling (Pritchard et al., 2020; Puranik & Apel, 2010), reading (Pagliarini et al., 2015) and writing composition (Connelly et al., 2006). Handwriting is a complex task that requires the coordination and interaction of many different processes including fine motor skills (Naider-Steinhart & Katz-Leurer, 2007; Smits-Engelsman et al., 2001) and cognitive skills including visual perception (Tseng & Chow, 2000), memory and sustained attention (Feder & Majnemer, 2007). If drinking water impacts on psychomotor experimental tasks, it is likely that it will impact on handwriting, but to date, there have been no published studies on the effects of drinking water on handwriting performance.

The aim of the present study was to explore the effect of water consumption on performance on two simple psychomotor tasks, one requiring hand-eye coordination and one not, and an everyday psychomotor activity, handwriting. It was hypothesised that handwriting performance would be better in children that consumed additional water compared to those that did not because the task requires a number of cognitive components, such as visual sustained and selective attention, that have been shown to be improved by water consumption in previous studies. We hypothesized that there would be no difference in performance in the drink and no drink group in the bead threading or finger tapping task as these tasks are less complex requiring only fine motor skills and in the case of bead threading simple hand-eye coordination.

Materials and Methods

Participants

Data were collected from 86 children, 37 males and 49 females, who were attending two primary schools in the UK. Sample size was consistent, and slightly higher, than similar previous studies in which statistically significant results were found (Edmonds et al., 2017; Edmonds, Beeley, Rizzo, Booth, & Gardner, 2021). One child's data (female) were removed as she was in the drink group but chose not to drink any water. The age range for the remaining 85 children was 8.8 years to 10.7 years (Mean = 10.1 years, SD = 0.6). There were three classes with a total of 40 children (19 males) randomly assigned to the drink condition (Mean = 10 years, SD = 0.5). and three classes with a total of 45 children (18 males) in the no drink condition (Mean = 10.1 years, SD = 0.5). Not all of the children recruited to the study completed all the tasks and the number of data included in the analysis for each outcome can be seen in Figure 1.The study received ethical consent from the University of East London' s Ethics Committee and adhered to the Declaration of Helsinki. Under the direction of class teachers, all children in the six classes(4 classes from one school, n = 57; 2 classes from the other school, n = 28) participated in the tasks as part of a teacher-led class science activity, but data were collated and reported here only if written consent was given from the legal guardian/parent and assent given from the child.

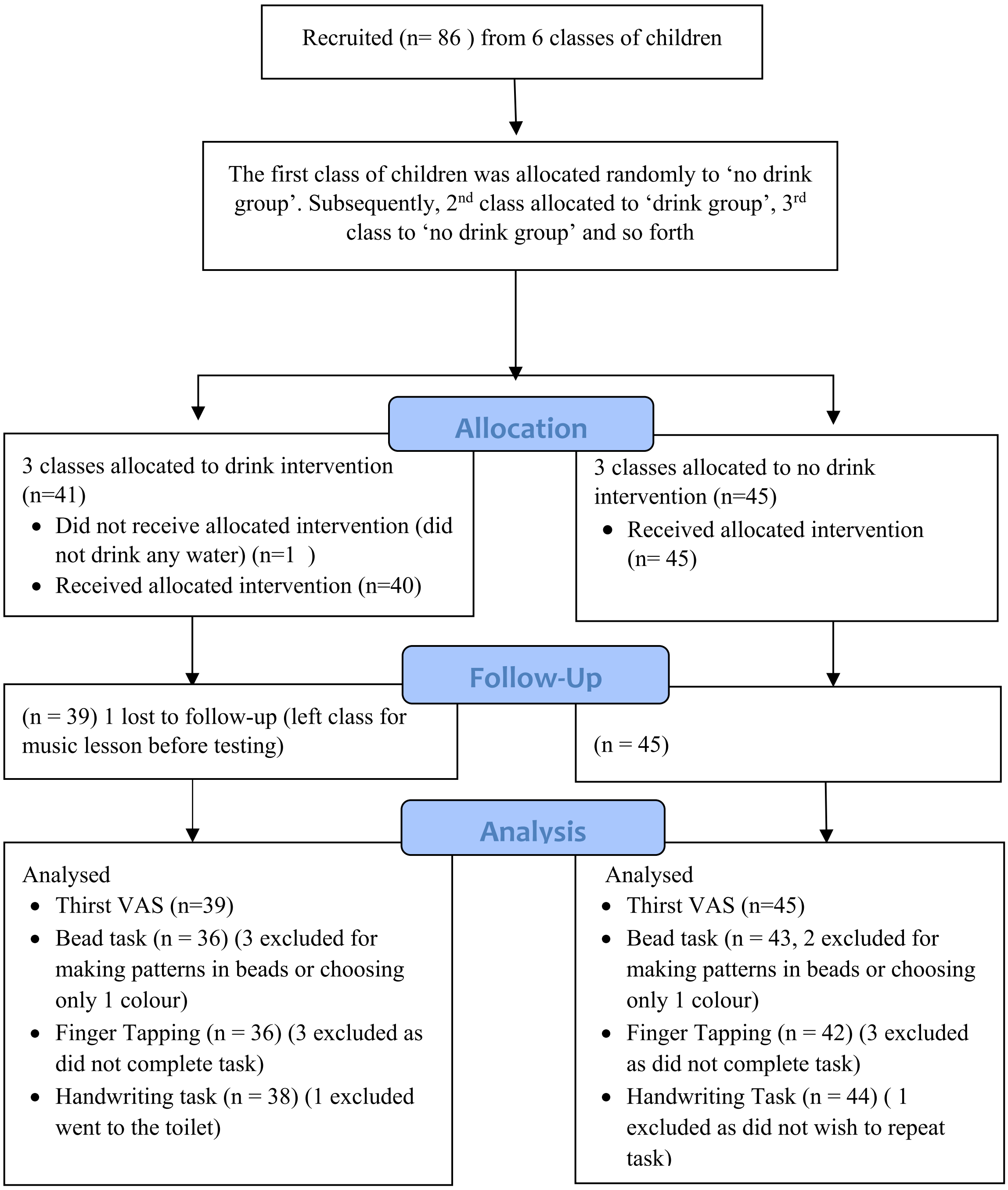

Figure 1. Consort Flow Diagram of the process from recruitment to analysis of a parallel randomised trial of two groups (Schulz, Altman, & Moher, 2010)

Materials

The participants were given a thirst scale and psychomotor tasks to complete both before and after the intervention. They were completed in the order described below.

Thirst Scale. The participants were presented with a Visual Analogue Scale (VAS) and asked to draw a cross along the line to represent how thirsty they felt. The scale was a 100mm long with a question asking 'how thirsty are you?', and a pictorial representation anchoring each end. The VAS represented a continuum with 'not' on the left hand side and 'very' on the right hand side. Distance in mm was measured from the left hand side of the line to the cross. The maximum score was 100 and a higher score indicated higher subjective thirst.

Finger-tapping. A hand held number counter was used to record the number of finger taps. Participants held the tapping device with their index finger placed on the counting button, which they pushed, and their thumb supporting the base. They were advised to put their elbow of the arm holding the tapping device, on to the desk, to give their arm stability. Participants completed three trials of 10 seconds both on the right hand and then the left hand (Spreen & Strauss, 1998). In each 10 second trial the participants were asked to tap as quickly as possible. After each trial the participant recorded the number of taps from the number counter window into their task booklet and reset the tapping device to 0000, ready for the next trial. The number of finger taps were measured by calculating the averages of the two trials with the smallest deviation between them and then adding the average scores for the left and right hand together.

Bead Threading. Each participant was supplied with a small plastic box containing 150 6 x 8mm, coloured, plastic, barrel beads and a piece of string that was 15cm in length, with a knot in one end. The participants were told to thread beads, as quickly as possible onto the string and to pick beads at random and not to make a pattern or choose any particular colour bead. The allotted time for the task was 30 seconds. At the end of the task the participants were asked to count how many beads they had threaded and write the number in their task pack; then to take the beads off the string and put them back into the box. The score was the total number of beads threaded.

Handwriting Test. The participants were given a handwriting speed and quality test which was adapted for this study from the Systemic Detection of Writing Problems Manual SOS-2-EN (Smits-Engelsman, Van Bommel-Rutgers, & Van Waelvelde, 2014). Participants were presented with five short sentences (e.g. ‘the sun is warm’) and four longer paragraphs. On a blank sheet of unlined A4 paper, they were instructed to copy as much of the text as they were able in three minutes, in their own handwriting, at their own speed and without erasing any mistakes. The participants could use their normal writing instrument whether that be a pencil or pen. Speed and quality of handwriting were then calculated according to the following test criteria.

Speed of handwriting was scored by counting how many letters the participants had copied in the three minutes, irrespective of whether words were copied correctly and including letters that were crossed out. The higher the score the faster the speed of writing.

Quality of handwriting was scored by assessing the handwriting using the standardised assessment instructions described in Table 1. This assesses quality by considering whether the sample handwriting deviates from the prescribed criteria on seven measures. For each measure, the first five lines of the child’s handwriting were assessed to determine how often the deviation occurred. If the deviation occurred in 0 or 1 lines it was scored as 0, if it occurred in 2 to 3 lines it was scored as 1, and a score of 2 was given if the deviation occurred in 4 or 5 lines. The total handwriting quality score was a composite score from all 7 measures and ranged from 0 (no deviations) to 14. Two researchers independently assessed the handwriting for the total score at baseline and test; both were blind to the conditions. A good degree of reliability was found between baseline (intraclass correlation coefficient (ICC) = 0.74 with 95%

confident interval = 0.45-0.88) and test total scores (ICC = 0.70 with 95% confident interval = 0.72-0.86). The higher the score, the worse the quality of writing.

Table 1. Handwriting Quality Measures

Measure No.	Type of Measure	Description of Measure
1	**Letter Form**	The strokes that make up the letter deviate from the accepted form
2	**Fluency**	Lines should flow fluently. Deviations are noted if there are sudden changes in direction or hesitations resulting in sharp angles within letter forms or between letters
3	**Transitions**	Transitions between letters should be smooth without broken lines or sudden changes in direction
4	**Letter Size**	A template is used to measure the average height of the letter in millimetres. Above or below the norm is considered a deviation.
5	**Regularity**	The variance between the height of the smallest and tallest body letter. The norm is considered between 1 and 3mm. Anything above is a deviation (read Smits-Engelsman, Van Bommel-Rutgers, & Van Waelvelde (2014) for more detailed information) .
6	**Word Spacing**	When spacing between words is less than that of an ‘o’ written by the child.
7	**Straight Line**	A template is used to determine when a sentence deviates from a straight line.

Procedure and Intervention

Testing was administered to a whole class group on each occasion. The first class to be tested was randomly allocated to the no drink condition. Subsequently, the second class was allocated to the drink condition, the third class to the no drink condition and so forth. The testing began at the beginning of the school day, at approximately 9.15am. The baseline tasks took approximately 20 minutes and then the intervention was administered whilst participants read quietly to themselves. Participants in the drink condition were each given a 500ml bottle of water and 5 minutes to drink as much or as little as they wished, after which the water bottles were labelled with the participant number and collected. The volume drunk was later measured and recorded. A volume of 500ml was chosen to ensure participants would consume the same range of water, between 25ml and 500ml , which has been shown to improve cognitive performance in previous studies (Booth, Taylor, & Edmonds, 2012; Edmonds, Crombie, & Gardner, 2013; Edmonds et al., 2017; Edmonds & Jeffes, 2009) In the no drink condition participants were not given a bottle of water. After the intervention the participants in both conditions were given a further 25 minute period in which they quietly read their books and then the second testing session began. The length of intervention time is consistent with lengths of time given in previous studies which range between 20 to 30 minutes (Benton & Burgess, 2009; Edmonds, Beeley, Rizzo, Booth, Garden, 2021). In the second session the tasks were completed in the same order as in the first session.

Statistical Analysis

The main analyses consisted of a series of one way independent analysis of covariance (ANCOVA). Drink/No Drink was the independent variable (IV) and test outcome scores were the dependent variables (DV). We included baseline scores as covariates to control for any potential differences at baseline between conditions. The drink group had a significantly higher handwriting quality score at baseline than the no drink group, $t(82) = 2.35$, $p = .02$. There were no other statistical differences between the two groups at baseline. We screened for outliers by checking box plots for extreme scores. Data analysis was carried out with outliers both in and excluded and they did not significantly change the result, thus we left outliers in the data set. Not all participants completed all the tasks (see Figure 1 for more details). The alpha level was set at $p < .05$ to determine statistical significance.

We also carried out some exploratory analyses. To explore whether thirst ratings at baseline altered the effect of water consumption on test scores, we observed whether any changes had occurred to the results after the addition of baseline thirst ratings as a covariate to each ANCOVA. A multivariate correlation explored the relationships between volume drunk and the change in performance between baseline and test for all outcome measures.

Results

Data presented in Table 2 shows the unadjusted baseline and test mean scores for all outcome measures by condition and time of test.

Table 2. Unadjusted Means and Standard Deviations (SD) for all measures by drink group and time of test

	Drink Group				*No Drink Group*			
	Baseline		Test		Baseline		Test	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Hand Writing Speed	160.45	45.37	212.84	50.27	164.81	42.78	201.16	50.24
Hand Writing Quality	6.39	2.37	8.48	2.41	4.58	2.83	5.79	3.02
Finger Tap	46.94	10.06	52.81	12.95	46.92	8.38	48.96	9.01
Bead Threading	6.94	2.12	8.27	2.99	7.34	2.49	8.63	2.34
Perceived Thirst	42.88	27.43	27.64	34.16	46.05	22.18	65.18	25.59

Was performance in the psychomotor tasks better in the drink group compared to the no drink group?

The effect of drink group when adjusted for baseline score on handwriting speed was significant, with children writing faster at test in the drink group than the no drink group $F(1,79)=5.299, p = .02$, $\eta^2 = .06$. However, there was no effect of the intervention on handwriting quality ($F(1,79)=3.151, p = .08$, $\eta^2 = .04$.). Performance on the other motor tasks was not enhanced by the intervention: finger-tapping ($F(1,75)=3.161$, $p = .08$, $\eta^2 = .04$) or bead threading ($F(1,76)=0.008$, $p = .93$, $\eta^2 = .00$.). As expected, perceived thirst was significantly lower at test in the group that drank water compared to the group that did not drink water $F(1,79)=24.760, p <.000$, $\eta^2 = .23$.

Did baseline thirst moderate the effect of the intervention on performance?

We carried out some exploratory analyses to assess whether subjective thirst moderated the effects of water consumption on task performance (Edmonds et al., 2017; Rogers et al., 2001). The perceived thirst baseline score was added as an additional covariate to the ANCOVA described above to determine if it moderated the effect of the drink condition on each outcome. The results showed that baseline thirst had no effect on test scores for any outcome measure and results remained consistent with those in the main analyses. Handwriting speed remained significantly faster in the drink group $F(1,78)=5.227, p = .02$ and there were no significant differences between the no drink and drink group for handwriting quality ($F(1,78)=2.848, p = .09$), finger-tapping ($F(1,74)=3.053, p = .08$) and bead threading ($F(1,75)=0.061, p = .81$). These results suggest that baseline thirst does not moderate the relationship between drink condition and test scores.

Did the volume of water drunk affect task performance?

We also carried out an exploratory analysis to explore whether volume of water drank was related to changes in performance between baseline and test (Edmonds et al., 2017). Children in the drink condition consumed between 13ml and 500ml water (Mean = 269.2ml, *SD* = 186.39ml). Data in Table 3 show that there was a significant positive correlation between the change in finger tapping performance between baseline and test and the volume drank ($r = .36, p < .05$); as the volume of water drunk increased so did the improvement in finger tapping performance. There were no significant relationships between volume consumed and the other outcome measures.

Table 3. Pearson's R and Significance Levels for Correlations between Volume and Difference Scores in the Water Condition

Measure	Pearson's correlation co-efficient	P value

Thirst Diff	.036	.825
HW Speed Diff.	-.209	.201
HW Quality Diff.	-.021	.899
Finger Tap Diff.	.358	.029*
Bead Thread Diff.	-.115	.499

*p<.05

Discussion

In our study, children's handwriting speed was enhanced at test if they consumed additional water compared to those who did not have additional water. In contrast, there was no effect of drinking water on handwriting quality. There was no significant difference between the drink and no drink group in the bead threading or finger tapping task. While children who had a drink rated themselves as less thirsty than participants that did not have a drink, thirst ratings at baseline did not moderate the effect of drinking water on task performance. Our exploratory analyses showed that there was no correlation between the volume of water drunk and changes in perceived thirst, handwriting quality, handwriting speed or bead threading. However, as the volume of water drunk increased, there was a bigger improvement between baseline and test in finger tapping performance.

These results are consistent with our hypothesis that handwriting performance would be enhanced by drinking additional water; handwriting speed was faster but handwriting quality did not change. Our findings also supported our hypotheses that drinking water would not impact bead threading and finger tapping. Previous studies have shown that more complex tasks, requiring more cognitive skills, such as the trail making test (Benefer et al., 2013) and a "Wii" console game (Booth, Taylor, & Edmonds, 2012) are improved by consuming additional water. Conversely no effects of drinking water have been found on simpler tasks such as manual line tracing task which requires hand eye coordination (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009; Chard, Trinies , Edmonds, Sogore, Freeman, 2019)

Our finding that handwriting speed was improved by water consumption is likely to be of great interest to educators. Handwriting is of utmost importance in children as good practice is essential for the development of other academic skills such as writing composition and reading ability (Connelly, Campbell, Maclean, & Barnes, 2006; Dinehart, 2015; Dinehart & Manfra, 2013; Pagliarini et al., 2015; Pritchard, Malone, & Hulme, 2020; Puranik & Apel, 2010). Evidence suggests that children who struggle with writing at speed may not be able to keep up with the volume of work at school and may consequently suffer from low self-esteem and a reduction in academic attainment (Feder & Majnemer, 2007). In our study, gains in handwriting speed were not at the expense of quality, which is counter to the generally accepted notion that as speed increases, so quality will deteriorate (Feder & Majnemer, 2007). While our study would benefit from replication, and in children of different ages, it suggests that drinking water interventions may be useful in the classroom to enhance the volume of work that children can produce.

In the current study, the subjective rating of thirst did not moderate the effect of water consumption on task performance. This is not consistent with previous studies of adults which showed that drinking water improved cognitive performance in participants who rated themselves as having high thirst at baseline (Edmonds, Gardner, 2013; Rogers, Kainth & Smit, 2001). However, the current study was carried out on children rather than adults and there is a question as to whether children have the same sensitivity to the feeling of thirst as adults (Kenney & Chiu, 2001). If children have yet to reach maturity in the ability to recognise and calibrate the perception of thirst, and/or relate it to the need to have a drink, this may explain why the subjective thirst ratings in the present and previous studies (Edmonds & Jeffes, 2009) in children did not moderate the effects of water consumption on task performance.

In the current study, our exploratory analysis showed that as the volume of water consumed increased so did the improvement in finger tapping between baseline and test. This finding was surprising given that there was no significant difference in the number of finger taps at test between those that had a drink of water and those that did not. It is plausible that there was not sufficient power to show a significant difference between those who had a drink and those who did not. This could be due to individual differences in the volume of water that participants drank, ranging from 13ml to 500ml water. Thus, the number of participants who drank a larger volume of water (and thus had a larger improvement in finger tapping) was small. Further studies in which the volume of water is manipulated and larger participant numbers are included will need to be carried out to examine this possibility further.

Consistent with our findings, previous studies have reported a dose response effect of water on performance in both motor and non-motor tasks. For example, ball catching performance was better for children that had consumed more than 200ml of water compared to those who consumed less than 200 ml (Booth et al., 2012). In the digit span task, a measure of working memory, performance has been reported to improve only when larger volumes, over 200ml, of water are consumed (Edmonds et al., 2017).

Conversely, handwriting speed showed no sensitivity to volume of water consumed. Results from the few studies to determine how water consumption improves cognitive performance suggest that there may be different mechanisms for different cognitive domains. For example, as previously stated, the digit span task requires large volumes of water to be consumed for performance to be improved (Edmonds et al., 2017). Conversely, performance on a letter cancellation task, which involves attention has been found to improve after drinking water (Edmonds et al., 2017), but also after simply wetting the mouth with no requirement for swallowing the water (Edmonds et al., 2018). Thus, handwriting speed may have been better in children that had a drink of water because specific cognitive domains were improved which simply required wetting of the mouth rather than a particular volume of water. Recent studies have suggested that, for some cognitive processes, the effect of drinking water on performance may be a result of changes in attention or focus (Edmonds et al., 2018). These findings are consistent with our study results which show that performance on some of the tasks were affected by water consumption while others were not. Further work is necessary to explore what the processes or mechanisms are responsible for the impact of water consumption on cognitive and fine motor skills and how volume may be related to these mechanisms.

A limitation of the current study was that it is possible that expectancy effects may have improved handwriting speed in the water group. The information sheet to teachers, parents and children advised that some studies had found an effect of drinking water on cognitive performance. However, previous studies have found no evidence for the effect of expectation of drinking water improving cognitive performance (Edmonds, Crombie, Ballieux, Gardner, & Dawkins, 2013; Ganio et al., 2011). In addition, the handwriting task which was better in the water group at test, was the last task in the battery, thus expectation did not appear to have an impact on the first two tasks in the battery. Therefore, we were confident that expectancy did not have a deleterious impact on the study.

A strength of the present study was concerned with the effect of drinking water on cognitive and motor performance and not concerned with whether this is mediated by a change in hydration status affected by drinking water. Measuring hydration status, particularly in a classroom rather than a clinical setting, is difficult and there is currently no single assessment gold standard (Armstrong, 2007). Best practice guidelines recommend the use of a combination of assessments which include: taking biomarkers from blood, urine, saliva or tears; measuring isotopes; body mass changes; perceived thirst and assessment of urine colour (read Barley, Chapman & Abbiss, 2020 for review). Many of these measures cannot be used to assess dynamic changes in hydration status (Barley, Chapman & Abbiss, 2020) and the accuracy and reliability of testing for acute changes after the consumption of a bolus of water is under debate (Sollanek et al., 2011; Williams et al., 1989). As a consequence, the current study focused on the effect of drinking as this lends itself to pragmatic classroom interventions in which teachers could try to encourage the whole class to drink, in the absence of any information about individual childrens' hydration status.

In conclusion, the results show that water consumption improved handwriting speed and that the volume of water consumed had a dose response effect on finger tapping speed. Our results suggest that the cost-effective, simple act of having a drink of water may improve children's handwriting speed in schools and consequently drinking water may be a factor in improving performance at school.

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