Proceedings

Annals of Nutrition & Metabolism

Ann Nutr Metab 2015;66(suppl 3):38–41
DOI: 10.1159/000381245

Published online: June 18, 2015

The Relationship between Total Water Intake and Cognitive Control among Prepubertal Children

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Key Words
Water · Cognition · Children · Attention · Reaction time

Abstract
Background: Cognitive control (also known as executive function) encompasses mental processes that underlie goal-directed behavior, and it enables us to adjust our behavior according to changing environmental demands. Previous research among children has demonstrated that aerobic fitness and obesity have contrasting and selective effects on cognitive control. However, the relationship between water intake and childhood cognitive control remains inadequately studied. This study investigated the relationship between total water intake and cognitive control among prepubertal children (8–9-year olds). ***Methods:*** Children between 8 and 9 years of age (n = 63) performed a modified flanker task to assess cognitive control related to inhibition (ability to resist distractions and maintain focus). Diet was measured using 3-day food records. Total water was defined as water consumed from drinking water, beverages, and food. ***Results:*** A comparison of task performance across the median intake of total water revealed that children above the median exhibited shorter reaction times across multiple conditions of the flanker task, requiring variable amounts of cognitive control. Further, after adjustment of age, IQ, socioeconomic status, weight status, and aerobic fitness level, the proportion of intake comprised of water (%TW) was negatively correlated with reaction time interference, that is, the ability to maintain task performance when task conditions demanded greater inhibition. ***Conclusions:*** These results indicate an association between water intake and cognitive control using a task that modulates inhibition. Specifically, higher water intake correlated with greater ability to maintain task performance when inhibitory demands are increased. Future work is needed to determine the mechanism by which water influences cognitive control among children.

Introduction

Adequate fluid intake is crucial to sustain vital physiological functions, including transportation of oxygen, nutrients, and waste products [1]. Considering the systemic adverse effects of dehydration, it is likely that the brain and cognitive function are not immune to the detrimental effects of inadequate fluid intake. However, the influence of water intake on childhood cognitive function is unclear. This is a matter of concern, because children,

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in particular, may be at risk for dehydration because they are dependent on adults for the provision of fluids [2]. Further, there is evidence suggesting that, relative to their hydrated counterparts, children who are chronically dehydrated exhibit poorer cognitive function [3].

Given that the brain continues to undergo developmental changes throughout childhood, the identification of dietary factors associated with cognitive function has important implications for cognitive health throughout the lifespan [4, 5]. Cognitive control (i.e., executive control) is of particular interest because it encompasses processes that underlie goal-directed behavior and are orchestrated by activity within brain circuits that rely heavily on the prefrontal cortex [6]. In other words, cognitive control enables us to adjust our behavior to changing environmental demands. Previous research among children has demonstrated that aerobic fitness and obesity have contrasting and selective effects on cognitive control [7]. In addition, an emerging body of literature has begun to characterize the role of dietary components in mediating cognitive control processes in childhood. However, much of this work has focused on the cognitive implications of caloric macronutrients (i.e., fats, carbohydrates, proteins). Therefore, the influence of water – perhaps the most essential nutrient – on cognitive control in childhood remains understudied.

Accordingly, we assessed the relationship between total water intake and cognitive control among prepubertal children. We hypothesized that higher water intake will correlate with performance on a task requiring variable amounts of cognitive control among prepubertal children.

Methods

This study was based on an exploratory analysis of baseline data collected from a subsample of prepubertal children between 8 and 9 years of age (n = 63) who participated in a randomized controlled trial [Fitness Improves Thinking in Kids (FITKids)]. Participants provided written assent, and their legal guardians provided written informed consent in accordance with the regulations of the University of Illinois Institutional Review Board. Data were also collected on IQ [8], socioeconomic status (SES), and pubertal status [9]. Height and weight were measured using a stadiometer (Seca; model 240) and a Tanita WB-300 Plus digital scale, respectively. Cardiorespiratory fitness was assessed using maximal oxygen consumption (VO_{2max}) via a computerized indirect calorimetry system (ParvoMedics TrueMax 2400). Children were asked to run on a treadmill at a constant speed with increases in grade increments of 2.5% every 2 minutes until volitional exhaustion. A Polar HR monitor (Polar WearLink®+ 31, Polar Electro, Finland) was used to measure the heart rate throughout the test. Criteria for achieving VO_{2max} are previously described [10, 11]. Water intake was assessed using the average of 3-day food records (2 weekdays and 1 weekend day). Food records were analyzed using the Nutrition Data Systems-Research (Nutrition Coordinating Center, Minneapolis, MN, USA) software. Water intake variables included average daily total water (TW), and % of total food weight comprised water (%TW) for subsequent analyses.

Participants completed a computerized flanker task to assess cognitive control [12]. Children were asked to respond (using a response pad) to a centrally presented target stimulus amid an array of four flanking stimuli, which were task irrelevant. The task consisted of congruent trials, in which flanking fish faced in the same direction as the target fish, and incongruent trials, in which flanking fish faced in the opposite direction from the target fish [13]. In the compatible condition, participants responded to the direction of the target fish with their consonant thumb. During the incompatible condition, participants responded in the direction opposite to that of the target fish. After 40 practice trials, participants completed 150 trials (75 trials × 2 blocks) in each compatibility. Stimulus duration was 200 ms, with a 1,700 ms intertrial interval. Interference scores for response accuracy (congruent – incongruent) and reaction time (incongruent – congruent) were also calculated, within compatibility condition, to index ability to maintain task performance between the two trial types.

Statistical analyses

Associations between water intake and flanker response accuracy and reaction time were assessed using partial correlations, adjusting for confounding variables (i.e., age, sex, IQ, SES, pubertal staging, VO_{2max}, BMI). An independent t-test was used to determine differences in task performance across groups bifurcated across the median level of water intake. The α-level was set at 0.05, and statistics were performed using SPSS 22 (IBM, Somers, NY).

Results

Participant characteristics, water intake, and flanker performance measures are summarized in tables 1 and 2. While the majority (59%) of participants had normal BMI-for-age (<85th percentile), approximately 70% of the participants were lower-fit (<30th percentile VO_{2max}-for-age). A comparison of high and low water consumers – based on the bifurcation of the sample at the median level of water intake (1,046 ml/day) – revealed that children above the median exhibited shorter reaction times during the congruent (p = 0.03) and incongruent trials (p = 0.03) of the compatible condition of the flanker task (figure 1). According to bivariate correlations, TW was not significantly related to congruent or incongruent accuracy or reaction time. However, %TW (r = –0.27, p = 0.02) was negatively related to reaction time interference in the incompatible condition. Further, partial correlation

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Table 1. Participant characteristics and water intake

	Mean (SEM)
Age, years	8.61 (0.1)
Pubertal staging[a]	1.27 (0.1)
Socioeconomic status, n (%)	
Low	16 (25)
Medium	23 (37)
High	4 (38)
Intelligence quotient	113 (1.8)
BMI, kg/m^2	18.3 (0.5)
BMI-for-age percentile	64.8 (3.8)
Weight status, n (%)	
Underweight	2 (3)
Normal weight	37 (59)
Overweight	9 (14)
Obese	15 (24)
VO_{2max}, ml/kg/min	26.5 (0.7)
Water, g/day	1,072.6 (37.3)
%Total water	74.6 (0.7)

[a]Pubertal staging was assessed using a modified Tanner staging questionnaire [26].

Table 2. Cognitive control (assessed using a flanker task) performance among participants

	Mean (SEM)
Compatible flanker	
Congruent reaction time, ms	516.9 (14.8)
Congruent accuracy, %	79.2 (1.5)
Incongruent reaction time, ms	548.3 (16.0)
Incongruent accuracy, %	71.5 (1.4)
Incompatible flanker	
Congruent reaction time, ms	581.4 (16.5)
Congruent accuracy, %	73.0 (1.8)
Incongruent reaction time, ms	598.7 (15.2)
Incongruent accuracy, %	70.4 (1.9)

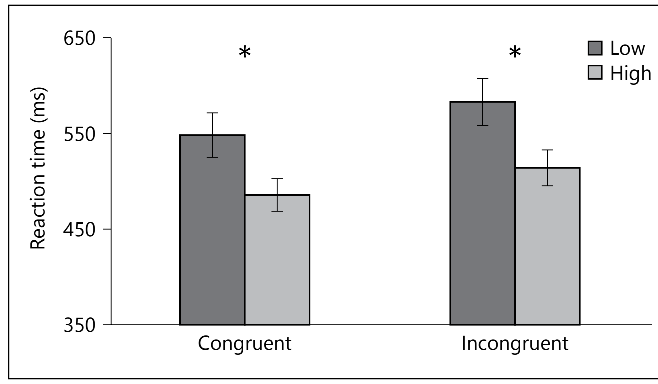

Fig. 1. Illustration that children above the median intake of water exhibit faster reaction times during the congruent and incongruent trials of the flanker task. During the congruent trials, flanking stimuli are presented in the same direction as the target stimulus and during the incongruent trials, flanking stimuli face the opposite direction from the target stimulus. Participants responded to the direction of the target fish with their consonant thumb.

analyses revealed that the negative association of %TW ($r = -0.31$, $p < 0.01$) remained significant even after adjusting for confounding variables. Thus, increasing water intake was selectively associated with better performance during tasks requiring greater cognitive control.

Discussion

Recent studies have delineated lifestyle factors, particularly the health behaviors of physical activity and diet and their interrelated physiological correlates of aerobic fitness and obesity, on childhood cognitive function [11, 14, 15]. Specifically, dietary lipids and fiber intake have been associated with cognitive control and memory among preadolescent children [14, 16]. The major finding of this study is that chronic water intake may be an additional dietary component related to children's cognitive function. Further, the negative relationship between water intake and task interference indicates that higher amounts of water intake may be selectively related to children's ability to increase cognitive control under more challenging task demands.

Among adults, there are well-established links between dehydration and diminished performance on cognitive tasks assessing attention, memory, and psychomotor function [17, 18]. Limited evidence indicates that this may be true for children as well. Bar-David et al. [3] separated 10- to 12-year olds into hydrated or dehydrated groups (no differences based on sex) based on hydration status assessed by urine osmolality [3]. The dehydrated group exhibited lower performance on the number span task, and it showed trends toward poorer performance on semantic flexibility and pattern identification. Further, provision of water has been shown to improve performance on the short-term memory and visual attention tasks [19–21]. However, the relationship between chronic water intake and specific aspects of cognitive function are not well characterized. Therefore, the findings from this study provide preliminary support for the importance of water intake for cognitive control in children.

While the findings from this study are novel, additional studies are necessary to replicate and substantiate these results. Further, the mechanism by which fluid intake mediates brain health and cognition remains unclear. Evidence from animal studies is suggestive of mechanisms involving dehydration-induced decrements in neuronal cell proliferation [22] and neuronal cell shrinkage resulting from water depletion from cells [23]. Alternatively, dehydration is known to increase circulating levels of stress hormones such as cortisol [24], which has been related to decrements in cognitive function [25]. Therefore, future studies that include the assessment of hydration physiology along with fluid intake and cognitive function are needed to develop a comprehensive understanding of the relationship between chronic water intake and childhood cognitive function.

Funding Source

This study was supported by NIH grants (HD055352 and HD069381) and USDA NIFA grant (2011-67001-30101).

Disclosure Statement

The authors have no conflicts of interest to disclose.

References

1 Benton D: Dehydration influences mood and cognition: A plausible hypothesis? Nutrients. 2011;3:555–573.
2 D'Anci K, Constant F, Rosenberg I: Hydration and cognitive function in children. Nutr Rev 2006;64:457–464.
3 Bar-David Y, Urkin J, Kozminsky E: The effect of voluntary dehydration on cognitive functions of elementary school children. Acta Paediatrica 2005;94:1667–1673.
4 Lenroot RK, Giedd JN: Brain development in children and adolescents: Insights from anatomical magnetic resonance imaging. Neurosci Biobehav Rev 2006;30:718–729.
5 Luna B: Developmental changes in cognitive control through adolescence. Adv Child Dev Behav 2009;37:233–278.
6 Best JR, Miller PH: A developmental perspective on executive function. Child Dev 2010;81:1641–1660.
7 Pontifex MB, Kamijo K, Scudder MR, Raine LB, Khan NA, Hemrick B, Evans EM, Castelli DM, Frank KA, Hillman CH: The differential association of adiposity and fitness with cognitive control in preadolescent children. Monogr Soc Res Child Dev 2014;79:72–92.
8 Kaufman AS: K-BIT: Kaufman brief intelligence test. American Guidance Service Circle Pines, MN, 1990.
9 Tanner JM: Growth at adolescence. Oxford: Blackwell Scientific Publications, 1962.
10 Armstrong L: ACSM's guidelines for exercise testing and prescription/american college of sports medicine. 7th ed. Philadelphia: Lippincott Williams & Wilkins, Philadelphia, 2006.
11 Hillman CH, Pontifex MB, Castelli DM, Khan NA, Raine LB, Scudder MR, Drollette ES, Moore RD, Wu CT, Kamijo K: Effects of the FITKids randomized controlled trial on executive control and brain function. Pediatrics 2014;134:e1063–e1071.
12 Eriksen CW, Eriksen BA: Effects of noise letters upon the identification of a target letter in a non-search task. Percept Psychophys 1974;2:249–263.
13 Pontifex MB, Saliba BJ, Raine LB, Picchietti DL, Hillman CH: Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. J Pediatr 2013;162:543–551.
14 Khan NA, Raine LB, Drollette ES, Scudder MR, Kramer AF, Hillman CH: Dietary fiber is positively associated with cognitive control among prepubertal children. J Nutr 2015;145:143–149.
15 Khan NA, Baym CL, Monti JM, Raine LB, Drollette ES, Scudder MR, Moore RD, Kramer AF, Hillman CH, Cohen NJ: Central adiposity is negatively associated with hippocampal-dependent relational memory among overweight and obese children. J Pediatr. 2015;166:302–308.
16 Baym CL, Khan NA, Monti JM, Raine LB, Drollette ES, Moore RD, Scudder MR, Kramer AF, Hillman CH, Cohen NJ: Dietary lipids are differentially associated with hippocampal-dependent relational memory in prepubescent children. Am J Clin Nutr 2014;99:1–8.
17 Cian C, Koulmann N, Barraud P, Raphel C, Jimenez C, Melin B: Influences of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. J Psychophysiol 2000;14:29.
18 Suhr JA, Hall J, Patterson SM, Niinistö RT: The relation of hydration status to cognitive performance in healthy older adults. Int J Psychophysiol 2004;53: 121–125.
19 Benton D, Burgess N: The effect of the consumption of water on the memory and attention of children. Appetite 2009;53:143–146.
20 Edmonds CJ, Jeffes B: Does having a drink help you think? 6–7-year-old children show improvements in cognitive performance from baseline to test after having a drink of water. Appetite 2009;53:469–472.
21 Fadda R, Rapinett G, Grathwohl D, Parisi M, Fanari R, Calò CM, Schmitt J: Effects of drinking supplementary water at school on cognitive performance in children. Appetite 2012; 59:730–707.
22 Levine S, Saltzman A, Katof B, Meister A, Cooper T: Proliferation of glial cells induced by lithium in the neural lobe of the rat pituitary is enhanced by dehydration. Cell Prolif 2002;35:167–172.
23 Finberg L, Luttrell C, Redd H: Pathogenesis of lesions in the nervous system in hypernatremic states. II. experimental studies of gross anatomic changes and alterations of chemical composition of the tissues. Pediatrics 1959; 23:46–53.
24 Francesconi RP, Sawka MN, Pandolf KB: Hypohydration and acclimation: Effects on hormone responses to exercise/heat stress. Aviat Space Environ Med 1984;55:365–369.
25 Kirschbaum C, Wolf O, May M, Wippich W, Hellhammer D: Stress-and treatment-induced elevations of cortisol levels associated with impaired declarative memory in healthy adults. Life Sci 1996;58:1475–1483.
26 Taylor SJC: Performance of a new pubertal self-assessment questionnaire: A preliminary study. Paediatr Perinat Epidemiol 2001;15:88.