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Original Research

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Fluid intake, hydration status and its association with cognitive function among adolescents in Petaling Perdana, Selangor, Malaysia

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ABSTRACT

BACKGROUND/OBJECTIVES: A cross-sectional study was undertaken to evaluate fluid intake and hydration status in association with cognitive function among 230 adolescents (10–14 years of age) in Petaling Perdana, Selangor, Malaysia.
SUBJECTS/METHODS: Urine color was used to measure hydration status, while fluid intake was assessed using the 15-item beverage intake questionnaire. Cognitive function was assessed using the Wechsler Intelligence Scale for Children, Fourth Edition.

RESULTS: More than half of the adolescents were mildly or moderately dehydrated (59.6%) and only one-third (33.0%) were well hydrated. Among the daily fluid types, intakes of soft drinks (r = −0.180; P = 0.006), sweetened tea (r = −0.184; P = 0.005) and total sugar-sweetened beverages (SSBs) (r = −0.199; P = 0.002) were negatively correlated with cognitive function. In terms of hydration status, cognitive function score was significantly higher (F-ratio = 4.102; P = 0.018) among hydrated adolescents (100.38 ± 12.01) than in dehydrated (92.00 ± 13.63) counterparts. Hierarchical multiple linear regression analysis, after adjusting for socio-demographic factors, showed that soft drinks (β = −0.009; P < 0.05) and sweetened tea (β = −0.019; P < 0.05) negatively predicted cognitive function (ΔR^2 = 0.044). When further control for sources of fluid, hydration status (β = −2.839; P < 0.05) was shown to negatively predict cognitive function (ΔR^2 = 0.021). The above variables contributed 20.1% of the variance in cognitive function.
CONCLUSIONS: The results highlight the links between fluid intake (soft drinks, sweetened tea, total SSBs) and hydration status with cognitive function in adolescents. Interventions aimed at decreasing the consumption of SSBs and increasing hydration status through healthy fluid choices, such as water, could improve cognitive performance in adolescents.

Keywords: Beverage; hydration; cognitive function; adolescents

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Conflict of Interest
The authors declare no potential conflicts of interests.

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INTRODUCTION

Water, as a source of hydration, is essential for the physical and physiological functions of the human body [1]. However, previous evidence has shown that adolescents have an insufficient level of water intake, possibly due to a shift from consuming plain water to sugar-sweetened beverages (SSBs) as their primary source of fluid and hydration [2]. For instance, data for 8,109 adolescents (10–18 years old) retrieved from 13 cross-sectional surveys showed that more than 50% of the whole adolescent population were at risk of inadequate water intake [3]. Similarly, the National Health and Nutrition Examination Survey conducted among American children and adolescents aged 6–19 years old reported that 54.5% of that cohort had inadequate hydration [4].

Although it is known that proper hydration is important for human homeostasis and crucial for survival, a relationship between hydration status and brain function, as well as its role in cognitive performance, was only described recently. In particular, the effect of dehydration on cognitive function was shown to be relevant among individuals with poor fluid regulation, such as children, as they are at risk of voluntary dehydration [5]. A study conducted among 168 children aged 9–11 years showed a negative correlation between dehydration and short-term memory, indicating the importance and benefits of drinking water for hydration [6]. Similarly, another study conducted among 125 children with a mean age of 10.98 ± 0.38 years reported that the more water consumed by the children, the better they performed in concentration and memory tests [7]. To the best of our knowledge, only one study has reported on the effects of dehydration on cognitive function in adolescents, and the authors reported adverse effects of dehydration on executive functions such as planning and visuospatial processing [8].

Consumption of SSBs as a source of fluid and hydration is apparent among children and adolescents. Increases in SSB consumption has been observed in both developed and developing countries [9,10], possibly due to the widespread availability of cheap SSBs or soft drinks. Although the consequences of excessive SSB consumption are important in the development of childhood obesity [11,12] and have been associated with increased cardiometabolic risks [9], less has been reported on the association of sugar consumption with cognition, behavior, and mental health [13]. A meta-analysis of sixteen intervention studies that examined the association between sugar and cognition revealed that the relationship was ambiguous [14].

Despite the importance of adequate hydration on health, there is a lack of published studies reporting the hydration status and fluid sources of adolescents in Malaysia [15], and there are no reports on the associations of hydration and fluid source with cognitive function. In addition, little has been reported on SSB consumption and cognitive function in adolescents. Most past studies were conducted using clinical or elderly cohorts [16,17]. Hence, there was a need to determine the associations between fluid intake, hydration status, and cognitive function in adolescents. Therefore, this study was undertaken to examine the associations between fluid intake, hydration status, and cognitive function in adolescents in Petaling Perdana, Selangor, Malaysia.

SUBJECTS AND METHODS

Study setting and subjects

This study was approved by the Ethics Committee of Research and Scholarly Activities of the Faculty of Applied Sciences, UCSI University (Proj-FAS-EC-16-001). Approval to conduct the study was obtained from the Ministry of Education, Malaysia (KPMSP.600-3/2/3JLD 27). Prior to data collection, authorization was obtained from participating primary school principals. Respondents and their parents were informed about the purpose of the study through information sheets distributed by their school teachers. Signed consent forms were obtained from the respondents and their parents prior to data collection.

This cross-sectional study was conducted among primary and secondary school children aged 10–14 years in the education district of Petaling Perdana, in the state of Selangor, Malaysia. A multi-stage sampling method was applied. Stratification by education was applied according to primary and secondary education levels. From a list of 57 schools that fulfilled the inclusion criteria of being multi-ethnic and co-educational, 2 national primary and 3 national secondary schools were randomly selected. From each school, one class from each year (primary 4 & 5; secondary 1 & 2) were selected randomly and invited to participate in this study. Parental information sheets and consent forms were distributed to the selected students via their teachers. Out of 500 child-parent pairs that were invited to participate, 230 child-parent pairs participated in and completed the study (response rate 46.0%).

Measurements

Socio-demographic background

To assess the socio-demographic background of the parent-child pairs, the child's date of birth, child's age, parent's sex, parent's ethnicity, parent's highest educational level, parent's occupation, and household monthly income information were gathered.

Daily fluid intake of children

Habitual beverage intakes of children were assessed using the 15-item beverage intake questionnaire [16]. The responses provided estimates of mean daily intakes of water, all beverages, and SSBs. Questionnaire instructions with examples on how to answer the questions were provided by the researchers to the adolescents. The questionnaire included questions on twelve beverage categories: water, 100% fruit juice, sweetened juice beverage or drink, whole milk, low-fat milk, soft drinks, diet soft drinks, sweetened tea, tea or coffee with sugar and/or creamer, tea or coffee black without sugar and/or creamer, energy/sports drinks, and malted drinks, which are popular among Malaysians [17]. Alcoholic beverages and reduced-fat milk were excluded as alcoholic beverages are forbidden for Muslim adolescents and reduced-fat milk is not commonly available in Malaysia. Available responses included "how often" ranging from "never or less than once per week" to up "3+ times per day" and "how much" ranging from "less than ¾ cup" to "more than 2½ cups". The total intake per week was divided by 7 to obtain the daily mean intake for each beverage. The SSBs category included 100% fruit juice, sweetened juice beverage, malt drinks, soft drinks, diet cola, sweetened tea, and tea/coffee with sugar and/or creamer. The daily mean intake of each beverage within the SSB category was summed to obtain the total SSB intake, whereas the daily mean intake of each type of fluid was summed to obtain the total daily fluid intake. The total daily fluid was then compared with the daily fluid intake requirements presented as Recommended Nutrient Intakes (RNIs) in the Malaysian Dietary Guidelines for Children and Adolescents [18].

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Hydration status

A urine color chart [19] was used to assess the hydration status of the subjects. The urine color chart consisted of 8 color scales ranging from pale yellow or straw-colored (1) to brownish green (8). Urine colors 1 to 3 indicated "well-hydrated", 4 indicated "normally hydrated or slightly dehydrated", 5 and 6 indicated "dehydrated", and 7 and 8 indicated "extremely dehydrated" [19]. Once the subjects were at school, subjects were provided with urine sample containers to collect first-morning urine. A total of 10 mL of urine was collected to represent the first-morning urine sample. Once the urine was collected, the urine color was determined by the same researcher.

Cognitive function

The cognitive function of the subjects was assessed using the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV), which is an appropriate test for children aged 6 to 16 years. To reduce test fatigue and burden of the respondents, only the similarities, digit span, block design, and coding subtests were used in this study. For each of the subtests, the raw scores were converted into scaled scores that were adjusted for age [20]. A composite score was derived from the 4 scaled subset scores and was converted into a cognitive function score using a conversion table provided by the provider of WISC-IV short forms [20]. The internal consistency of the cognitive function scores in the current study was acceptable ($\alpha = 0.71$). Before use, the original subtests were translated into Malay and back-translated to English by 2 qualified psychologists who were proficient in both languages. The face validity of the items was then examined by a qualified and registered clinical psychologist. Before administration of the test, the researcher underwent relevant training by a qualified clinical psychologist. Test administration was conducted in a quiet room using uniform procedures.

Data analysis

Data were analyzed using IBM SPSS Statistics (version 22.0; IBM Corp., Armonk, NY, USA). Independent sample t-tests were used to determine differences between means of daily fluid intake, hydration status, and cognitive function of male and female subjects. One-way analysis of variance was used to compare differences in cognitive function across fathers' and mothers' educational level and monthly household income categories. Pearson correlation coefficients were used to determine the correlations between continuous variables. Hierarchical multiple linear regression was performed to test the contribution of individual variables to cognitive function. To determine the differential contribution of each block of variables toward the prediction of cognitive function, socio-demographic features (age, sex, ethnicity, education level, household income) were entered in the first block. Fluid intake types (water, 100% fruit juice, sweetened juice beverage, whole milk, low-fat/fat-free milk, malted drink, soft drinks, diet cola, sweetened tea, tea/coffee without sugar and/or creamer, tea/coffee without sugar and/or creamer, energy/sports drink) were used in the second block, and hydration status was used in the last block. Statistical significance was set at $P < 0.05$.

RESULTS

A total of 230 adolescents (37% male and 63% female; mean age 12.50 ± 1.61 years) participated in this study (**Table 1**). More than half (60.8%) of the adolescents were Malay, with the remaining being Chinese (19.6%) and Indian (19.6%). The majority of parents had at least a secondary school education (84.7% fathers and 70.8% mothers), and most (53.4%) had household incomes within the RM1,500 to RM5,999 range.

Table 1. Socio-demographic characteristics of respondents (n = 230)

Characteristics	Respondents	
	n (%)	Mean ± SD
Age (yrs)		12.50 ± 1.61
10	61 (26.5)	
11	34 (14.8)	
13	60 (26.1)	
14	75 (32.6)	
Sex		
Male	85 (37.0)	
Female	145 (63.0)	
Ethnicity		
Malay	140 (60.8)	
Chinese	45 (19.6)	
Indian	45 (19.6)	
Father's educational level		
Primary	35 (15.2)	
Secondary	66 (28.7)	
STPM/diploma	68 (29.6)	
Tertiary	61 (26.5)	
Mother's educational level		
Primary	66 (28.7)	
Secondary	67 (29.1)	
STPM/diploma	56 (24.3)	
Tertiary	41 (17.8)	
Monthly household income		5,975.92 ± 6,201.92
Non-response	25 (10.9)	
< RM1,500	6 (2.6)	
RM1,500–RM2,999	33 (14.3)	
RM3,000–RM4,499	57 (24.8)	
RM4,500–RM5,999	33 (14.3)	
> RM6,000	76 (33.0)	

RM1,500 = USD360; RM3,000 = USD767; RM4,500 = USD1,151; RM6,000 = USD1,533.
STPM, the sijil tinggi persekolahan Malaysia (Malaysian higher school certificate).

Daily fluid intake of the respondents is summarized in **Table 2**. Water was the main source of fluid intake (877.00 ± 492.08 mL/day) followed by malted drinks (221.88 ± 272.38 mL/day) and sweetened juice beverages (149.73 ± 200.14 mL/day). The least consumed beverages were low-fat milk (65.39 ± 141.62 mL/day), tea/coffee without sugar and/or creamer (30.92 ± 91.04 mL/day), and diet soft drinks (12.11 ± 42.89 mL/day). The mean total daily intake of SSBs of the male subjects (970.52 ± 738.78 mL/day) was significantly higher than that of females (673.54 ± 543.86 mL/day) ($t = −3.088$; $P = 0.002$). Similarly, the mean total daily fluid intake of males (2,149.26 ± 1,070.17 mL/day) was significantly higher than that of females (1,680 ± 724.61 mL/day) ($t = −3.674$; $P = 0.001$). When comparing total daily fluid intake with the RNI, 29.6% (36.5% males; 25.5% females) of the adolescents achieved the daily RNI of 2,000–2,200 mL of fluid [18]. No significant difference in RNI achievement was detected between the male and female subjects.

Hydration status and cognitive function of the respondents are summarized in **Table 3**. According to the urine color chart, more than half of the adolescents were mildly or moderately dehydrated (59.6%) or dehydrated (7.4%), while only one-third (33.0%) of the adolescents were well hydrated. There was no significant difference in hydration status between the male and female subjects. More than half (59.3%) of the respondents had an average cognitive function score, while 22.2% and 18.5% had below- or above-average cognitive function, respectively. No significant difference between average cognitive function scores of males and females was detected.

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Table 2. Distribution of daily fluid intake according to fluid type and respondents' sex (n = 230)

Daily fluid intake (mL/day)	Male (n = 85)	Female (n = 145)	Total (n = 230)	t/z	*P*-value
Water[1)]	968.76 ± 542.44	823.21 ± 453.38	877.00 ± 492.08	−1.902	0.057
100% fruit juice[2)]	96.71 ± 144.82	75.19 ± 121.50	83.14 ± 130.71	1.207	0.229
Sweetened juice beverage[2)]	126.32 ± 132.39	163.44 ± 226.63	149.73 ± 200.14	−1.360	0.175
Whole milk[2)]	115.63 ± 203.15	104.46 ± 149.30	108.59 ± 170.84	0.478	0.633
Low fat milk[1)]	94.59 ± 205.36	48.27 ± 80.59	65.39 ± 141.62	−0.855	0.393
Malt drinks[1)]	308.05 ± 351.0	171.38 ± 197.91	221.88 ± 272.38	−3.016	0.003*
Soft drinks[2)]	90.39 ± 212.76	61.50 ± 191.06	72.18 ± 199.38	1.061	0.290
Diet soft drinks[2)]	12.10 ± 29.77	12.12 ± 49.08	12.11 ± 42.89	−0.003	0.998
Sweetened tea	63.61 ± 112.77	73.52 ± 109.67	69.86 ± 110.68	−0.065	0.514
Tea/coffee with sugar and/or creamer[2)]	49.28 ± 151.03	42.03 ± 93.07	44.71 ± 117.59	0.451	0.653
Tea/coffee without sugar and/or creamer[1)]	46.14 ± 115.03	22.00 ± 72.13	30.92 ± 91.04	−1.487	0.137
Energy/sports drink[1)]	121.92 ± 237.55	47.22 ± 103.76	74.83 ± 169.63	−4.377	0.001**
Total sugar-sweetened beverages (mL)[1)]	970.52 ± 738.78	673.54 ± 542.86	783.29 ± 637.84	−3.088	0.002*
Total daily fluid Intake (mL)[1)]	2,149.26 ± 1,070.17	1,680.13 ± 724.61	1,853.51 ± 895.41	−3.674	0.001**
%RNI	88.85 ± 42.56	81.49 ± 35.11	84.21 ± 38.11	1.418	0.158
≤ RNI	54 (63.5)	108 (74.5)	162 (70.4)		
≥ RNI	31 (36.5)	37 (25.5)	68 (29.6)		

RNI, recommended nutrient intake.
[1)]Mann-Whitney U test; [2)]Independent t-test.
Significant at $^{*}P < 0.05$, $^{**}P < 0.01$.

Table 3. Distribution of hydration status and cognitive function scores according to sex (n = 230)

Characteristics	Male (n = 85)	Female (n = 145)	Total (n = 230)	t/χ^2	*P*-value
Urine color chart[1)]				0.821	0.663
Hydrated (1–3)	26 (30.6)	50 (34.7)	76 (33.0)		
Mildly or moderately dehydrated (4–6)	54 (63.5)	83 (57.6)	137 (59.6)		
Dehydrated (7–8)	5 (5.9)	11 (7.6)	17 (7.4)		
Cognitive function score[2)]	97.75 ± 11.88	98.36 ± 11.31	98.13 ± 11.50	−0.385	0.701
Extremely low (below 70)	0 (0.0)	1 (1.1)	1 (0.7)		
Borderline (70–79)	2 (4.8)	3 (3.2)	5 (3.7)		
Low average (80–99)	9 (21.4)	15 (16.1)	24 (17.8)		
Average (90–109)	25 (59.5)	55 (59.1)	80 (59.3)		
High average (110–119)	3 (7.1)	17 (18.3)	20 (14.8)		
Superior (120–129)	1 (2.4)	2 (2.2)	3 (2.2)		
Very superior (130 & above)	2 (4.8)	0 (0.0)	2 (1.5)		

[1)]χ^2 test; [2)]Independent t-test.

Bivariate analysis results are summarized in **Table 4**. The analysis revealed that the cognitive function score was significantly higher (F-ratio = 5.087; $P = 0.002$) among adolescents of fathers with tertiary education level (102.75 ± 12.46) compared to adolescents of fathers with primary (96.20 ± 8.64) or secondary (95.50 ± 10.27) education, but there was no difference among the various educational levels of mothers. The cognitive function score among adolescents from households with a monthly income of RM1,500 (USD360) and above (98.54 ± 11.30) was significantly higher (F-ratio = 6.512; $P < 0.001$) than the cognitive function score of adolescents from households with a mean monthly income of less than RM1,500 (83.00 ± 8.58). However, age (r = 0.029; $P = 0.661$), sex (t = −0.615; $P = 0.539$), and mother's educational level (F-ratio = 0.977; $P = 0.421$) were not significantly associated with cognitive function score. Regarding daily fluid intake, soft drinks (r = −0.180; $P = 0.006$), sweetened tea (r = −0.184; $P = 0.005$), and total SSBs (r = −0.199; $P = 0.002$) intakes were negatively correlated with cognitive function score in adolescents, but no significant relationship was detected for the other beverage categories. Concerning hydration status, the mean cognitive function score was significantly higher (F-ratio = 4.102; $P = 0.018$) among hydrated adolescents (100.38 ± 12.01) than in dehydrated adolescents (92.00 ± 13.63).

Table 4. Association between socio-demographic factors, daily fluid intake, hydration status, and cognitive function (n = 230)

Factors	Cognitive function score	
	t/F/r	*P*-value
Socio-demographic factors		
Age	0.029	0.661
Sex	−0.615	0.539
Father's educational level[1)]	5.087	0.002*
Mother's educational level	0.977	0.421
Monthly household income[1)]	7.881	< 0.001*
Daily fluid intake		
Water	0.129	0.051
100% fruit juice	−0.117	0.077
Sweetened juice beverage	−0.082	0.213
Whole milk	−0.113	0.088
Low fat milk	0.015	0.821
Malt drink	−0.066	0.322
Soft drinks[2)]	−0.180	0.006**
Diet soft drinks	−0.098	0.139
Sweetened tea[2)]	−0.184	0.005**
Tea/coffee with sugar and/or creamer	−0.104	0.117
Tea/coffee without sugar and/or creamer	−0.120	0.069
Energy/sports drink	−0.020	0.763
Total daily fluid intake	−0.109	0.100
Total sugar-sweetened beverages[2)]	−0.199	0.002**
Hydration status	4.102	0.018*

[1)]One-way analysis of variance; [2)]Pearson's correlation analysis.
Significant at **P* < 0.05, ***P* < 0.01.

Table 5 provides a summary of the results of the hierarchical multiple linear regression model with cognitive function as the outcome. The addition of fluid intake and hydration status increased the overall fit of the model. Fathers' education (β = 0.745; $P < 0.05$) and household income (β = 2.642; $P < 0.001$) were significant positive predictors of cognitive function of adolescents ($\Delta R^2 = 0.136$). After controlling for socio-demographic variables, soft drinks

Table 5. Hierarchical regression analyses predicting cognitive function in adolescents (n = 230)

Predictors	β	ΔR²
Step 1		0.136
Age	0.439	
Sex	0.389	
Father's educational level	0.745*	
Monthly household income	2.642***	
Step 2		0.044
Age	0.499	
Sex	0.163	
Father's educational level	0.819**	
Monthly household income	2.276***	
Soft drinks	−0.009*	
Sweetened tea	−0.019*	
Step 3		0.021
Age	0.428	
Sex	0.043	
Father's educational level	0.898**	
Monthly household income	2.152**	
Soft drinks	−0.009*	
Sweetened tea	−0.014*	
Hydration status	−2.839*	
R² (full model)		0.201

Cognitive function: F (7,221) = 7.935, *P* < 0.001. Dummy coding: hydrated = 0; mildly, moderately & dehydrated = 1.
Significant at **P* < 0.05, ***P* < 0.01, ****P* < 0.001.

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($\beta = -0.009$; $P < 0.05$) and sweetened tea ($\beta = -0.019$; $P < 0.05$) were significant negative predictors of cognitive function ($\Delta R^2 = 0.044$). When further controlled for sources of fluid, hydration status ($\beta = -2.839$; $P < 0.05$) was a significant negative predictor of cognitive function of adolescents ($\Delta R^2 = 0.021$). The variables explained 20.1% of the variances in cognitive function of adolescents ($R^2 = 0.201$).

DISCUSSION

The results show that less than one-third (29.6%) of the adolescents in this study meet the RNI of 2,000–2,200 mL of fluid daily [21], and that result is similar to those in previous studies [15]. The adolescents' mean total daily fluid intake in the current study was much lower than those in Indonesia [22] and Latin America [23] but higher than that in European adolescents [24] Those results were consistent with the hydration status results for the adolescents, which showed that more than half (67.0%) of the adolescents were inadequately hydrated which was similar to the results of a study in Egypt [25] and much higher than that reported in a study in the United States [4].

The pattern of beverage consumption observed in this study was similar to those in past studies in which plain water was the main source of fluid [15,26]. In this study, water intake was followed by that for malted drinks, a fluid source that is prevalent among Malaysian children [17]. However, in other countries [26], milk consumption is more prevalent, indicating that the consumption of milk is notably lower among Malaysian adolescents. Our results also showed that a significant proportion of the fluid intake by Malaysian adolescents was from SSBs, and that proportion was much higher than those in Indonesia [22] and Latin America [23], indicating that SSBs are a frequent replacement of plain water as a significant fluid source among Malay adolescents. This high level of SSB consumption has raised concerns due to the link between SSBs and obesity, type 2 diabetes, and cardiometabolic risks [9,11].

The current study revealed that consumption of soft drinks, sweetened tea, and total SSBs were negatively correlated with the cognitive function level of the adolescents. When soft drinks and sweetened tea were included in our hierarchical model, they remained as negative predictors of cognitive function in adolescents. To date, few studies have reported on the effects of SSBs on cognition. One meta-analysis of 16 intervention studies that examined the association between sugar and cognition has been reported, and the study concluded that the relationship was ambiguous [14]. Nevertheless, results in some animal studies support the suggestion that excess sugar intake may adversely influence cognitive performance and lead to poor executive function [13,27]. Another study that examined the association of sugar intake with cognition in children showed that sugar consumption, especially that in SSBs, during childhood was inversely associated with verbal intelligence scores at mid-childhood [28]. One explanation for this inverse relationship is that sugar in such beverages can damage the hippocampus, which in turn can impair spatial learning and memory, as has been reported in a previous animal study [29]. Intake of SSBs can also result in lower cognitive performance through metabolic-related complications such as elevated blood sugar, insulin resistance [30], and inflammation [31].

Similar to the results in past studies, when hydration status was examined, adolescents who were well hydrated had a better cognitive performance level than that in those who

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were dehydrated [6,7]. In the present study, this relationship remained after controlling for socio-demographic factors and the consumption of soft drinks and sweetened tea in the hierarchical model. A possible explanation for a reduced level of cognition due to dehydration is that dehydration can alter the level of electrolytes in the body. Changes in electrolyte levels associated with dehydration can alter brain activity and neurotransmission system performance, leading to alteration of cognitive function [32]. In addition, dehydration can cause changes in blood-brain barrier permeability, leading to a decrease in the amount of blood flow in areas of the brain, among which some are responsible for specific cognitive function [33].

To our knowledge, this is the first study that associated SSB consumption and hydration status with cognitive function among Malaysian adolescents. However, the variables measured were only able to explain 20.1% of the variance in cognitive function. Other factors related to cognitive function such as sleep habits [34], physical activity [35,36], and diet [36] of the adolescents were not examined in this study. Examining these additional correlates of cognitive function may have increased the level of variance in the adolescents' cognitive function that was explained by the model.

Several limitations of the present study should be considered. Causal inferences are not possible due to the cross-sectional nature of this study. Furthermore, as the respondents were only recruited from one geographical area in Malaysia, generalizability to all adolescents in the country was not possible. Additionally, there are possible inaccuracies in the answers provided by the subjects due to the effects of response bias and social desirability. Despite these limitations, the current study did improve on the level of information provided by previous research. As little has been reported on the relationship of SSBs consumption and hydration status with cognitive function, the current study expands the level of knowledge presented in earlier studies, particularly in an adolescent Malaysian context.

In conclusion, some of the highlights of the study results include the revelation of links between fluid intake (soft drinks, sweetened tea, total SSBs) and hydration status with cognitive function in adolescents. Although these factors may not entirely explain alterations in the cognitive performance of adolescents, some fluid sources, such as SSBs, and hydration status do have important roles in altering cognitive performance in adolescents. With the increasing consumption of SSBs among adolescents, an expansion of efforts to promote healthier fluid intake options to stay hydrated may help to prevent adverse effects on adolescents' cognition. Interventions aimed to decrease the consumption of SSBs and increase hydration status through healthier options, such as water, should be developed. Fluid-related programs aimed to improve cognitive performance of adolescents may also have bodyweight- and mood-related benefits.

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