The Negative Influence of Adiposity Extends to Intraindividual Variability in Cognitive Control Among Preadolescent Children

Morgan R. Chojnacki1, Lauren B. Raine2, Eric S. Drollette3, Mark R. Scudder4, Arthur F. Kramer2,5, Charles H. Hillman2,6, and Naiman A. Khan1,3

Objective: The objective of this study was to investigate the relationship between adiposity and cognition by using mean accuracy, mean reaction time, and intraindividual variability (IIV) among preadolescents.

Methods: Children 7 to 9 years old (N = 233, 133 females) underwent dual-energy x-ray absorptiometry and a maximal oxygen consumption test to assess whole-body adiposity and aerobic fitness relative to fat-free mass (VO2FF), respectively. Attentional inhibition was assessed by using a modified flanker task. IIV was assessed as standard deviation of reaction time and as a coefficient of variation of reaction time (CVRT). Hierarchical linear regression analyses were performed to examine the relationships between adiposity and cognitive measures following the adjustment of significant demographic factors, intelligence quotient, and VO2FF.

Results: Whole-body adiposity was negatively related to congruent trial mean accuracy and reaction time and to CVRT in both the congruent and incongruent trials. Differences in cognitive function across weight status were selectively evident for measures of IIV, such that children with overweight/obesity (≥85th BMI-for-age percentile) exhibited higher CVRT for both the congruent and incongruent trials.

Conclusions: This work provides additional evidence linking childhood obesity to poorer cognitive function and includes novel data extending the negative influence of adiposity to measures of intraindividual response variability in cognitive control, even after accounting for intellectual abilities, aerobic fitness, and demographic factors.

Introduction

Currently, one in three children in the United States has overweight/obesity (≥85th BMI-for-age percentile) (1), which is concerning because obesity contributes to numerous chronic diseases, including cardiovascular disease, metabolic syndrome, and type 2 diabetes mellitus (2). In addition to its cardiovascular and metabolic implications, obesity in midlife is also a known risk factor for adverse cognitive health outcomes, including a greater risk for Alzheimer disease and dementia (3). Furthermore, psychosocial consequences of obesity include poorer educational attainment, higher rates of poverty, and lower household income (4). Given the detrimental impact of obesity on cardiovascular disease and cognitive health in adulthood, the question of whether these relationships are evident in childhood has received increased scrutiny.

A converging body of literature indicates that greater aerobic fitness, as early as preadolescence, promotes superior cognitive performance and alterations in brain structure and function (5). Cognitive control encompasses a complex set of goal-directed processes, including attention, memory, learning, and perception (6), and has been shown to be positively related to greater aerobic fitness. Improved cognitive control during development is predictive of later academic achievement and has been linked to greater educational attainment, higher income and socioeconomic status (SES), and better access to health care (7). In contrast to fitness effects on the brain, mechanisms underlying how obesity or excess fat mass influence cognitive control are not clear, although indirect mechanisms involving adipocyte-induced neuroinflammation have received considerable attention (8). Excess adiposity can lead to increased levels of circulating free fatty acids, proinflammatory cytokines, and immune cells,
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which in turn may contribute to neuroinflammation (8,9). For example, proinflammatory cytokines such as IL-6 and TNFα are known to exert neurodegenerative effects in several brain diseases (8,10). Additionally, inflammation and oxidative stress often coexist, and oxidative stress is associated with astrocyte activation, brain proinflammatory cytokine production, and cognitive impairment (8,11). Although additional research is needed to illustrate the mechanisms by which adiposity affects cognitive function, correlational and longitudinal studies often support a negative relationship between obesity and cognitive control (12). Given the inverse relationship between obesity weight status and poorer aerobic fitness, these physiological factors likely impart counteractive effects on cognitive control, yet the two are seldom examined together. Therefore, relatively little is known about the influence of adiposity on children’s cognitive function while accounting for fitness.

In addition to the need for more research examining the cognitive implications of childhood obesity while accounting for fitness, further work is also required to characterize the specific measures of cognitive function susceptible to the influence of childhood obesity. Previous cognitive and neuropsychological research has disproportionately focused on measures of central tendency, such as mean differences in performance (12), across individuals while neglecting measures of within-individual variability, therefore limiting our understanding of the true extent to which obesity may influence children’s cognitive function. Intraindividual variability (IV) provides metrics of within-person fluctuations in behavioral performance and offers insight into the degree of consistency in cognitive control during task performance (13). Specifically, IV standard deviation of reaction time (SDRT) and intraindividual coefficient of variation of reaction time (CVRT) can serve as useful indices of patterns of behavioral responses that underlie the consistency of cognitive control performance and have been shown to have relevance for a several cognitive abilities in everyday life, as well as for the study of neurological disease (14). However, the extent to which childhood obesity may impact IV during cognitive control tasks has not been directly examined.

Accordingly, the present study examined the relationships between adiposity and cognitive performance by using measures of central tendency and IV, while also accounting for demographic factors and aerobic fitness. We hypothesized that greater adiposity would be related to poorer mean performance as well as higher IV among preadolescent children. We also anticipated that children with overweight and obesity would have significantly higher IV relative to their healthy weight counterparts.

Methods

Participants

Participants were 7- to 9-year-old preadolescent children recruited as part of the Fitness Improves Thinking in Kids 2 randomized controlled trial, a physical activity after-school intervention program assessing the effect of daily exercise on cognitive function between 2013 and 2017 (NCT01619826). Children who completed all tasks (N = 233) were included at their baseline measurement, prior to randomization and intervention. Exclusion criteria included neurological disorders, physical disabilities, and psychoactive medication use, as reported by parents in an eligibility questionnaire. All participants were required to have normal or corrected-to-normal vision. Participants and their legal guardians provided written consent in accordance with the ethical standards and regulations of the institutional review board at the University of Illinois at Urbana-Champaign (#12321).

Procedure

Testing occurred over two laboratory visits. During the first visit, participants completed informed assent/consent, the Woodcock Johnson Test of Cognitive Abilities to estimate intelligence quotient (IQ), measurements of height and weight, and a maximal oxygen consumption (VO2peak) test (15) to assess aerobic fitness. Concurrently, parents completed surveys assessing demographics, health history, and pubertal status according to the modified Tanner Staging Scales (16,17). SES was determined from eligibility for school meal assistance programs, maternal and paternal education levels, and the number of parents with full-time employment. During the second visit, participants completed a modified flanker task (18) designed to assess attentional inhibition and a dual-energy x-ray absorptiometry (DXA) assessment of whole-body and visceral adiposity.

IQ assessment

The Woodcock-Johnson Test of Cognitive Abilities was used to estimate IQ. Tests include audio recordings, a subject response booklet, and subject response pages. The test is individually administered by a trained examiner on the basis of the guidelines provided in the examiner’s manual (19). Basal and ceiling criteria are listed in the test book for each subtest, and raw scores are calculated for each test. Test and cluster scores are then calculated by using the Woodcock-Johnson III Normative Update Compscore and Profiles program (Houghton Mifflin Harcourt, Itasca, Illinois).

Pubertal stage assessment

The modified Tanner Staging Scales were presented to the parents as a document with five separate line drawings depicting various stages of external genitalia development (males), breast development (females), and pubic hair development (males and females). Parents were asked to identify the line drawing that depicted their child’s developmental status, and the average of scores was used to determine the child’s pubertal stage. Previous research has validated the Tanner Scale in different samples of children and has shown good agreement with clinician examination with k values ranging from 0.68 to 0.76 (17,20).

Anthropometric and adiposity assessment

Participants’ height and weight were measured, without shoes, by using a stadiometer (model 240; Seca, Hamburg, Germany) and a Tanita WB-300 Plus digital scale (Tanita, Tokyo, Japan), respectively. Each measurement was taken three times, and the average was used for analyses. BMI-for-age-percentile cutoffs from the Centers for Disease Control and Prevention were used to determine weight status (21). Fat mass and muscle mass were measured by using DXA with a Hologic Discovery A bone densitometer (software version 12.7.3; Hologic, Bedford, Massachusetts). The whole-body fat percentage (%Fat) was expressed by using the standard software measure (22).
Cardiorespiratory fitness assessment

VO2peak was assessed by using a modified Balke treadmill protocol (15). This modification involved maintaining a constant speed on the treadmill while increasing the workload (i.e., grade) of the treadmill. The modified Balke protocol follows the American College of Sports Medicine Guidelines for Exercise Testing and Prescription (23,24) in children and is regarded as valid and reliable for estimating cardiorespiratory fitness in children (25). Children were fitted with a heart rate monitor (Polar WearLink + 31; Polar, Espoo, Finland) or the duration of the assessment. Children started with a warm-up period and then jogged at a constant speed with increasing grade increments of 2.5% every 2 minutes until perceived exhaustion. Oxygen consumption was measured by using a computerized indirect calorimetry system (True Max 2400; ParvoMedics, Sandy, Utah), with averages for oxygen uptake and respiratory exchange ratio assessed every 20 seconds. Concurrently, ratings of perceived exertion were measured every 2 minutes by using the children’s OMNI rating of perceived exertion scale. VO2peak was defined as the highest oxygen consumption corresponding to a minimum of 2 of the following 4 criteria: (1) a peak heart rate ≥ 185 beats per minute, (2) a respiratory exchange ratio > 1.0, (3) a ratings of perceived exertion score of ≥ 8, and/or (4) a plateau in oxygen consumption corresponding to an increase of < 2 mL/kg per minute, despite an increase in workload (15). Aerobic fitness percentiles were determined by using normative values for VO2peak (26).

Attentional inhibition assessment

A modified flanker task (18) presented a target stimulus (cartoon fish) amid an array of four flanking stimuli. Participants were asked to respond to the centrally presented target with the flanking stimuli irrelevant to the task. This modified version of the flanker task consisted of both congruent trials, in which the flanking fish faced the same direction as the target fish (> > > > >), and incongruent trials, in which the flanking fish faced the opposite direction from the target fish (> > < > >) (28). Congruent and incongruent trials were equiprobable and random. Participants responded to the direction of the target fish, left or right, with their consonant thumb. Participants completed 54 practice trials followed by two blocks of 84 trials. The viewing distance was 1 m, the stimulus duration was 250 milliseconds, and the interstimulus interval was jittered at 1,600, 1,800, or 2,000 milliseconds. For behavior data, primary variables of interest included mean response time (time in milliseconds from stimulus presentation until response execution), response accuracy (percentage of correct responses), SDRT, and CVRT (SD of reaction time/ Mean of reaction time) for all correct trial types (congruent and incongruent).

Statistical analysis

Normality was first assessed for each of the main outcomes by using Kolmogorov-Smirnov and Shapiro-Wilk tests, skewness and kurtosis values, and a visual examination of Normal Q-Q plots and histograms. Outliers were defined as values ± 3 SD from the mean and were removed from subsequent analyses (see Figure 1). To examine the relevance of IV for behavioral performance, Pearson correlations were used to assess the relationships of SDRT and CVRT with accuracy and reaction time in both congruent and incongruent trials. Pearson correlations were also used initially to assess bivariate relationships between adiposity, cognitive measures, and fitness and demographic variables, including BMI, age, pubertal timing, sex, and SES (two-tailed P < 0.05 considered significant). Hierarchical linear regression analyses were performed to examine variability in cognitive performance. The demographic and IQ variables that were significant in the bivariate correlations were entered into step 1. Steps 2 and 3 were used for VO2FF and %Fat, respectively, in the models in which they correlated in the bivariate analysis. Each predictor was evaluated by studying its significance (α-level, 0.05). Finally, one-way analysis of variance (ANOVA) was used to determine differences in IV across weight status grouping utilizing a 2 × 3 (type: congruent, incongruent × group: health weight, overweight, obesity) factorial model. Post hoc analyses included independent samples t tests with Bonferroni correction. All analyses were completed by using SPSS version 24 (IBM Corporation, Armonk, New York).

Results

Preadolescent children ages 7 to 9 (N = 314) were recruited from the east-central Illinois region. See Figure 1 for the CONSORT diagram. The complete breakdown of demographics, body composition, and cognitive performance can be found in Table 1. SES categorization of the participants was 40% low, 36% middle, and 25% high. According to the Tanner pubertal staging questionnaire, 51% of participants were stage 1, 45% were stage 2, and 5% were stage 3. Categorizations for BMI showed that 56% of the children were classified as having healthy weight, 19% as having overweight, and 23% as having obesity.

Table 2 shows the results of the bivariate correlations. For the congruent trials, correlations with SDRT showed a negative relationship with accuracy (r = −0.27, P < 0.01) and a positive relationship with reaction time (r = 0.63, P < 0.01); similarly, correlations with CVRT showed a negative relationship with accuracy (r = −0.51, P < 0.01).
Table 1: Demographics, IQ, adiposity, and flanker performance

| Measure                      | Mean (SD) or % |
|------------------------------|---------------|
| N = 233                      |               |
| Age, y                       | 8.67 (0.54)   |
| Sex                          |               |
| Male                         | 42.9% (n = 100)|
| Female                       | 57.1% (n = 133)|
| SES                          |               |
| Low                          | 39.5% (n = 92)  |
| Medium                       | 35.6% (n = 83)  |
| High                         | 24.9% (n = 58)   |
| IQ                           | 108.41 (12.92) |
| Pubertal timing              | 1.36 (0.47)    |
| BMI, kg/m²                   | 18.83 (4.00)   |
| Weight status                |               |
| Underweight                  | 2.6% (n = 6)   |
| Healthy weight               | 56.2% (n = 131) |
| Overweight                   | 18.5% (n = 43)  |
| Obesity                      | 22.7% (n = 53)  |
| VO₂peak relative             | 42.13 (7.20)   |
| VO₂peak percentile           | 36.6 (30.40)   |
| VO₂FF                        | 61.00 (7.26)   |
| %Fat                         | 31.62 (6.88)   |
| Flanker congruent            |               |
| Accuracy (%)                 | 80.26 (12.01)  |
| Reaction time, ms            | 552.35 (103.62) |
| SDRT, ms                     | 182.43 (52.23) |
| CVRT                         | 0.33 (0.08)    |
| Flanker incongruent          |               |
| Accuracy (%)                 | 72.93 (13.57)  |
| Reaction time, ms            | 600.54 (113.64) |
| SDRT, ms                     | 193.84 (56.28) |
| CVRT                         | 0.32 (0.08)    |

For the incongruent trials, SDRT was negatively correlated with accuracy ($r = -0.28, P < 0.01$) and positively associated with reaction time ($r = 0.54, P < 0.01$), and CVRT was negatively associated with accuracy ($r = -0.59, P < 0.01$) but not associated with reaction time. Overall results (i.e., collapsed across congruency) indicated that flanker SDRT was significantly correlated with age ($r = -0.23, P < 0.01$), SES ($r = -0.15, P < 0.05$), IQ ($r = -0.23, P < 0.01$), and VO₂FF ($r = -0.16, P < 0.05$). Additionally, CVRT was correlated with age ($r = -0.25, P < 0.01$), IQ ($r = -0.23, P < 0.01$), VO₂FF ($r = -0.19, P < 0.01$), and %Fat ($r = 0.20, P < 0.01$).

Results of the ANOVA can be seen in Figure 2. Results showed a significant effect of weight status in CVRT for both congruent [$F (3,229) = 4.46, P < 0.01$, $η² = 0.06$] and incongruent [$F (3,229) = 6.77, P < 0.01$, $η² = 0.08$] trials, with the healthy weight group exhibiting lower variability compared to both overweight and obesity groups. Post hoc comparisons by using the Bonferroni test indicated that both congruent ($P < 0.02$) and incongruent ($P < 0.01$) trials of CVRT were lower in individuals with healthy weight than in individuals with obesity.

Hierarchical regression results are summarized in Table 3 and Table 4. Whole-body adiposity was a significant predictor of congruent accuracy ($β = -0.15, P = 0.02$), reaction time ($β = -0.14, P = 0.03$), and CVRT ($β = 0.15, P = 0.02$), as well as incongruent CVRT ($β = 0.15, P = 0.02$). VO₂FF was not a significant predictor of variance in any of the final models ($P > 0.05$). Age, IQ, VO₂FF, and %Fat explained 15% of the variance in congruent CVRT ($ΔR² = 0.15, F = 10.24, P < 0.01$). Age, SES, VO₂FF, and %Fat accounted for 18% of the variance in incongruent CVRT ($ΔR² = 0.18, F = 9.70, P < 0.01$).

Discussion

The use of IIV as a marker of cognitive impairment or dysfunction has been demonstrated in clinical studies among patients with brain disorders such as attention-deficit/hyperactivity disorder and Alzheimer disease (29,30). However, few have attempted to examine IIV in generalizable or nonclinical study populations, particularly in childhood. The results of the study were consistent with our a priori hypothesis, given that we observed negative relationships between adiposity and task accuracy. Furthermore, children with greater adiposity exhibited higher IIV, indicating that the negative influence of excess fat mass extends to measures of dispersion in attentional inhibition, following adjustment for demographic factors, intelligence, and aerobic fitness. These findings were further supported by comparisons across weight status categories. Children with overweight and/or obesity exhibited greater IIV during both congruent and incongruent trials of the modified flanker task, relative to their healthy weight counterparts. Interestingly, differences across weight status categories were only evident for measures of IIV and not central tendency, providing further evidence supporting the susceptibility of measures of dispersion to the potentially negative influence of childhood obesity.

Although previous studies have observed an inverse relationship between aerobic fitness and IIV, these studies did not consider %Fat as a contributing factor (13). The results here indicated that fitness significantly contributed to the variation in CVRT during the incongruent trials; however, the inclusion of %Fat in the regression models appeared to have a moderating influence on the initial relationships observed for fitness. This moderating influence of %Fat indicates that excess adiposity exerts a considerable negative impact on cognitive control that mitigates some of the positive contribution of fitness to the cognitive measures. Alternatively, the sample studied was relatively homogeneous regarding fitness and was predominantly comprised of lower-fit children. Conducting similar analyses in a heterogeneous sample that includes a greater proportion of higher-fit children may reveal a positive influence of fitness that is independent of adiposity. Future studies among children with varying levels of fitness are necessary to further confirm the findings observed here.

Emerging evidence indicates that behavioral and emotional problems are more common among children with obesity, with the most frequently implicated psychosocial factors including externalizing (e.g., VAT, visceral adipose tissue; VO₂peak, maximum aerobic capacity; %Fat, whole-body percent fat; SDRT, standard deviation of reaction time; CVRT, coefficient of variation of reaction time; SES, socioeconomic status; IQ, intelligence quotient.)
impulsivity) and internalizing (e.g., depression and anxiety) behaviors (31). Furthermore, obesity has been linked to poorer abilities in cognitive control processes such as attention, memory, and inhibition (12). In two systematic reviews, higher BMI was associated with poorer cognitive control performance; however, there was little consistency within and across the different domains of cognitive control (12). The conflicting state of the knowledge may be, at least in part, due to the metric of performance studied. Virtually all previous studies on obesity and children’s cognitive and neuropsychological function have relied on central tendency measures, with little known regarding the influence of behaviors and physiological health on IIV. To our knowledge, the current study is the first to examine the relationship between measures of intraindividual performance and adiposity among preadolescent children.

The findings of the current study provide support linking IIV in cognitive control performance to the interrelated health factors of aerobic fitness and adiposity. However, the mechanisms underlying this observation are not clear. One possible mechanism may include the differential trajectories of development or maturation in cognitive control across health factors. For example, considering factors beyond adiposity and fitness, we observed that age was a significant predictor of both IIV and central tendency. As children develop and mature, they exhibit improved performance in cognitive control tasks, displaying both higher response accuracy and shorter response times (32). Similarly, IIV performance during cognitive control tasks also decreases throughout childhood and adolescence (33). These findings show consistently that younger children exhibit higher variability during cognitive control tasks. Conversely, Myers et al. observed that older adults (mean age = 73.9 y) exhibited greater IIV in their reaction time than did younger adults (mean age = 20.9 y) (34). In the same study, the older adults also displayed longer reaction time than the younger adults (34). Der and Deary found similar results in a study of 7,130 adult participants; they found that the reaction time increased throughout the adult age range and that reaction time variability decreased in early adulthood but then increased throughout late adulthood (35). Collectively, these investigations suggest that the IIV-age relationship follows a U-shaped curve throughout the lifespan, with improvements through young adulthood and decrements through older adulthood. These studies provide initial support for the theory of a developmental mechanism contributing to the differences in IIV, and the results in the current work show consistently that older children exhibited lower response variability.

Additional insights into the underpinnings of response variability can be gained from magnetic resonance imaging studies. Previous studies have demonstrated that variability indexes a demand for top-down cognitive control (36). Furthermore, patients with damage to the dorsolateral prefrontal cortex or the superior medial frontal cortex exhibited increases in IIV during a cognitive control task that required feature discrimination and integration (37). Diffusion tensor imaging studies have shown that reduced performance variability

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**TABLE 2 Bivariate correlations between demographics, IQ, weight status, and flanker performance**

|           | Congruent |           |         | Incongruent |           |         |
|-----------|-----------|-----------|---------|-------------|-----------|---------|
|           | Accuracy  | RT        | SDRT    | CVRT        | Accuracy  | RT        | SDRT    | CVRT        |
| Age       | 0.25**    | -0.19**   | -0.27** | -0.22**     | 0.21**    | -0.16*    | -0.29** | -0.24**     |
| Sex       | 0.02      | -0.01     | -0.03   | -0.02       | 0.01      | -0.04     | -0.14*  | -0.10       |
| SES       | 0.12      | -0.06     | -0.08   | -0.05       | 0.14      | -0.07     | -0.19** | -0.17*      |
| IQ        | 0.24**    | -0.06     | -0.23** | -0.23**     | 0.26**    | -0.04     | -0.20** | -0.20**     |
| Pubertal timing | -0.04    | -0.13     | -0.08   | -0.00       | -0.11     | -0.12     | -0.01   | 0.07        |
| BMI       | -0.11     | -0.19**   | 0.01    | 0.16*       | -0.13*    | -0.18**   | 0.03    | 0.18**      |
| VO2FF     | 0.09      | 0.01      | -0.10   | -0.13*      | 0.15      | -0.03     | -0.18** | -0.19**     |
| %Fat      | -0.14*    | -0.16*    | 0.02    | 0.16*       | -0.14*    | -0.13**   | 0.07    | 0.18**      |
| Congruent | SDRT      | -0.27**   | 0.63**  | -          | -0.18**   | 0.54**    | -       | -           |
|           | CVRT      | -0.51**   | -0.00   | -          | -0.51**   | -0.06     | -       | -           |
| Incongruent | SDRT    | -0.34**   | 0.47**  | -          | -0.28**   | 0.54**    | -       | -           |
|           | CVRT      | -0.59**   | -0.13*  | -          | -0.59**   | -0.11     | -       | -           |

**Correlation is significant at the 0.01 level (two-tailed).**
**Correlation is significant at the 0.05 level (two-tailed).**

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Additional insights into the underpinnings of response variability can be gained from magnetic resonance imaging studies. Previous studies have demonstrated that variability indexes a demand for top-down cognitive control (36). Furthermore, patients with damage to the dorsolateral prefrontal cortex or the superior medial frontal cortex exhibited increases in IIV during a cognitive control task that required feature discrimination and integration (37). Diffusion tensor imaging studies have shown that reduced performance variability...
reflected the maturation of white matter connectivity (38). Tamnes et al. reported that irrespective of age, lower IIV was associated with higher fractional anisotropy, lower mean diffusivity, lower axial diffusivity, and lower radial diffusivity; all indicating that children (8- to 19-year-olds) with more mature white matter exhibit lower degrees of performance variability (38). Additionally, increased BMI is associated with a global and distributed decrease in white matter microstructural integrity, as well as with detectable brain volume deficits in people with obesity, which include atrophy in the frontal lobes, anterior cingulate gyrus, hippocampus, and thalamus, when compared with normal-weight subjects (39). These findings indicate that obesity is associated with decreased brain volume, supporting the theory that brain structure and development contribute to response time variability.

Limitations to this study include using a report of cross-sectional data rather than using an intervention approach. The cross-sectional design yields the possibility that observed fitness and adiposity differences may have resulted from a combination of extraneous factors not accounted for in the present investigation, such as diet, survey response bias, or preexisting health conditions and undiagnosed mental disorders. Additionally, data were not collected regarding the amount of time that preadolescent children had been exposed to overweight or obesity. Children who have had overweight/obesity longer may have further cognitive impairment, and additional research will need to account for this factor. Furthermore, it is possible that the relationships between fitness, adiposity, and IIV are bidirectional. Therefore, additional randomized controlled and longitudinal trials are needed to elucidate the influence of change in health factors (i.e., fitness and fatness) to changes in cognitive control, with the current work highlighting the importance of utilizing dispersion measures, rather than utilizing central tendency measures alone, as potentially more sensitive markers of obesity-related decrements in cognitive control in children.

**Conclusion**

The current work is based on a large data set comprising fitness, adiposity, and cognitive control data in preadolescent children. The findings point to the importance of children maintaining a healthy

### TABLE 3 Results for hierarchical regression for congruent flanker

|          | Accuracy |          | Reaction time |          | CVRT |          |
|----------|----------|----------|---------------|----------|------|----------|
|          | β        | R²       | F             | β        | R²   | F        |
| Step 1   | 0.14**   | 19.36**  | Step 1        | 0.04**   | 8.52**| Step 1   | 0.12**   | 16.17**  |
| Age      | 0.30**   |          | Age           | −0.19**  |       | Age      | −0.27**  |         |
| IQ       | 0.29**   |          | IQ            | −0.28**  |       | IQ       |          |         |
| Step 2   | 0.17**   | 15.20**  | Step 2        | 0.06**   | 6.66**| Step 2   | 0.13**   | 11.46**  |
| %Fat     | −0.15*   |          | %Fat          | −0.14*   |       | %Fat     | 0.15**   | 10.24**  |

**Significant at the 0.01 level (two-tailed).**
*Significant at the 0.05 level (two-tailed).**

IQ, intelligence quotient; VO2FF, maximum lean aerobic capacity; %Fat, whole-body percent fat; CVRT, coefficient of variation of reaction time.

### TABLE 4 Results for hierarchical regression for incongruent flanker

|          | Accuracy |          | Reaction time |          | SDRT |          | CVRT |          |
|----------|----------|----------|---------------|----------|------|----------|------|----------|
|          | β        | R²       | F             | β        | R²   | F        | β    | R²       | F     |
| Step 1   | 0.14**   | 11.96**  | Step 1        | 0.03*    | 6.36*| Step 1   | 0.19** | 12.94**  | 1.13**| 11.79**  |
| Age      | 0.25**   |          | Age           | −0.16*   |       | Age      | −0.33**|          |       | −0.28**  |
| SES      | 0.07     |          | SES           | −0.15*   |       | SES      | −0.11  |         |       |         |
| IQ       | 0.29**   |          | IQ            | −0.24**  |       | IQ       | −0.23**|         |       |         |
| Step 2   | 0.15**   | 9.66**   | Step 2        | 0.04**   | 4.81**| Step 2   | 0.20** | 11.07**  | 1.15**| 10.39**  |
| VO2FF    | 0.10     |          | VO2FF         | −0.11†   |       | VO2FF    | −0.14* |         |       |         |
| Step 3   | 0.16**   | 8.55**   | %Fat          | −0.12†   |       | Step 3   | 0.18** | 9.70**   | 0.15*  |
| %Fat     | −0.12†   |          | %Fat          |          |       | %Fat     |        |         |       |         |

**Significant at the 0.01 level (two-tailed).**
*Significant at the 0.05 level (two-tailed).**
†Marginally significant at the 0.10 level (two-tailed).
IQ, intelligence quotient; SES, socioeconomic status; VO2FF, maximum lean aerobic capacity; %Fat, whole-body percent fat; SDRT, standard deviation of reaction time; CVRT, coefficient of variation of reaction time.
weight status for better cognitive control. They also indicate that that increased adiposity, regardless of fitness level, exhibits a deleterious relationship with aspects of children’s cognitive control. The association between adiposity and IV points to the important influence of excess fat mass on markers of cognitive control, which may serve as a developmental barrier and contribute to long-term decrements in cognitive function.

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