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Obesity

Sex Differences in the Relationship Between Childhood Self-Regulation and Adolescent Adiposity

Kristin N. Javaras [1,2,3], *Jeffrey M. Armstrong* [4], *Marjorie H. Klein* [4], *Marilyn J. Essex* [4], *Richard J. Davidson* [1], *and H. Hill Goldsmith* [1]

Objective: Research suggests that higher childhood self-regulation (CSR) predicts lower adiposity in adolescence. However, it is unclear whether this relationship differs by sex or by baseline weight status. Thus, this study investigated these questions in a longitudinal, community-based cohort.

Methods: The cohort included 221 girls and 214 boys. At age 9, CSR was assessed via parent/teacher reports of effortful control, and childhood BMI *z* scores (BMI*z*) were calculated from staff measurements. Late-adolescent waist-to-height ratio was based on staff measurements at age 18.

Results: CSR has a small inverse correlation with concurrent childhood BMI*z* in girls, but not in boys. Prospectively, however, CSR has a small inverse association with late-adolescent weight-to-height ratio in both sexes, after adjusting for childhood BMI*z* and other childhood predictors. This prospective association is marginally stronger for girls with higher (vs. lower) childhood BMI*z*.

Conclusions: CSR inversely predicts changes in adiposity across adolescence in both sexes, with some evidence that this association is stronger for girls with higher (vs. lower) childhood adiposity. However, this inverse association between CSR and adiposity may emerge earlier in girls. Future research should examine the causal status of CSR and its relationship to behaviors (e.g., diet).

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Study Importance

What is already known?

- Higher childhood self-regulation (CSR) predicts lower adiposity in adolescence.
- However, existing research has not fully clarified whether the relationship between CSR and adolescent adiposity differs by sex.

What does this study add?

- Findings from a longitudinal, community-based sample suggest that CSR has a small inverse correlation with concurrent childhood BMI *z* scores (BMI*z*) in girls only.
- However, after controlling for childhood BMI*z*, CSR inversely predicts a small and similar proportion of the variance in late-adolescent waist-to-height ratio in both boys and girls.

How might these results change the focus of clinical practice?

- Results suggest that interventions targeting self-regulation early in childhood may have effects on adiposity only in girls.
- However, interventions with longer follow-up periods or beginning later in childhood may affect adiposity in both sexes.

Introduction

The risk of developing excess adiposity is heightened during the adolescent period, especially during early and late adolescence (1). This heightened risk occurs in the context of myriad physiological developments, especially during early adolescence (1), as well as in the context of numerous psychosocial developments, such as increased autonomy, which accelerates in late adolescence (2). As a result, individual characteristics may increasingly influence adiposity throughout the adolescent period, thereby representing a potential target for intervention in combination with interventions targeted at other levels (e.g., family, school and neighborhood, nation).

Accumulating evidence suggests that childhood self-regulation (CSR), a potentially modifiable individual characteristic, may be a risk factor for the development of excess adiposity in adolescence. CSR broadly refers to adaptive modulation of one's own state, including behavior, cognition, and emotion (3). Higher CSR has been linked to better outcomes across a variety of domains, including the health domain (4). Most relevant here, several longitudinal studies have found that CSR inversely predicts adolescent adiposity (5-10). In a large national study of child development, higher self-regulation in early childhood predicted smaller changes in BMI *z* scores (BMI*z*) from early childhood through early (6,8) and middle (6) adolescence. Further, CSR's inverse association with BMI*z* changes appeared to strengthen with longer BMI*z* follow-up (6). In the same national study and also in a smaller study, higher self-regulation in middle childhood predicted smaller residualized changes in BMI*z* from middle childhood to early adolescence (7) and in overweight status from

[1] Department of Psychology, University of Wisconsin–Madison, Madison, Wisconsin, USA. Correspondence: Kristin N. Javaras (kjavaras@mclean.harvard.edu) [2] Division of Women's Mental Health, McLean Hospital, Belmont, Massachusetts, USA [3] Department of Psychiatry, Harvard Medical School, Boston, Massachusetts, USA [4] Department of Psychiatry, University of Wisconsin–Madison, Madison, Wisconsin, USA.

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middle childhood to middle adolescence (9). In a study conducted only in girls, higher CSR in middle childhood predicted lower *levels* of BMI, waist circumference, and percentage of body fat across middle childhood, late childhood, and early and middle adolescence; however, CSR predicted *changes* in adiposity from middle childhood to middle adolescence only for BMI (5,10). Based on these generally positive findings from observational research, recent interventional research has examined whether interventions targeting CSR have downstream effects on adiposity (11,12). However, the efficacy of these interventions cannot be fully assessed without understanding *for whom* they are most likely to work, a question not adequately addressed by existing observational research.

In particular, CSR may have a stronger association with subsequent adiposity in girls, for both biological and psychosocial reasons. Because of a complex set of hormonal changes, girls' percentage of body fat increases during puberty (1), whereas boys' percentage of body fat tends to decrease throughout the adolescent period (13). These biological differences may lead to a more influential role for self-regulation in determining adiposity trajectories for girls. Psychosocially, adolescent girls tend to place greater importance on thinness than boys. Especially by late adolescence, concern about fatness and desire for weight loss are more prevalent in girls than boys (14,15), with a relatively small percentage of adolescent boys in the middle or lower end of the BMI range expressing these concerns (14). In contrast, concern about smallness and desire for weight gain are more prevalent in adolescent males (15), especially in the lower BMI percentiles (15), with a relatively small percentage of adolescent girls expressing these concerns (16). Further, although both male and female adolescents express desire for toned muscles (16), muscle-increasing behaviors (17) are higher in adolescent boys compared with girls. As a result of these psychosocial differences, more self-regulation may be deployed toward maintaining lower weight in girls, whether consciously or not, because doing so tends to be a greater motivational priority for girls (18). However, despite these biological and psychosocial rationales for sex differences, most observational studies examining the relationship between CSR and subsequent adiposity have not conducted sex-stratified analyses (6,7,9), with one exception (8). A few studies have tested moderation by sex and reported insignificant results (7,9), but their power to detect interactions has been limited (e.g., because of small samples or correction for testing multiple interactions). Further complicating matters, existing studies of both sexes have used BMI as a measure of adiposity (6-9). However, BMI has differential measurement error with respect to adiposity in males and females, with BMI more likely to overestimate the percentage of body fat in young men (19).

Further, CSR may have a stronger association with subsequent adiposity in girls who have greater adiposity at baseline. Greater baseline adiposity may reflect a propensity to gain weight, whether due to genetic and/or environmental factors, leaving these girls especially likely to experience large increases in adiposity during adolescence (1) and allowing a bigger potential role for CSR in influencing weight trajectory. Some studies of the relationship between CSR and BMI have examined moderation by baseline BMI, and the interaction did not achieve significance; however, power to detect interactions was again limited (7,9).

Thus, the present study sought to clarify whether CSR has a stronger relationship with subsequent adiposity in girls, especially in girls with greater baseline adiposity, using a longitudinal, community-based sample and a measure of adiposity (i.e., waist circumference) that is highly correlated with the total percentage of adiposity in men as well as women (20,21).

Methods

Participants and procedures

Participants were the offspring of women initially recruited during the second trimester of pregnancy through obstetrics/gynecology and low-income clinics around Milwaukee (80%) and Madison (20%) as part of the Wisconsin Maternity Leave and Health Project, now referred to as the Wisconsin Study of Families and Work (22). A total of 560 live offspring were born to these women. Of these, 78% were followed longitudinally after infancy; these 435 offspring (221 girls; 214 boys) constitute our study cohort, which will be referred to as the "full cohort" sample. At the last assessment included in the present study (age 18), 365 offspring (henceforth "participants" or "children") remained in the study. Based in part on proximity to the laboratory, 232 of these participants were selected to participate in a laboratory visit that included anthropometric measurements at age 18. Of the 232, 197 participants (108 girls; 89 boys) had no missing data for the variables of interest and will be referred to as the "complete case" sample.

Participants' parent or guardian (and, at older ages, the participants themselves) gave written informed consent, in accordance with University of Wisconsin Health Sciences Institutional Review Board requirements.

Procedures and measures

Figure 1 illustrates data collection relevant to the present study, including the (approximate) age at which each variable was measured.

Late-adolescent adiposity. Waist circumference and height were measured by study staff during a laboratory visit at "age 18" (mean age = 18.5 years; SD = 0.27 years). All measurements were obtained on a hard, flat surface by trained study staff, with the participant wearing clothes but not shoes. Height was measured to the nearest 0.25 in using a retractable, steel measuring tape and a level, with the participant standing against a wall. Waist circumference was measured to the nearest 0.5 cm at the superior border of the iliac crest, after normal expiration, with study staff standing on the participant's right side and using a flexible, nonstretch, retractable measuring tape. These measurement procedures were repeated until two readings within 0.25 in (height) or 0.5 cm (waist circumference) were obtained, and those two readings were then averaged. Because the ratio of waist circumference to height is a better measure of adiposity than waist circumference alone (21), the resulting height and waist circumference measurements were used to create a late-adolescent waist-to-height variable to use as the adiposity outcome. Although waist-to-height ratio is highly correlated with BMI (e.g., 0.92 in girls and 0.90 in boys in the complete case sample), total adiposity is better predicted by waist-to-height ratio than by BMI. For example, in a large nationally representative sample of children and adolescents, waist-to-height ratio, sex, and age explained 80% of the variance in the percentage of body fat measured via dual x-ray absorptiometry (21).

Childhood predictors. CSR was measured at "age 9" (mean age = 9.5 years; SD = 0.25 years) by questionnaires assessing effortful control, which refers to top-down cognitive processes involved in suppressing dominant responses in favor of subdominant responses (23) in service of self-regulation (3). The questionnaires assess two component processes of effortful control: effortful attention (focusing and shifting

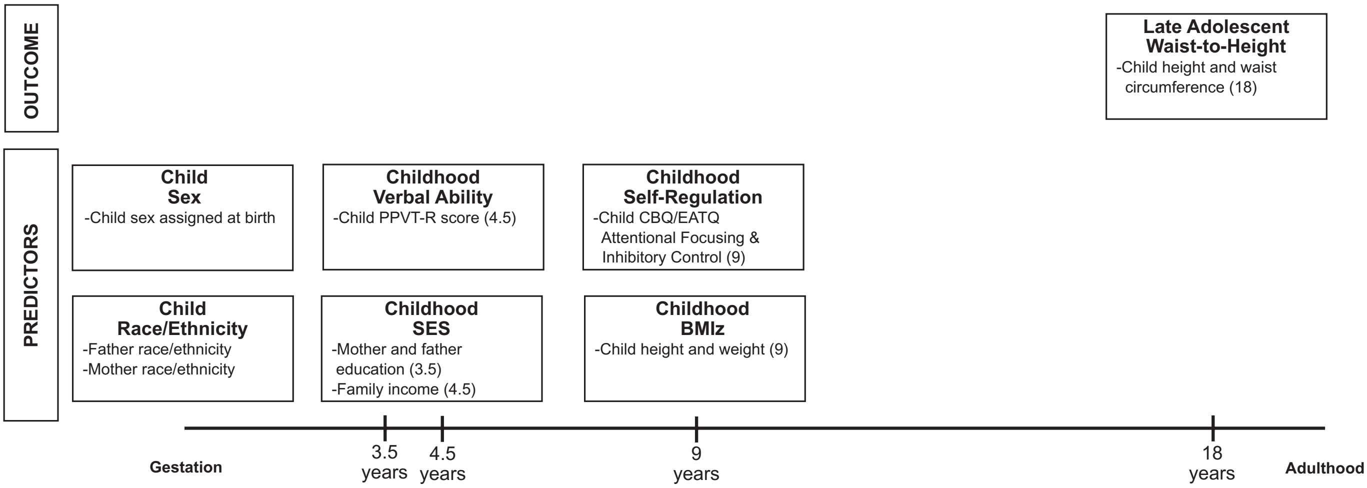

Figure 1 Depiction of data collection. Study participants are referred to as "child." Age (in years) at which the measure was collected appears in parentheses. BMIz, BMI z scores; CBQ, Children's Behavior Questionnaire; EATQ, Early Adolescent Temperament Questionnaire; PPVT-R, Peabody Picture Vocabulary Test–Revised; SES, socioeconomic status.

attention, including from punishment and reward) and inhibitory control (suppression of behaviors that are typically considered inappropriate) (24). Mothers, fathers, and teachers completed a shortened Attention scale from the revised Early Adolescent Temperament Questionnaire (24) and a shortened Inhibitory Control scale from the Children's Behavior Questionnaire (25), using the Early Adolescent Temperament Questionnaire's 5-point response scale (1 = almost always untrue, 5 = almost always true), with an option of selecting "not applicable." Both scales had good internal consistency for all informants ($\alpha > 0.70$), and cross-informant correlations ranged from 0.47 to 0.54 for the Attention scale and 0.44 to 0.53 for the Inhibitory Control scale. For each scale, we calculated total scores for each informant by averaging their (nonmissing) responses to all items in the scale, and we then averaged the resulting total scores for that scale across all available informants (26). Finally, we averaged the Attention and Inhibitory Control scales together (27) and standardized the result to create the CSR predictor. Standardization was done separately by sex so that the CSR predictor would have the same variance for boys and girls to facilitate comparison of the sex-specific regression coefficients for CSR.

Analyses also controlled for other childhood factors that may be related to CSR and also predict subsequent overweight/obesity (4,28). Because obesity is more prevalent in black and Hispanic adolescents in the United States (29), we included information on the participant's race/ethnicity, as reported by the mother. Because of sparsity in certain race/ethnicity categories, we combined the original response categories to create a two-category race/ethnicity predictor (Table 1) (29).

Because childhood socioeconomic status (SES) is an inverse predictor of subsequent obesity (28), we included information provided by the participant's mother about maternal and paternal education at age 3.5 and family income at age 4.5. Because these variables were highly correlated, we performed a principal component analysis on their correlations, which is a data-reduction technique used in previous studies examining SES in this sample (30). We then used the first principal component, which accounted for 56% of the variance in (standardized) maternal education, paternal education, and family income, as the childhood SES predictor.

Childhood cognitive ability, an inverse predictor of subsequent obesity (31), was assessed using the Peabody Picture Vocabulary Test–Revised at age 4.5. The age-normed standard scores were used as the childhood verbal ability predictor.

Information on childhood BMI, a strong positive predictor of subsequent obesity (32), was collected during a home visit at age 9. All measurements were performed on a hard, flat surface by trained study staff, with the child wearing clothes but not shoes. Height was measured using procedures identical to those used at age 18. Weight was measured to the nearest 0.5 lb using a Health o Meter EVERWeigh Lithium Electronic Scale (Sunbeam Health Division, Bridgeview, Illinois). The procedure was repeated until two readings within 0.5 lb were obtained, and those two readings were then averaged. Age- and sex-specific BMI*z* was calculated from the height and weight measurements based on the revised (2000) growth charts of the Centers for Disease Control and Prevention (33), and the resulting *z* scores were used as the childhood BMI*z* predictor.

Analyses

Following recommendations for analyzing data sets with missing data (34), we performed analyses in the complete case sample and also used principled missing-data methods to perform analyses in the full cohort sample (details and results reported in online Supporting Information Appendix A). Analyses used R version 3.4.4 (R Foundation for Statistical Computing, Vienna, Austria).

All analyses excluded participants who, at age 18, were taking certain medications (e.g., prednisone, stimulants) or had certain recently diagnosed or medically unstable diseases (e.g., hyperthyroidism, Grave's disease) known to affect weight. (Of note, the relatively low prevalence of these medications and conditions precluded statistical adjustment.) Prior research suggests that failing to exclude or adjust for individuals on prescription stimulants obscures the relationship between attention-deficit/hyperactivity disorder (ADHD), which is strongly related to CSR, and higher BMI (35), which is not surprising given the effects of stimulant use on weight trajectory (36).

TABLE 1 Summary statistics for variables of interest in complete case sample[a]

	Girls ($n=101$)			Boys ($n=80$)			Girls vs. boys[b]	
	Mean (or %)	SD	Observed range	Mean (or %)	SD	Observed range	Difference in means (or odds)	95% CI for difference (or odds)
Late-adolescent outcome								
Age 18 waist circumference (in)	30.5	4.4	(24.9 to 46.7)	32.3	3.9	(25.8 to 42.1)	–1.8	(–3.0 to –0.6)
Age 18 height (in)	65.3	2.4	(58.1 to 72.1)	70.1	2.5	(64.0 to 76.5)	–4.8	(–5.5 to –4.1)
Age 18 waist-to-height ratio	0.47	0.06	(0.39 to 0.69)	0.46	0.05	(0.35 to 0.62)	0.01	(–0.01 to 0.02)
Childhood predictors								
Age 9 self-regulation[c]	3.7	0.5	(2.1 to 4.6)	3.4	0.5	(2.2 to 4.7)	0.25	(0.09 to 0.41)
Race/ethnicity[d]	—	—	—	—	—	—	0.20	(0.00 to 1.72)
Black and/or Hispanic	5.9%	—	—	1.2%	—	—	—	—
White or Asian and non-Hispanic	94.1%	—	—	98.8%	—	—	—	—
Age 3.5 maternal education (y)	15.1	2.2	(10 to 20)	15.3	1.8	(12 to 19)	–0.2	(–0.8 to 0.4)
Age 3.5 paternal education (y)	14.7	2.2	(10 to 20)	15.2	2.5	(9 to 20)	–0.5	(–1.2 to 0.2)
Age 4.5 family income ($)	$66,968	$37,512	($20,000 to $300,000)	$67,560	$42,065	($21,000 to $280,000)	–$592	(–$12,450 to $11,266)
Age 4.5 verbal ability (standard scores)[e]	106.8	15.0	(62.0 to 144.0)	106.5	14.6	(76.0 to 153.0)	0.4	(–4.0 to 4.7)
Age 9 BMI *z* scores	0.4	1.0	(–2.4 to 2.7)	0.4	1.1	(–2.0 to 2.4)	–0.1	(–0.4 to 0.2)

[a]The complete case sample consisted of 197 participants (108 girls; 89 boys). Prior to analysis, eight participants (three girls; five boys) were removed because they were taking stimulant medication at age 18, and an additional eight participants (four girls; four boys) were removed because they had other disqualifying medications or disease at age 18, resulting in an analytic sample of 181 participants (101 girls; 80 boys). Summary statistics are provided for these 181 participants.
[b]For continuous variables, the (Welch) two-sample *t* test with unequal variance was used to calculate the 95% CI for the difference in means for girls versus boys. For categorical variables, the Fisher exact test was used to calculate the 95% CI for the odds ratio characterizing the odds of the variable's categories (e.g., black and/or Hispanic vs. white or Asian) by sex (girls vs. boys).
[c]Summary statistics calculated on the original scale for age-9 self-regulation (1 = strongly disagree; 5 = strongly agree).
[d]The black and/or Hispanic category includes individuals who selected the following response categories: black non-Hispanic, white Hispanic, other Hispanic, and other race. The white or Asian category includes individuals who selected the following response categories: white non-Hispanic, Asian or Pacific Islander, and Native American or Alaskan.
[e]Age-normed standard scores from the Peabody Picture Vocabulary Test–Revised.

TABLE 2 First-order correlations between variables of interest in complete case sample

Correlation	Late-adolescent waist-to-height ratio (transformed)	CSR	Childhood SES	Childhood verbal ability	Childhood BMIz
Late-adolescent waist-to-height ratio (transformed)	—	−0.28	−0.24	0.04	0.62
CSR	−0.04	—	0.28	0.26	−0.16
Childhood SES	0.00	0.37	—	0.24	−0.07
Childhood verbal ability	−0.17	0.07	0.18	—	0.14
Childhood BMI*z*	0.64	0.15	−0.07	−0.14	—

Correlations provided for 181 participants (101 girls; 80 boys) from complete case sample who were included in regression analyses. Correlations for boys appear below cells with em dashes, and correlations for girls appear above cells with em dashes.
BMIz, BMI *z* scores; CSR, childhood self-regulation; SES, socioeconomic status.

We first calculated sex-specific summary statistics for the outcome and predictors (Table 1). We also used the Fisher *z* transformation to test for sex differences in the (first-order) cross-sectional correlation between CSR and childhood BMI*z* and in the (first-order) longitudinal correlation between CSR and late-adolescent waist-to-height ratio.

Next, we used multiple regression models to examine how the relationship between CSR and late-adolescent waist-to-height ratio differs for girls and boys, in both baseline and adjusted models. In all models, the outcome (i.e., waist-to-height ratio) was transformed using the Box-Cox transformation with $\lambda = -2.5$ to address violations of normality. The baseline model (model 1) included race/ethnicity, and other models successively introduced additional predictors (i.e., childhood SES and verbal ability in model 2 and childhood BMI*z* in model 3) to test how adjustment affected the relationship between CSR and late-adolescent waist-to-height ratio in each sex. All models included an interaction term between sex and CSR as well as interactions between sex and all other predictors, given the potential for sex differences in their association with late-adolescent waist-to-height ratio (e.g., Sobal and Stunkard (37)).

Finally, we used multiple regression (model 4) to examine whether childhood BMI*z* moderates the effects of CSR on late-adolescent waist-to-height ratio by adding interactions among childhood BMI*z*, CSR, and sex into the fully adjusted model (i.e., model 3).

Results

Summary statistics

Table 1 presents sex-specific summary statistics for the 181 participants included in the complete case analyses. In summary, approximately 6% of girls and 1% of boys were black and/or Hispanic. At (participant) age 3.5, both mothers and fathers had about 15 years of education on average, and at (participant) age 4.5, the mean family income was more than $65,000. Also, at age 4.5, mean scores on the Peabody Picture Vocabulary Test–Revised were slightly above, but still within 1 SD of, the norm for that age. The means of childhood BMI*z* and late-adolescent waist-to-height ratio were below the risk cutoff for both boys and girls. However, both measures varied considerably across individuals, with 13.9% of girls and 12.5% of boys at or above the 95th percentile for childhood BMI*z* and with 18.8% of girls and 22.5% of boys at or above a ratio of 0.50 for late-adolescent waist-to-height ratio. Regarding sex differences, boys had greater mean height and waist circumference at age 18, as would be expected, but the mean of late-adolescent waist-to-height ratio did not differ significantly by sex. Likewise, there were no sex differences for predictors, except that the mean of CSR was slightly lower for boys than for girls prior to standardization.

Table 2 presents sex-specific first-order correlations for (transformed) late-adolescent waist-to-height ratio and all continuous predictors. Of note, the cross-sectional correlation between CSR and childhood BMI*z* was weakly negative in girls ($r = -0.16$, 95% CI:the longitudinal correlation between −0.34 to 0.04) but was weakly positive in boys ($r = 0.15$, 95% CI: −0.07 to 0.36), with the difference in the two correlations being statistically significant (Fisher $z = 2.01$, $P = 0.04$). In contrast, the longitudinal correlation between CSR and (transformed) late-adolescent waist-to-height ratio was negative in both sexes; although this correlation was larger in magnitude for girls ($r = -0.28$, 95% CI: −0.45 to −0.09) than boys ($r = -0.04$, 95% CI: −0.26 to 0.18), the difference only approached statistical significance (Fisher $z = 1.63$, $P = 0.10$).

Regression analyses

Table 3 presents results from models for late-adolescent waist-to-height ratio, including coefficients for girls, boys, and the difference between girls and boys. In the model adjusted only for race/ethnicity (model 1), CSR was a significant inverse predictor of late-adolescent waist-to-height ratio in girls ($\beta = -0.212$, $P < 0.01$) but was not a significant predictor in boys ($\beta = -0.060$, $P = 0.55$), explaining 8.1% of the variation in girls but only 0.4% in boys. Additional adjustment for childhood SES and childhood verbal ability (model 2) had little effect in either sex, decreasing the magnitude of the CSR coefficient by about 3% in girls and increasing it by about 10% in boys. However, after additional adjustment for childhood BMI*z* (model 3), the inverse relationship between CSR and late-adolescent waist-to-height ratio became considerably weaker in girls ($\beta = -0.122$, $P = 0.06$) but became stronger in boys ($\beta = -0.173$, $P = 0.05$), explaining 2.3% of the variation in girls and 3.0% in boys. The fact that adjustment for childhood BMI*z* had different effects in girls and boys is not surprising, given that CSR was already negatively correlated with childhood BMI*z* in girls but was positively correlated with childhood BMI*z* in boys. As a result, in models for late-adolescent waist-to-height ratio, additional adjustment for childhood BMI*z* decreased the magnitude of the (negative) coefficient for CSR by about 40% in girls but increased it by 150% in boys. In accordance with these findings, the difference

TABLE 3 Regression results for late-adolescent waist-to-height[a] ratio in complete case sample

Predictors[b]	Girls[c] Est.	Girls[c] 95% CI	Girls[c] *P* value	Boys[d] Est.	Boys[d] 95% CI	Boys[d] *P* value	Difference for girls vs. boys[e] Est.	Difference for girls vs. boys[e] 95% CI	Difference for girls vs. boys[e] *P* value
Model 1: adjusted for race/ethnicity									
Intercept	−1.914	(−2.542 to −1.286)	<0.001	−1.276	(−2.832 to 0.281)	0.11	−0.638	(−2.316 to 1.040)	0.46
CSR	−0.212	(−0.358 to −0.066)	<0.01	−0.060	(−0.253 to 0.133)	0.55	−0.152	(−0.394 to 0.090)	0.22
Race/ethnicity	−0.602	(−1.249 to 0.046)	0.07	−1.264	(−2.827 to 0.299)	0.12	0.663	(−1.029 to 2.355)	0.45
Childhood SES	—	—	—	—	—	—	—	—	—
Childhood verbal ability	—	—	—	—	—	—	—	—	—
Childhood BMI*z*	—	—	—	—	—	—	—	—	—
Δ R^2 for CSR	—	—	8.1%[f]	—	—	0.4%[g]	—	—	0.8%[h]
Model 2: adjusted for race/ethnicity, childhood SES, and childhood verbal ability									
Intercept	−2.894	(−4.188 to −1.600)	<0.001	−0.467	(−2.369 to 1.434)	0.63	−2.426	(−4.726 to −0.126)	0.04
CSR	−0.206	(−0.360 to −0.052)	<0.01	−0.066	(−0.273 to 0.140)	0.53	−0.140	(−0.397 to 0.118)	0.29
Race/ethnicity	−0.575	(−1.220 to 0.070)	0.09	−1.145	(−2.706 to 0.416)	0.15	0.571	(−1.118 to 2.260)	0.51
Childhood SES	−0.154	(−0.324 to 0.017)	0.08	0.051	(−0.161 to 0.263)	0.64	−0.204	(−0.476 to 0.068)	0.15
Childhood verbal ability	0.009	(−0.002 to 0.020)	0.11	−0.009	(−0.021 to 0.003)	0.16	0.017	(0.001 to 0.034)	0.04
Childhood BMI*z*	—	—	—	—	—	—	—	—	—
Δ R^2 for CSR	—	—	6.8%[f]	—	—	0.4%[g]	—	—	0.6%[h]
Model 3: adjusted for race/ethnicity, childhood SES, childhood verbal ability, and childhood BMIz									
Intercept	−2.767	(−3.796 to −1.738)	<0.001	−1.736	(−3.284 to −0.188)	0.03	−1.031	(−2.890 to 0.828)	0.28
CSR	−0.122	(−0.247 to 0.003)	0.06	−0.173	(−0.340 to −0.007)	0.05	0.051	(−0.157 to 0.259)	0.63
Race/ethnicity	−0.165	(−0.691 to 0.361)	0.54	−0.551	(−1.801 to 0.700)	0.39	0.386	(−0.970 to 1.743)	0.58
Childhood SES	−0.131	(−0.266 to 0.005)	0.06	0.119	(−0.051 to 0.288)	0.17	−0.249	(−0.466 to −0.032)	0.03
Childhood verbal ability	0.003	(−0.006 to 0.011)	0.56	−0.004	(−0.014 to 0.005)	0.38	0.007	(−0.006 to 0.020)	0.30
Childhood BMI*z*	0.430	(0.305 to 0.554)	<0.001	0.507	(0.373 to 0.641)	<0.001	−0.077	(−0.260 to 0.106)	0.41
Δ R^2 for CSR	—	—	2.3%[f]	—	—	3.0%[g]	—	—	0.1%[h]
Model 4: adjusted for race/ethnicity, childhood SES, childhood verbal ability, childhood BMIz, and CSR × childhood BMIz									
Intercept	−2.716	(−3.745 to −1.687)	<0.001	−1.695	(−3.296 to −0.095)	0.04	−1.021	(−2.923 to 0.882)	0.30
CSR	−0.090	(−0.221 to 0.041)	0.18	−0.167	(−0.345 to 0.010)	0.07	0.078	(−0.143 to 0.298)	0.49
Race/ethnicity	−0.115	(−0.644 to 0.414)	0.67	−0.573	(−1.842 to 0.696)	0.38	0.458	(−0.916 to 1.833)	0.52
Childhood SES	−0.130	(−0.266 to 0.005)	0.07	0.121	(−0.050 to 0.293)	0.17	−0.252	(−0.470 to −0.033)	0.03
Childhood verbal ability	0.002	(−0.007 to 0.010)	0.72	−0.005	(−0.014 to 0.005)	0.37	0.006	(−0.007 to 0.019)	0.36
Childhood BMI*z*	0.412	(0.286 to 0.539)	<0.001	0.507	(0.373 to 0.642)	<0.001	−0.095	(−0.279 to 0.089)	0.32
CSR × childhood BMI*z*	−0.088	(−0.195 to 0.020)	0.12	−0.015	(−0.166 to 0.136)	0.85	−0.073	(−0.258 to 0.113)	0.44

[a]Late-adolescent waist-to-height ratio was transformed using the Box-Cox transformation with $\lambda = -2.5$ (i.e., [waist-to-height ratio$^{(-2.5)}$ − 1]/[−2.5]).
[b]All models include sex as a predictor as well as interactions between sex and all other predictors.
[c]Coefficients for girls (e.g., the coefficient for CSR in girls) correspond to the main effect of the predictor (e.g., CSR) when the sex variable is coded as 0 for girls and 1 for boys.
[d]Coefficients for boys (e.g., the coefficient for CSR in boys) correspond to the main effect of the predictor (e.g., CSR) when the sex variable is coded as 1 for girls and 0 for boys.
[e]Coefficients for differences in girls versus boys (e.g., the coefficient for the difference in CSR for girls minus boys) correspond to the interaction between the predictor (e.g., CSR) and sex when the sex variable is coded as 1 for girls and 0 for boys.
[f]Δ R^2 for CSR = R^2 for *girls only* from model *including CSR* (with all coefficients sex-specific) − R^2 for *girls only* from model *excluding CSR* (with all coefficients sex-specific).
[g]Δ R^2 for CSR = R^2 for *boys only* from model *including CSR* (with all coefficients sex-specific) − R^2 for *boys only* from model *excluding CSR* (with all coefficients sex-specific).
[h]Δ R^2 for CSR = R^2 for *girls and boys* from model *including CSR* (with all coefficients sex-specific) − R^2 for *girls and boys* from model *including CSR* (with all coefficients except CSR sex-specific).
BMIz, BMI *z* scores; CSR, childhood self-regulation; Est., estimate; SES, socioeconomic status.

between the CSR coefficient for girls and boys was negative in model 1 (β = −0.152, P = 0.22) and model 2 (β = −0.140, P = 0.29) but was slightly positive in model 3 (β = 0.051, P = 0.63), although it was not statistically significant in any of the models. Finally, in model 4, the interaction between CSR and childhood BMI*z* approached significance in girls (interaction term = −0.088, P = 0.12) but not in boys (interaction term = −0.015, P = 0.85). As depicted in Figure 2, the adjusted association between CSR and late-adolescent waist-to-height ratio was negative for girls with childhood BMI*z* 1 SD above the mean (β = −0.177, P = 0.02), but it was effectively zero for girls with childhood BMI*z* 1 SD below the mean (β = −0.002, P = 0.99). In contrast, the adjusted association between CSR and late-adolescent waist-to-height ratio was relatively comparable for boys with childhood BMI*z* 1 SD above the mean (β = −0.182, P = 0.06) and boys with childhood BMI*z* 1 SD below the mean (β = −0.153, P = 0.27).

The pattern of results described here for the complete case sample was generally replicated in the full cohort sample (see online Supporting Information Appendix A for details). However, for girls, the magnitude of the inverse relationship between CSR and late-adolescent waist to height ratio was smaller in the full cohort than in the complete case sample, whereas the magnitude of this relationship for boys was larger in the full cohort than the complete case sample.

Discussion

Our first aim was to examine whether the relationship between CSR and subsequent adiposity differs by sex, using a longitudinal, community-based sample and a measure of adiposity that is similarly accurate in both girls and boys. We found that, cross-sectionally, CSR had a small inverse correlation with childhood BMI*z* in girls but not in boys. However, CSR inversely predicted a small portion of the variation in late-adolescent waist-to-height ratio in both girls and boys, after adjustment for childhood BMI*z* as well as other childhood predictors.

These results suggest that CSR may have a stronger inverse association with concurrent childhood adiposity in girls than in boys. However, our results do *not* support the hypothesis that CSR is a stronger inverse predictor of changes in adiposity across adolescence in girls. Our findings in this regard are consistent with prior research, as studies that adjust for childhood BMI have not found significant sex differences in the association between middle childhood CSR (or related constructs such as ADHD or conscientiousness) and subsequent BMI (7,9). In contrast, in prior studies that do not adjust for childhood adiposity (38,39), middle childhood CSR predicts end-point BMI more strongly or more consistently in girls, consistent with the results seen when our analyses were not adjusted for childhood BMI*z*. One possible interpretation of this pattern of results is that self-regulation has an effect on subsequent adiposity that emerges earlier in girls, whether for biological or sociocultural reasons. Alternatively, it is possible that CSR has (theoretically) comparable effects on subsequent adiposity throughout childhood and adolescence in both girls and boys, but, in practice, the higher prevalence of prescription stimulant use in boys with low CSR (40) masks CSR's effects on adiposity until late adolescence in boys (35). Another possibility is that CSR (actually) has comparable effects on subsequent adiposity throughout childhood and adolescence in both girls and boys, but this is not reflected in the cross-sectional association between CSR and adiposity in boys because CSR has less interindividual consistency across time in boys (41). Finally, CSR may not have a causal effect on adiposity in either girls or boys, but it might be less strongly associated with the factors affecting subsequent adiposity in younger boys.

Our second aim was to examine whether the relationship between CSR and subsequent adiposity differs depending on childhood adiposity levels. Our results provide some support for the hypothesis that CSR is a stronger predictor of (residualized) changes in adiposity across adolescence for girls with higher (vs. lower) childhood BMI*z*, although the interaction did not achieve statistical significance. Prior studies have not found a significant interaction between CSR and childhood adiposity (7,9), although these studies did not examine this interaction

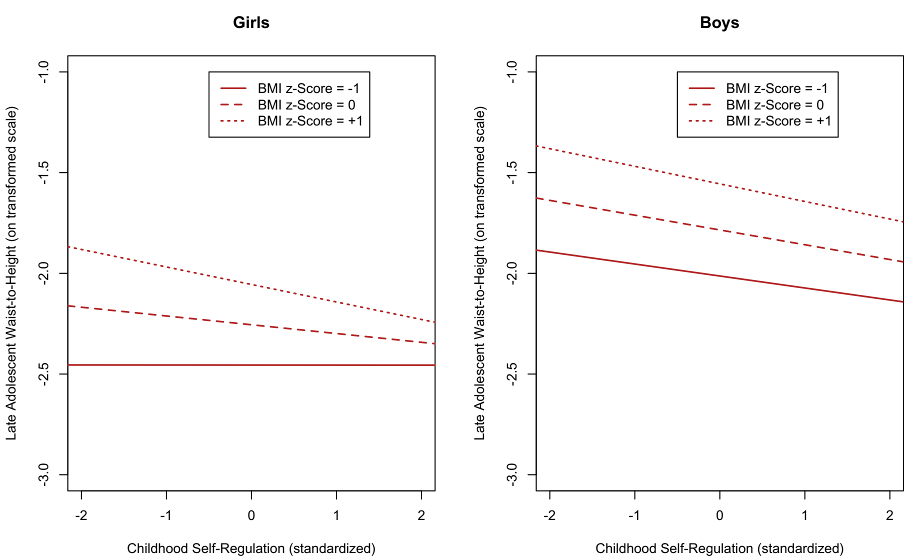

Figure 2 Relationship between childhood self-regulation and late-adolescent waist-to-height ratio, by childhood BMI *z* score, in the complete case sample. All models are adjusted for race/ethnicity, childhood SES, childhood verbal ability, and childhood BMI *z* score. BMI, body mass index; SES, socioeconomic status. [Color figure can be viewed at wileyonlinelibrary.com]

separately by sex and also had limited power (e.g., because of small samples or correction for testing multiple interactions). However, an intervention targeting CSR had greater effects on body size changes over time in children with larger body sizes at baseline (12).

Our study has several limitations. First, although waist-to-height ratio is more highly correlated with total adiposity than are more commonly used measures, such as BMI (21), our outcome measure is still not a perfect measure of total adiposity. Also, it is possible that a higher proportion of the boys had not reached their peak height by the time of outcome measurement (i.e., age 18), making the outcome measure potentially less stable across time in boys. Second, despite being community-based, the sample was not fully representative of the population, and it consisted primarily of white non-Hispanic participants, who tend to have a lower prevalence of overweight/obesity than black and/or Hispanic adolescents (29). Third, we examined differences based on the sex assigned to participants at birth. As a result, our study does not shed light on whether the relationship between CSR and subsequent adiposity differs based on gender identity. Fourth, although our study cohort was not small and any missingness in adiposity outcomes was at least partly by design, the presence of missing data nonetheless limited our power to detect certain effects (e.g., two-way and especially three-way interactions). Further, the presence of missing data can bias results, although principled missing-data methods can reduce bias considerably. Fifth, regarding potential confounders, childhood SES and verbal ability were measured at least 4 years prior to CSR, which could have contributed to the negligible effect that adjusting for these variables had on the association between CSR and late-adolescent waist-to-height ratio. Sixth, we were not able to adjust for stimulant medication use in childhood or earlier adolescence, which may have impacted results, given the relationship between CSR and ADHD and the effects of stimulant medications on weight trajectory (35). Seventh, we did not examine behavioral mediators (e.g., fruit/vegetable consumption, binge and emotional eating, physical activity, sleep) (6,42), an important next step for research (7), especially because marked changes in diet and physical activity occur during adolescence (1). In addition, our analyses did not examine whether environment, caregiver characteristics, and behaviors in particular moderated (or mediated) the effects of CSR (43). Finally, although analyses were prospective and adjusted for potential confounders (e.g., SES), we cannot definitively state that higher CSR *causes* smaller changes in adiposity during adolescence. Interventional research is needed to demonstrate causality. To date, findings for interventions targeting CSR have been mixed. Some (12), but not all (11), studies have found effects on adiposity, with discrepancies possibly due in part to longer follow-up periods in studies with positive results (6).

Limitations aside, our findings do have important implications for assessing the efficacy of interventions targeting CSR. Specifically, if the association between CSR and subsequent adiposity is indeed causal, interventions occurring early in childhood may have effects on adiposity only in girls. However, interventions with longer follow-up periods or beginning later in childhood may affect adiposity in both sexes, although outcome measures other than BMI (e.g., waist circumference) (20) may be needed to detect effects in boys from mid-to-late adolescence onward. In addition, effects on adiposity may be detectable only in girls with higher, but not lower, baseline adiposity.**O**

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