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Effects of an obesity intervention program on cognitive function in children: A randomized controlled trial

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What is already known about this subject?

Childhood obesity is associated with poorer cognitive function. Physical activity and fitness are shown to be beneficial to cognitive function. Few randomized controlled trials have examined the effects of physical activity-based obesity interventions on cognitive function in children and results were mixed.

What this study adds

The randomized controlled trial demonstrated that the one-year obesity intervention program may benefit emotional control, monitoring, and visuospatial construction skills in children.

Abstract

Objective: Adiposity may be associated with poorer cognitive function in children. The purpose of the study was to examine the effects of an obesity intervention on cognitive function in children.

Design and Methods: One hundred and fifteen children were randomly allocated to either the Day Camp Intervention Arm (DCIA) or the Standard Intervention Arm (SIA). The children in the DCIA participated in a 6-week day camp intervention and a subsequent 46-week family-based intervention. The camp intervention mainly consisted of fun-based physical exercise and health classes. The SIA was offered one weekly fun-based physical exercise session for 6 weeks and one educational meeting. Anthropometrics and cognitive function were measured at baseline, 6 weeks, and 52 weeks.

Results: At 6 weeks, the improvement in visuospatial construction skills was larger in the DCIA than the SIA (standardized mean difference, 0.47, 95% CI, 0.08 to 0.86, P=0.02). At 52 weeks, the improvement in emotional control (standardized mean difference, -0.42, 95% CI, -0.68 to -0.16, P=0.002) and monitoring (standardized mean difference, -0.32, 95% CI, -0.63 to -0.02, P=0.04) were larger in the DCIA than the SIA. No group differences were observed in changes in other cognitive outcomes.

Conclusions: The obesity intervention may benefit emotional control, monitoring, and visuospatial construction skills in children.

Introduction

The prevalence of childhood overweight and obesity has increased markedly in most countries during the past several decades (1). Obesity adversely affects many organ systems and is associated with numerous health consequences in children and adolescents, such as elevated blood pressure, insulin resistance, hyperlipidaemia, low-grade systemic inflammation, and psychosocial complications (2, 3). In addition, longitudinal studies have shown that being obese in middle life increases the risk of dementia later in life (4, 5). Research also indicates that obesity is correlated with increased rate of brain atrophy in adults (6). Furthermore, some studies have linked obesity with poorer general cognitive function or intelligence score in children and adolescents (7, 8). The association between obesity and cognitive function was more consistently found within the domain of executive functions (7, 9, 10). Executive function, also called cognitive control, are important for physical health, mental health, and success in school and late life (11). Executive function encompasses inhibitory control (e.g. regulation of one’s emotion and behaviours), working memory, cognitive flexibility, planning, and reasoning, etc. (11, 12). However, it remains unclear whether the observed relationship infer causal effects of obesity. It is possible that lower general intellectual/cognitive function and executive dysfunction increase the risk of being obese. In fact, a large-scale perspective study showed that childhood intelligence was inversely related to the risk of obesity in adulthood (13). Moreover, studies showed that poor executive function correlated with obesity-related behaviours, such as disinhibited eating, consumption of energy-dense food and sedentary behaviours (14, 15).

Recently, studies examined the effects of physical activity and fitness on cognitive function in children and adolescents. In preadolescents, cardiorespiratory fitness (CRF) has been found to be positively associated with inhibitory control (16, 17) and memory (18, 19) compared with lower-fit counterparts. Lee et al. showed that adolescents who regularly participated in physical activity performed better in executive functions (20). In a randomized controlled trial (RCT), Hillman et al. showed that a 9-month afterschool physical activity program for preadolescents improved inhibitory control and cognitive flexibility (21).

Two RCT studies examined the effects of obesity interventions on neuropsychological function in overweight and obese children. The findings, however, are not consistent. The study by Davis et al. showed a dose-response benefit of a 3-month exercise intervention on an aspect of executive function (planning) in 7-

11 years old overweight children compared with control group (22). However, Krafft et al. reported that an 8-month afterschool aerobic exercise intervention did not result in a greater improvement in inhibitory control in 8-11 years old overweight children compared with the control group (23). Additionally, the effects of a program aimed at reducing obesity on children's everyday executive function have not been examined. Children's everyday executive function have been negatively linked with obesity-related behaviours (14) and risks of being obese (24). The Odense Overweight Intervention Study (OOIS) was a one-year multi-component intervention for 5th-grade overweight and obese children, which resulted in a significant reduction in body fat (25). The purpose of the current study was to evaluate the effects of the OOIS intervention on cognitive function.

Methods

Study design and participants

The study design of OOIS has been reported elsewhere in detail (26). Briefly, the OOIS was an RCT study conducted from 2012 through 2014 in Odense, Denmark. The participants were recruited from the mandatory annual schoolchild examination of 5th grade school children in Odense, Denmark. The children's height, weight and waist circumferences were measured by school nurses from September to December of 2011 and 2012. In total, 3750 children were screened. Children were eligible for participation if they exceeded age- and sex-specific BMI cut-points for overweight based on criteria from the International Obesity Task Force (IOTF) (27). The exclusion criteria included: (1) participation in other intervention programs; (2) attending special school or class; (3) known clinically diagnosed endogenous cause of overweight; (4) motor-control handicap; (5) known violent behavior. One hundred fifteen children were recruited. The participants were randomly allocated to either the Day Camp Intervention Arm (DCIA, N=55) or the Standard Intervention Arm (SIA, N=51). The allocation sequence was generated by sex stratified concealed block randomization (1:1) with a block size of 2 to 6 (random permuted blocks). It is noteworthy that 6 children who were slightly below the IOTF overweight cut-points at screening were also suggested by the school nurses to participate in the OOIS project. This was due to the fact that the nurses thought that the children were at risk of being overweight. Because the 6 children were included in the randomization, they were not excluded from the analyses. Written informed consent was obtained from children's parents or legal guardians. Additional verbal agreements from children were obtained before examinations. Figure 1 depicts the participant flowchart.

Interventions

Day camp intervention arm

The intervention for day camp group comprised two parts - an intensive 6-week day camp intervention and a subsequent 46-week family-based intervention program (52 weeks in total). The day camps were located in the city of Odense (the third largest city in Denmark), and took place from mid-May to end of June in 2012 and 2013, respectively. Participants stayed at a day camp from 7 a.m. to 8.30 p.m. for 7 days per week. In the camp, the children were engaged in fun-based physical activity and sports (3 hours or longer per day) and health classes (nutrition, physical activity and health, goal setting, etc.). The children in DCIA achieved about 90 minutes of moderate to vigorous physical activity during a camp day measured by accelerometry (25). During a camp day, three meals and three snacks were prepared and served according to the national Danish dietary recommendations with no caloric restrictions (28). After the 6-week day camp intervention, a family-based lifestyle intervention program was followed during the subsequent 46 weeks. The intervention consisted of one physical activity day and four parents-involved meetings targeting daily physical activity and dietary behaviour.

Standard intervention arm

The standard intervention consisted of one weekly fun-based physical activity session (two hours duration) for 6 weeks. One health and lifestyle educational session for the parents was delivered by a dietician and physical activity specialist.

Neuropsychological measures

Aspects of children's executive functions were assessed by the Stroop colour word test (SCWT) and the behaviour rating inventory of executive function (BRIEF). Visuospatial construction and nonverbal memory were assessed by the Rey complex figure test (RCFT). The SCWT and RCFT were administered individually by trained researchers. The testing environment was comfortable and free from distraction.

SCWT

The SCWT is a well-known paradigm for assessing selective attention and inhibition of prepotent responses during decision-making tasks (29). A paper and pencil version of the Stroop colour and word test Children's Version for Ages 5-14 was used for this study (30). Briefly, the task consists of three conditions (word page, colour page, and colour-word page). In each condition, the participants were instructed to read as many words as possible within 45 seconds. In the word condition, the children were instructed to read words (RED, BLUE and GREEN) in black ink. In the colour condition, the children were instructed to name the colour of a list of *XXXX*s printed in different colours (red, blue and green). In the colour-word condition, the children were instructed to name the colour of incongruent colour-inked words (e.g. RED printed in blue colour). An interference score was derived from the difference between colour-word score and colour score (30). The task was administered at baseline, 6 weeks and 52 weeks. Eight observations in total were excluded from analyses due to unsuccessful administration of the task.

RCFT

The RCFT is a widely-used test of visuospatial construction and nonverbal memory (31). The test is divided into four parts: copy trial, immediate recall trial, delayed recall trial and recognition trial. For this study only the RCFT copy trial and immediate recall trial were administered. In the copy trial, the participants were instructed to copy the figure as accurately as possible with no time constraints. The figure was removed from sight when the copying was finished. After a 3-minute delay (in immediate recall trial), participants were asked to reproduce the figure from memory (without forewarning). During the 3-minute delay, the participants were instructed to read some sentences which were not related to the test. The RCFT test was administered at baseline, 6 weeks and 52 weeks. The scoring of RCFT was performed by a trained researcher (TH) with blinding of the intervention allocations. The inter-rater reliability coefficient (Pearson's r) was 0.96, which was evaluated using 15 randomly selected drawings scored independently by two researchers (JRMJ and TH).

BRIEF

The BRIEF is a measure of executive functioning in real-life environments that has been used in both clinical and research settings (32, 33). The BRIEF parent form is comprised of 8 clinical scales (inhibit, shift, emotional control, initiate, working memory, plan/organize, organization of materials, and monitor). There are 86 items in total. The children's parents were asked to rate the scales according to children's behaviour during last 6 months. For each item, scoring options were "1 = Never," "2 = Sometimes," or "3 = Often." Higher scores indicate more problems. The eight scales are combined to two indexes and one composite summary score. Behavioural regulation index (BRI) consists of the inhibit, shift, and emotional control scales. Metacognition index (MI) consists of the initiate, working memory, plan/organize, organization of materials, and monitor scales. The BRI represents a child's ability to shift cognitive set and modulate behaviour and emotions, whereas the MI represents the ability to initiate, plan, organize, and sustain future-oriented problem solving in working memory. Global executive composite (GEC) is a summary score of all scales scores (BRI + MI). BRIEF was rated at baseline and 52 weeks.

Anthropometrics and body fat percentage

Height was measured to the nearest 0.5 cm without footwear. Body weight was measured to the nearest 0.1 kg in underwear using a Soehnle professional medical electronic scale (Soehnle Industrial Solutions GmbH, Backnang, Germany). BMI was calculated as weight (kg) divided by height squared (m). Body fat mass was assessed by the dual energy X-ray absorptiometry (DEXA). The scanning was performed by an experienced operator on a GE Lunar Prodigy (GE Medical Systems, Madison, WI).

Parental educational level and ethnicity

The information about parental education level and ethnicity was obtained by questionnaires at baseline. The classification of parental educational level was based on parents' highest educational level. The education level was collapsed into three categories: (1) Basic school no more than 10 years, (2) High school or non-university vocational programs, (3) College or university degrees. The parental educational level was used as an indicator of parental social economic status. Ethnicity was categorized into Danish and non-Danish.

Pubertal development

Puberty development was assessed using Tanner scale (34) at baseline. The children self-reported their sexual development by comparison with Tanner's drawings in a confidential room. For this study, girls were staged according to breast development. Boys were staged according to genital development.

Statistics

Descriptive characteristics at baseline were summarized by group. For continuous variables, potential differences were examined using an independent sample t-test. Categorical variables were assessed using Chi-squared test or fisher's exact test. Mixed effects models were used to analyse intervention effects. The analyses modelled for effects of time, group, and time by group interaction with sex and cohort (children from the first year or second year) as covariates. The analyses were conducted according to the *intention to treat* principle. Mixed effects modelling allow the inclusion of partial data of participants who may have dropped out or who were unavailable to follow-ups. No imputation of data was applied. Maximum likelihood estimation was used for all models. The scores of cognitive measures were standardized based on the mean and standard deviation (SD) at baseline. The standard scores were used for analyzing the intervention effects. The association between SWCT and BRIEF was analysed by Pearson product-moment correlation. All statistical analyses were conducted with STATA 12 for Windows (StataCorp LP, Texas, USA), and the level of significance was set at $P < 0.05$ (two-sided).

Results

Participant flow is presented in Figure 1. Nine children withdrew (5 from the SIA and 4 from the DCIA) after the randomization, which led to 51 children in the SIA and 55 children in the DCIA at baseline. Descriptive characteristics at baseline are shown in Table 1. There were no significant between-group differences on those characteristics at baseline. All the participants met our predefined compliance criteria of attendance of 85 % of the camp days (34 days out of 40 days). For the subsequent family-based intervention, the mean adherence of meetings was 3.4 (SD 1.9) times. Retention rate of the DCIA were 93% at 6 weeks and 87% at 52 weeks. Retention rate of the SIA were 84% at 6 weeks and 75% at 52 weeks.

Table 2 summarizes the results for baseline, follow-ups and changes in the scores of SCWT and RCFT. At 6 weeks, the improvement in visuospatial construction skills was larger in the DCIA than that in the SIA (standardized mean difference, 0.47, 95% CI, 0.08 to 0.86, P=0.02). There was no significant between-group difference in the changes in visuospatial construction skills from baseline to 52 weeks. Although both groups improved in visual memory (RCFT 3-minutes recall) from baseline to 6 weeks and from baseline to 52 weeks, there were no significant differences in changes between the two groups. The SCWT interference score was not significantly changed by the intervention programs from baseline to 6 weeks and from baseline to 52 weeks.

The BRIEF scale was rated mostly by child's mother (84% at baseline and 79% at 52 weeks). There were no significant correlations between SWCT interference score and BRIEF scores (all P>0.05). The baseline, 52-week follow-up, and changes in BRIEF scores are shown in Table 3. There were no significant differences in changes on BRI, MI, and GEC between the two groups. Subsequent analyses of BRIEF subscales revealed that the DCIA had larger improvements in emotional control (standardized mean difference, -0.42, 95% CI, -0.68 to -0.16, P=0.002) and monitoring (standardized mean difference, -0.32, 95% CI, -0.63 to -0.02, P=0.04) compared with the SIA. No between-group differences were found in changes on other BRIEF subscales.

Discussion

In this study, we examined the effects of a one-year intervention program on cognitive function in overweight and obese children. Compared with the SIA, the DCIA had a greater improvement in body composition and CRF at both 6 weeks and 52 weeks (25) , which has been reported elsewhere (25). With regard to cognitive function, a significant group by time interaction was found for the RCFT copy trial at 6 weeks. However, the difference was not sustained to 52 weeks. Significant group by time interactions were found for the BRIEF emotional control and monitor subscales. No between-group differences were observed in the changes of the SCWT interference score at both follow-ups.

In the current study, children in the DCIA participated in an intensive obesity intervention program for 6 weeks in a day camp and were followed up at 52 weeks. For the BRIEF scales, the DCIA showed a tendency toward a greater improvement on BRI summary score compared with the SIA. However, when analysing the subscales included in BRI, only the changes in emotional control subscale was significantly different across the two groups. Emotion control is the affective aspect of executive function ("hot" executive function), which is associated with the brain's emotion control and reward system, including orbital and medial prefrontal cortex system (35). To the best of our knowledge, this was the first report to investigate the effects of obesity intervention on "hot" executive function in children. Most objective neuropsychological tests measure executive function skills without assessing emotions (36). The findings suggest that our obesity intervention program may benefit the children's emotional regulation. Despite the lack of group differences in MI score, the improvement on monitor subscale was larger in the DCIA than in the SIA. It suggests that children's work-checking habits and personal monitoring may be improved as results of the intervention program. We did not observe any between-group difference on other subscales, including the plan/organize subscale. Davis et al.

investigated the effect of a 3-month exercise intervention program on cognitive function in overweight children 7-11 years of age (22). Their results showed that the exercise intervention selectively improved executive function (planning skills) compared with control group. However, a cognitive test (Cognitive assessment system) was used in their study, whereas we used the BRIEF parental rating questionnaire to assess everyday executive function. Nevertheless, the changes in almost all (9 out of 11) BRIEF scores were in favour of the DCIA, although most were not statistically significant. It may stress the importance for future studies to evaluate overweight children's everyday executive functions including emotional control and monitoring after participating in physical activity or obesity intervention programs. However, it is noteworthy that the BRIEF is not an objective measure of everyday executive functions and it was rated by child's parents (mostly by mother) in our study. The parents were not blinded to the interventions and it is possible that the BRIEF results to some extent reflect rating bias. The fact that BRIEF did not correlate significantly with the SCWT interference score in our study points to the need of more studies of the validity of BRIEF scores.

The DCIA experienced a greater improvement in the performance of visuospatial construction at 6 weeks compared with the SIA. We did not observe any between-group differences in improvements on memory function. Many studies conducted in animals have suggested a beneficial effect of exercise on spatial memory (37). Few studies examined the effects of physical activity and fitness on memory in children (38). In preadolescent children, Monti et al. demonstrated that relational memory was improved after 9 months of afterschool aerobic exercise intervention (38). We speculate that the lack of effects of our intervention program aimed at overweight and obese children may be due to study differences in characteristics of cognitive tasks and intervention components.

At both 6 weeks and 52 weeks the changes in the SCWT interference score were not significant different between groups. Krafft et al. conducted an 8-month intervention study in 8-11 years old overweight children. Similar to our findings, they did not find intervention effects in the change of performances of flanker and antisaccade tasks (23). As mentioned earlier, Davis et al. found a selective improvement in planning skills after a 3-month exercise intervention in overweight children (22). The reasons for the inconsistent findings in the literature are not clear. It is likely that the heterogeneity of intervention programs may explain, at least partly, the inconsistent findings. Given that the increasing prevalence of childhood obesity and its potential negative effects on cognitive function, future research are needed to identify effective obesity intervention programs which not only improve body composition but potentially also benefit brain and cognitive function. Recently, Crova et al. reported that cognitively challenging physical activities were beneficial to executive function in overweight children. In their study, a 6-month physical education (PE) program including cognitively demanding activities led to improved executive function in overweight children aged 9-10 years old. In contrast, the control group who participated in traditional PE class did not experience the same improvements (39). The study suggested that it may be relevant to include cognitively challenging physical activities in future obesity intervention programs, in order to improve cognition. Additionally, there is no gold-standard measure of executive function available, although Stroop tasks are often used (29). A variety of cognitive tasks have been used to assess the intervention effects in previous studies. These cognitive tasks tap various aspects of executive function and assess different cognitive skills. This fact may also explain part of the reasons for the inconsistent findings which have characterized this field of research.

The strengths of the study include its RCT design, one-year follow-up, and a measure of everyday executive function. However, the camp intervention program was relatively intensive and short in duration. This may limit the direct comparisons with other studies. The sample size and statistical power of OOIS were calculated on the basis of expected changes in BMI, not the outcomes of the current study, because the initial purpose of OOIS was to examine the effects on body weight (26). Thus, it was possible that the sample size was underpowered for some the outcomes in this study. Nevertheless, it is still of importance to evaluate the effects of changes in neuropsychological functions after an obesity intervention. The generalizability of the results may be limited by the fact that only 5^{th}-grade overweight and obese children were included in the study. It is also worth mentioning that we did not apply Bonferroni correction for multiple testing. Nevertheless, the effect on emotional control was still significant, even though Bonferroni correction was applied.

Conclusion

The obesity intervention may benefit cognitive function in 5^{th}-grade overweight and obese children, probably in the emotional control and monitoring aspects of executive function and visuospatial construction skills. More research may be needed to provide further evidence on the beneficial effects of participating in obesity interventions or physical activity on cognitive function in children.

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TABLE 1 Baseline participant characteristics

Characteristics	No.	SIA (N=51)	DCIA (N=55)	Total (n=106)
Age (year)	106	12.0 (0.4)	12.0 (0.4)	12.0 (0.4)
Sex (girls)	106	30 (58.8%)	29 (52.7%)	59 (55.7%)
Parental highest education	99			
I		10 (21.3%)	15 (28.8%)	25 (25.3%)
II		15 (31.9%)	24 (46.2%)	39 (39.4%)
III		22 (46.8%)	13 (25.0%)	35 (35.4%)
Race	106			
Danish		36 (70.6%)	34 (61.8%)	70 (66.0%)
Non Danish		15 (29.4%)	21 (38.2%)	36 (34.0%)
Tanner stage	106			
I		1 (2.0%)	3 (5.5%)	4 (3.8%)
II		13 (25.5%)	15 (27.3%)	28 (26.4)
III		27 (52.9%)	27 (49.1%)	54 (50.9%)
IV		7 (13.7%)	10 (18.2%)	17 (16.0%)
V		3 (6.0%)	0	3 (2.8%)
Weight (kg)	106	59.5 (8.7)	61.7 (8.6)	60.6 (8.7)
Height (cm)	106	155.5 (5.7)	156.4 (6.6)	156.0 (6.1)
BMI (kg/m^2)	106	24.5 (2.9)	25.2 (2.8)	24.8 (2.9)
Total body fat (%)	104	39.2 (6.2)	39.5 (6.2)	39.3 (6.2)

Abbreviation: BMI, body mass index; DCIA, day camp intervention arm; SIA, standard intervention arm

Data are expressed as mean (SD) for continuous variables and frequency for categorical variables. There were no significant group differences (p>0.05).

Parental education were mainly based on parents' highest education (I = Basic school no more than 10 years; II = High school or non-university vocational programs; 3.5 years of college education; III = College or university degrees).

TABLE 2 Baseline, follow-up and changes in SCWT and RCFT at 6 weeks and 52 weeks

	Mean (SD), N=SIA/DCIA			Within-group change at 6 weeks	Within-group change at 52 weeks	Between-group differences in changes at 6 weeks		Between-group differences in changes at 52 weeks	
	Baseline	6 weeks	52 weeks	Mean (95 % CI)	Mean (95 % CI)	Mean (95 % CI)	P	Mean (95 % CI)	P
SCWT Interference	N=50/51	N=41/51	N=36/47						
SIA	-25.48 (6.07)	-24.17 (5.84)	-22.97 (6.13)	0.13 (-0.19 to 0.45)	0.32 (-0.02 to 0.66)	-0.16 (-0.60 to 0.29)	0.49	-0.40 (-0.86 to 0.06)	0.09
DCIA	-24.39 (6.44)	-24.73 (7.08)	-25.17 (7.21)	-0.02 (-0.33 to 0.28)	-0.08 (-0.39 to 0.23)				
RCFT Copy	N=51/55	N=43/51	N=38/48						
SIA	32.30 (3.13)	31.95 (5.37)	31.49 (5.94)	-0.12 (-0.40 to 0.17)	-0.17 (-0.51 to 0.17)	0.47 (0.08 to 0.86)	**0.02**	0.21 (-0.26 to 0.67)	0.38
DCIA	30.73 (3.78)	32.24 (3.04)	31.04 (3.47)	0.36 (0.09 to 0.62) *	0.03 (-0.27 to 0.34)				
RCFT Recall	N=51/55	N=43/51	N=38/48						
SIA	18.10 (8.61)	21.80 (7.61)	22.58 (7.47)	0.44 (0.23 to 0.65)*	0.54 (0.28 to 0.79)*	0.19 (-0.10 to 0.48)	0.20	-0.005 (-0.35 to 0.34)	0.98
DCIA	14.55 (7.45)	19.75 (7.03)	19.16 (5.78)	0.63 (0.43 to 0.82)*	0.53 (0.30 to 0.77)*				

Note: The higher score the better cognitive function. *indicates p<0.05 compared with baseline.

Abbreviations: DCIA, day camp intervention arm; RCFT, Rey complex figure test; SCWT, Stroop colour word test; SIA, standard intervention arm.

The crude means (SD) were presented for baseline and 2 follow-ups.

The within-group and between-group differences in changes are expressed as fitted mean (95 % CI) of standardized outcomes with adjustment of sex and cohort.

TABLE 3 Baseline, follow-up and changes in BRIEF summary scores and subscales at 52 weeks

	Mean (SD), N=SIA/DCIA		Within-group change at 52 weeks	Differences in changes at 52 weeks	
	Baseline (N=40/48)	52 weeks (N=36/41)	Mean (95 % CI)	Mean (95 % CI)	P
BRIEF BRI					
SIA	42.33 (9.55)	42.14 (9.74)	0.07 (-0.12 to 0.26)	-0.25 (-0.51 to 0.003)	0.05
DCIA	45.73 (10.52)	43.76 (10.87)	-0.18 (-0.35 to -0.01)*		
BRIEF MI					
SIA	78.35 (17.81)	77.94 (14.63)	-0.03 (-0.21 to 0.16)	-0.10 (-0.35 to 0.14)	0.42
DCIA	79.83 (17.66)	77.37 (18.80)	-0.13 (-0.29 to 0.03)		
BRIEF GEC					
SIA	120.68 (25.40)	120.08 (22.75)	0.01 (-0.17 to 0.18)	-0.17 (-0.40 to 0.07)	0.16
DCIA	125.56 (26.67)	121.12 (28.31)	-0.16 (-0.32 to -0.002)*		
Inhibit					
SIA	14.52 (3.42)	14.33 (3.84)	0.06 (-0.16 to 0.28)	-0.11 (-0.40 to 0.18)	0.47
DCIA	15.08 (4.00)	14.61 (4.57)	-0.05 (-0.24 to 0.15)		
Shift					
SIA	12.05 (3.54)	12.11 (3.20)	0.01 (-0.24 to 0.26)	-0.07 (-0.41 to 0.26)	0.66
DCIA	12.94 (3.22)	12.73 (3.21)	-0.06 (-0.29 to 0.16)		
Emotional control					
SIA	15.75 (3.85)	15.69 (3.96)	0.09 (-0.11 to 0.28)	-0.42 (-0.68 to -0.16)	**0.002**
DCIA	17.71 (4.80)	16.41 (4.82)	-0.33 (-0.50 to -0.16)*		
Initiate					

SIA	14.05 (3.15)	14.17 (3.06)	0.03 (-0.23 to 0.29)	0.002 (-0.35 to 0.36)	0.99
DCIA	14.29 (3.27)	14.32 (3.69)	0.03 (-0.21 to 0.27)		
Working memory					
SIA	17.03 (5.11)	16.44 (4.34)	-0.12 (-0.34 to 0.09)	-0.02 (-0.31 to 0.27)	0.92
DCIA	17.31 (4.75)	16.63 (4.73)	-0.14 (-0.33 to 0.05)		
Plan/Organize					
SIA	20.78 (5.26)	20.89 (4.49)	0.01 (-0.18 to 0.21)	-0.14 (-0.40 to 0.13)	0.31
DCIA	21.21 (5.21)	20.59 (5.61)	-0.12 (-0.30 to 0.05)		
Organization of materials					
SIA	12.63 (3.41)	11.97 (3.19)	-0.17 (-0.42 to 0.09)	0.08 (-0.26 to 0.43)	0.64
DCIA	12.17 (3.65)	11.90 (3.52)	-0.08 (-0.32 to 0.15)		
Monitor					
SIA	13.87 (4.07)	14.47 (3.11)	0.12 (-0.11 to 0.35)	-0.32 (-0.63 to -0.02)	**0.04**
DCIA	14.85 (3.70)	13.93 (3.84)	-0.20 (-0.41 to 0.001)		

Note: The lower score the better executive function. *indicates p<0.05 ompared with baseline.

Abbreviations: BRIEF, Behaviour rating inventory of executive function; BRI, Behavioural regulation index; DCIA, day camp intervention armMI, Metacognition index; GEC, Global executive composite;SIA, standard intervention arm.

The crude means (SD) were presented for baseline and follow-up.

The within group and between group differences in changes are expressed as fitted mean (95 % CI) of standardized outcomes with adjustment of sex and cohort.

Figure 1 Participants flowchart