Appetite 56 (2011) 766–769

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Short communication

Impaired mental rotation performance in overweight children

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ARTICLE INFO

Article history:
Received 4 January 2011
Received in revised form 24 February 2011
Accepted 28 February 2011
Available online 17 March 2011

Keywords:
Overweight
Children
Cognitive development
Motor development
Mental rotation

ABSTRACT

Overweight children seem to have cognitive impairment. Since there is a relationship between motor and visual-spatial ability and because of the reduced motor abilities of overweight children we assumed that these children might show an impaired mental rotation performance. Sixteen overweight children (10 years of age) and 16 control children (10 years of age) were matched by age, gender, and socio-economic status. Each participant completed a general intelligence test, a motor test, and a chronometric mental rotation test. The results show differences in both motor ability and mental rotation accuracy. Overweight children made more errors when the rotation task was difficult compared to normal weight children. This study gives a clue to overweight children's problems in spatial cognitive tasks.

Introduction

Over the last few decades the prevalence of being overweight in childhood has increased considerably in almost all countries around the world (Wang & Lobestein, 2006). It is well investigated that being overweight as a child might lead to a number of diseases in adulthood, such as metabolic syndrome, hypertension, and cancer (Aggoun, 2007). Besides these medical problems, an association between cognitive impairment and being overweight is increasingly investigated (Li, Dai, Jackson, & Zhang, 2008). Possible reasons for this relationship are widely discussed. Some explanations are differences in the brain structure (Ho et al., 2010), a possible genetic predisposition, lower socio-economic status, or reduced physical activity (Bar-Or et al., 1998). Since cognitive functions include attention, perception, memory, language, problem solving, et cetera, the impaired cognitive function must be investigated in more detail. In a study with a nationally representative sample of more than 2500 children aged 8–16 years, an association between BMI and cognitive functioning was revealed. Z-scores from block-design test performance, a measurement of visual-spatial organization and general mental ability, was lower among children who were overweight or at risk of being overweight than those of children with normal weight (Li et al., 2008). This result holds true even when familial characteristics, sports participation, physical activity, hours spent watching TV, blood pressure, and lipid profile were adjusted. Cserjési, Molnár, Luminet, and Lénard (2007) showed that 12 overweight schoolboys at the age of 12 showed cognitive deficits in shifting and attention abilities compared to a control group of 12 boys with normal weight. Recently Verdejo-Garcia et al. (2010) showed selective alterations of particular components (inhibition, flexibility, and decision making) of executive functions in overweight adolescents compared to normal weight adolescents. Besides this, school age children that are overweight show a lower performance in many motor abilities than children that are not overweight (Okely, Booth, & Chey, 2004). There seems to be some relation between motor ability, being overweight, and spatial performance.

Motor development and movement experience are relevant factors for cognitive performance. This is especially true for spatial abilities (Campos et al., 2000), which are cognitive processes that involve visualization, orientation, and mental rotation (Linn & Petersen, 1985). Mental rotation is the ability to imagine how an object would look if rotated away from the orientation in which it is actually presented (Shepard & Metzler, 1971).

The relationship between motor ability and mental rotation performance has been investigated in correlation analyses (Jansen & Heil, 2010), quasi-experimental designs, experimental designs with interference and training studies. In a quasi-experimental approach it was shown that children with spina–bifida, a malformation of the central nervous system due to a defect of a neural tube closure in early embryogenesis, showed an impaired mental rotation ability compared to a healthy control group who was matched by age, sex and verbal-IQ (Wiedenbauer & Jansen-Osmann, 2007). Using an experimental interference paradigm Wexler, Kosslyn, and Berthoz (1998) found if a manual rotation task was compatible with a mental one, reaction times were faster and fewer errors were made. Besides this, the influence of motor training on mental rotation was shown in a training study, in

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0195-6663/$ – see front matter
doi:10.1016/j.appet.2011.02.021

which adults learned juggling for a period of three months. Their improvement in the post mental rotation test compared to the pre-test was much higher than that of the control group who did not receive juggling training (Jansen, Titze, & Heil, 2009).

The investigation of cognitive impairment in overweight children is limited by the fact that quasi-experimental designs were used, which are vulnerable to selection threats. Due to the experimental studies on the influence of motor training on mental rotation performance we assume that children that are overweight might have an impaired motor as well as impaired mental rotation performance. The investigation of cognitive impairment in overweight children is limited by the fact that quasi-experimental designs were used, which are vulnerable to selection threats. Because of this and the importance of family characteristics in the development of obesity, the socio-economic status of the families of the participants was controlled as well as their general intelligence.

Methods and procedures

Participants

Sixteen overweight children (6 girls and 10 boys, mean age in years M = 10.00, SD = .89) and 16 healthy control children (6 girls and 10 boys, mean age in years M = 9.94, SD = .68) took part in the study. They were matched pair wise according to sex, age, and socio-economic status. The socio-economic status was determined by (a) education and (b) profession of the parents as well as (c) the household after tax income. Each value of the three variables was classified into five categories. The lowest categories were assigned score 1, the highest categories were assigned a score of 5. The scores for educational achievement and occupational status were weighted twofold. Afterwards all three scores were added, resulting in total scores ranging between 5 and 25. The total scores were clustered in three categories: Category 1 was labelled "low", when scores ranged between 5 and 11, category 2 was "middle" when scores ranged between 12 and 18 and category 3 was "high" when scores ranged from 19 to 25 (compare Jöckel et al., 1998). Since the two groups were matched, they did not differ in their socio-economic status-categories (overweight children that, M = 1.81, SD = .65; control M = 1.81, SD = .65; $F(1, 30)$ = 0, n.s.).

Being overweight was determined by the Body Mass Index, BMI (kg/m^2) according to reference data obtained in a medical survey of children's health in Germany (Kromeyer-Hauschild et al., 2001). Overweight was defined as a BMI-Score over a 90% percentile, matched by age and sex. Obesity was defined as a BMI-Score over a 97% percentile, also matched by age and sex. Ten (3 girls) of the 16 overweight children in our study were extremely overweight and considered obese. The mean BMI of the overweight children was M = 25.44 (SD = 5.51), of the control children was M = 16.78 (SD = 1.80).

Overweight children were recruited from special courses for this target group in different towns in north-west Germany. Children of the control group were recruited from schools in north-west Germany. All parents had to complete a questionnaire about their social status (see above). They all gave written consent for the participation of their children. The experiment was in accordance with the Helsinki Declaration of 1975.

Materials

The children had to complete the Coloured Progressive Matrices test (Raven et al., 1976), a chronometric mental rotation test (Jansen-Osmann & Heil, 2007), and a motor test (Jouck, 2008).

CPM: Coloured Progressive Matrices test

The CPM test was designed to measure a child's ability to form perceptual relations and to reason by analogy, independent of language. Spearman's g is measured with this test. The CPM consists of 36 items arranged in three sets of 12 items each. Each item contains a large pattern with a missing segment. Below the figure are six alternative segments to complete the pattern, only one of which is correct. Each set involves a different principle or "theme" for obtaining the missing segment. Within a set the items are roughly arranged in increasing order of difficulty. The results are analyzed in terms of developmental categories. Retest reliability reads .90, inner consistency .64–.82.

DKT: motor test

The DKT is a heterogeneous test battery for children and adolescents between six and 16 years and is used for valuation of motor performance among all basic motor skills. It consists of 7 items. Lateral jumping and one legged stand measured the co-ordination ability. Strength was measured by sit-ups, standing long jump and push-ups. Endurance was measured by the distance covered in a 6 min run. Flexibility was measured by the "sit and reach", a task where the children sit in front of a box and had to reach as far as possible. Norm data were obtained for 2385 children from 6 different schools. The results were transformed into (German) school grades, where a "1" is the best and a "6" is the worst grade. The norms to calculate grades were differentiated by age and gender. The retest-reliability for this test was r = .76.

Chronometric mental rotation test

The mental rotation stimuli consisted of 3 different letters (F, P, R, Font: Times New Roman). Each one had a maximum size of 7 cm × 7 cm on the screen with a space of 14 cm in between. Participants were free to choose the most comfortable viewing distance. Two stimuli were presented at the same time on the monitor. The right stimulus was either identical to the left or mirror-reversed. The angular disparity between the 2 stimuli was either 30°, 90°, or 150° in a clockwise or counter-clockwise direction (see Fig. 1 for an example). The experiments were run on a PC with a 15″ monitor (refresh rate: 75 Hz).

The children had to decide if the two stimuli were the same or mirror-reversed. By pressing a computer mouse key they had to respond as quickly and as accurately as possible. Trials were presented in four blocks of 36 trials. Each trial began with a 500 ms background grey screen. After that, the pair of letters appeared and remained on until the child gave the response. All children received feedback in form of a "+" for a correct response and in form of a "−" for an incorrect response. The feedback was presented for 500 ms in the middle of the screen. The next trial began after 500 ms. Every combination of 3 different objects, type of response (same/mirror reversed), angular disparity (30°, 90°, and 150°), and direction of rotation (clockwise/counter clockwise), occurred 4 times resulting in 144 trials. The participant's reaction time and the error rates were measured.

Procedure

Each child was tested in two single sessions. In the first session, each child had to complete the chronometric mental rotation test. In the second session, each child had to complete the CPM and the DKT. The DKT Test was conducted in a gym. The mental rotation test as well as the CPM was presented in a quiet room.

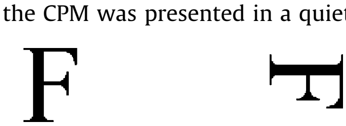

Figure 1. An example of the items of the mental rotation task.

Design and statistical analysis

An univariate analyses of variance with factor "group" (overweight children vs. normal weight children) was calculated for the CPM performance.

For the analysis of the seven subtests of the DKT a MANOVA with the factor "group" (overweight children vs. normal weight children) was conducted.

For the analysis of the chronometric mental rotation test we used a 2×3 mixed ANOVA with the between subject-factor "group"(overweight children vs. normal weight children), and the within subject factor "angular disparity"(30°, 90°, and 150°). Reaction time and error rate served as dependent variables. For the reaction time analysis only correct responses were used. Moreover, because angular disparity is not defined unequivocally for "different" responses (Jolicoeur, Regehr, Smith, & Smith, 1985), the statistical analysis was restricted to same responses only. Finally, a stepwise multiple regression to predict mental rotation performance from the obtained motor variables was conducted.

Results

Performance in the CPM

The two groups did not differ in their general intellectual abilities as measured by the developmental level in the CPM (overweight children) $M = 3.44$, $SE = .24$; (normal weight children) $M = 2.88$, $SE = .22$, $F(1, 30 = 2.95$, n.s.).

Performance in the motor test

A MANOVA showed that the factor "group" had large effects on motor performance $F(7, 24) = 5.89$, $p < .001$, $\eta^2 = .63$. The two groups differed in their motor ability in almost all items significantly, with the exception of the flexibility measurement of the "sit and reach task" ($F(1, 30) = .48$, n.s.). Overweight children showed an almost significant lower performance than normal weight children in lateral jumping, $F(1, 30) = 3.94$, $p = .056$, $\eta^2 = .12$, one legged stand, $F(1, 30) = 10.45$, $p < .01$, $\eta^2 = .26$, sit ups, $F(1, 30) = 3.94$, $p = .058$, $\eta^2 = .12$, long stand jump, $F(1, 30) = 17.64$, $p < .001$, $\eta^2 = .37$, push-ups, $F(1, 30) = 5.31$, $p < .05$, $\eta^2 = .15$ and endurance, $F(1, 30) = 24.39$, $p < .001$, $\eta^2 = .45$.

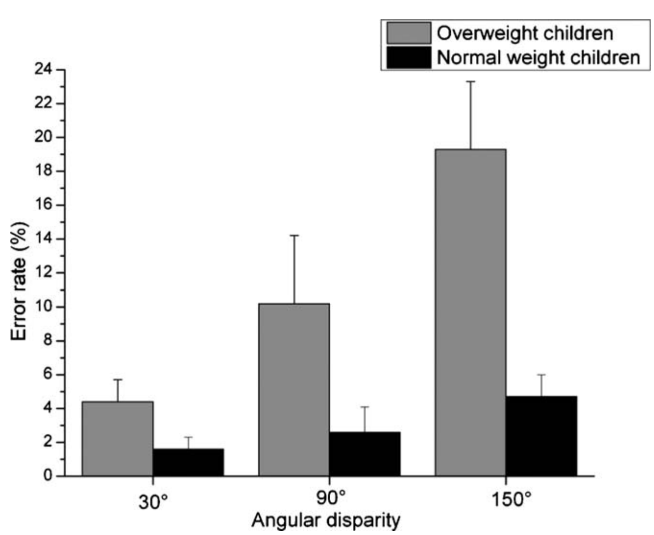

Figure 2. Error rates in the chronometric mental rotation test as a function of group and angular disparity.

Performance in the chronometric mental rotation test

Reaction time

The univariate analysis of variance revealed a significant main effect for the factor angular disparity, $F(2, 60) = 58.64$, $p < .001$, $\eta^2 = .62$. The reaction time for 30° ($M = 1263$, 23 ms, $SE = 69$, 24) was shorter than the ones at 90° ($M = 1707$, 11 ms, $SE = 121$, 75) which was shorter than the reaction time at 150° ($M = 2045$, 44 ms, $SE = 136$, 66). There was neither a significant main effect for group, $F(1, 30) = .21$, n.s., nor a two-way interaction between both factors, $F(2, 60) = .9$, n.s.

Error rates (Fig. 2)

The univariate analysis of variance revealed a significant main effect for the factors "angular disparity", $F(2, 60) = 7.76$, $p < .001$, $\eta^2 = .20$ and "group" $F(1, 60) = 8.87$, $p < .01$, $\eta^2 = .23$ as well as an interaction between both factors, $F(2, 60) = 3.28$, $p < .05$, $\eta^2 = .1$.

Error rates increased with increasing angular disparity (means for the 3 angular disparities read 3%, 6.4%, and 12%, respectively, standard errors read .8, 2.3, and 2.3), and are higher for overweight children ($M = 11\%$, $SE = 2.6$) than for normal weight children ($M = 3\%$, $SE = 1.1$). The interaction between both factors is based on the fact that this effect is due to the difference between both groups for the items which are rotated 150°, $F(1, 30) = 9.95$, $p < .01$, $\eta^2 = .25$. This difference is still significant if the CPM-performance is included as a co-variate, $F(1, 30) = 6.96$, $p < .05$, $\eta^2 = .19$.

Motor and mental rotation performance

Because the two groups differ in the error rate for items which were rotated at 150°, a correlation between the error rate in the chronometric test and the CPM performance ($r = .36$, $p < .05$) as well as the overall performance of the motor test ($r = .54$, $p = .001$) was calculated.

Furthermore a multiple regression (Enter method) with mental rotation performance (error rates at 150°) as dependent variable with the predictors of the 7 dimensions of the DKT and the CPM was calculated (see Table 1). The multiple regression results show that 29.5% of the variance ($R^2 = .477$) is explained by the eight predictors. The model is shown to be significant, $F(8, 31) = 2.62$, $p < .05$. The only significant predictor included was the coordination ability item "one legged stand" (see Table 1).

Discussion

The results of this study demonstrate that overweight children showed impaired motor as well as impaired mental rotation performance compared to a control group which was matched by age, gender, and socio-economic status. This impairment which was mostly evident for difficult tasks, meaning an angular disparity of 150° between the two objects to be judged, cannot be traced back to a general intelligence difference compared to the children

Table 1
Multiple regression with mental rotation performance as dependent variable and the 7 dimensions of the DKT and the performance of the CPM as predictors.

Predictor	Regression coefficient	β	T	p
One legged stand	4.07	.437	2.39	<.05
CPM	5.92	.381	2.02	>.05
Sit-up	3.89	.322	1.69	>.05
Push-ups	−3.34	−.197	−1.00	>.25
Lateral jumping	2.18	.178	.877	>.25
6 min run	−1.33	−.132	.621	>.25
Standing long jump	.52	.040	.209	>.25
Sit and reach	−.01	−.001	−.003	>.25

that were not overweight. Our results provide evidence for a higher error rate but not for a slower reaction time in overweight children. This means that these children react as fast as the control group at the expense of correctness. Further studies have to follow which investigate if this result is due to different strategies in both child groups.

The reduced mental rotation performance from children that are overweight is in accordance with another study (Li et al., 2008), where lower visual-spatial organization in overweight children was shown. Furthermore, it was demonstrated that obesity which results from excess sucrose intake impairs spatial learning and memory in rats (Jurdak, Lichtenstein, & Kanarek, 2008).

This study also shows a relationship between motor ability and mental rotation performance, as demonstrated in earlier studies (Jansen & Heil, 2010). Furthermore, it suggests that one predictor of the impaired mental rotation performance might be lower co-ordination ability. This is in accordance with a study where it was shown that juggling as a coordinative motor task enhances mental rotation performance (Jansen et al., 2009).

Of course this assumption has to be made cautiously because we only found one of two variables of co-ordination ability as a significant predictor of mental rotation performance. In addition, even though we matched for socio-economic status and controlled for general intelligence we did not include such measurements as e.g. self-stereotyping. The stereotype threat theory means that a negative stereotype about a group's ability is made relevant in a test situation and the members of the group fear being evaluated based on the stereotype (Steele, 1997). Research has shown that people tend to underscore in complex cognitive tasks that are stereotyped (e.g. Steele & Aronson, 1995). Campbell and Collaer (2009) showed that stereotypes also influence visual-spatial ability. Regarding weight it has been shown that overweight children have a lower self-esteem than normal weight children (Pierce & Wardle, 1997) and that body esteem is a mediator for the relation of a weight-related stigma and the physical activity competence (Schmalz, 2010). Because of this the lower performance of overweight children in the mental rotation task as well as in the motor task might also be mediated by their own stereotype.

This experiment provides evidence that children who are overweight might not only suffer from some kind of attention deficits but also from mental rotations deficits. Further studies have to follow where the influence of motor training and possible stereotype-threat is investigated in an experimental design with overweight and normal weight children. Only with the help of those studies could the underlying mechanism for the impaired mental rotation performance in overweight children be investigated.

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