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Beneficial effect of physical activity on linear growth rate of adolescents in a South African shanty town

H. SALOME KRUGER[1], INGE STEGMAN[2], HESTER H. VORSTER[1], COLLEEN M. DOAK[2] AND BARRIE M. MARGETTS[3]

[1]*Centre of Excellence for Nutrition, North-West University, Private Bag X6001, Potchefstroom, 2520, South Africa; E-mail: salome.kruger@nwu.ac.za*
[2]*School of Life Sciences, Vrije Universiteit, Amsterdam, Netherlands*
[3]*Public Health Nutrition, University of Southampton, United Kingdom*

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Abstract

It is not known if nutritional and/or other interventions could improve linear growth in adolescents. The purpose of this study was to assess the role of physical activity in promoting linear growth velocity of black adolescents in a low-income shanty town in South Africa. Two schools in a disadvantaged shanty town participated in the study as intervention (n=250) and reference (n=66) groups. Due to practical considerations a quasi-experimental study design was used. Demographic, dietary intake, habitual physical activity and Tanner stage data were collected and anthropometric measurements were carried out over three years. Height for age z-scores (HAZ) were calculated and regression lines were fitted through HAZ values plotted against time. Slopes of HAZ regression lines for each child were used to represent the child's linear growth velocity over the study period. A physical activity intervention was carried out over two years. The main outcome measure, mean growth velocity of children from the intervention versus the reference school was compared using analysis of covariance (ANCOVA), with HAZ at baseline, and habitual physical activity, Tanner stage, and dietary energy, protein, zinc and iron intakes as covariates, and growth velocity (slope of the regression line) as dependent variable. The mean slopes of HAZ regression lines of the intervention (+0.002) and reference groups (-0.007) were significantly different (p=0.009). ANCOVA showed a significantly higher slope of the HAZ regression line in the intervention group than in the reference group [F(1,292)=3.87, p=0.05]. The results indicate a possible role for physical activity in promoting the linear growth of adolescents in low-income areas.

Keywords: Adolescents, linear growth, physical activity, South Africa, stunting.

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Introduction

Stunting, defined as a height-for-age Z-score (HAZ) <= -2.0 standard deviations is a public health problem in school-age children in developing countries (Wamani, Astrom, Peterson, Tumwine & Tylleskar, 2007; Friedman, Phillips-Howard, Mirel, Terlouw, Okello, Vulule, Hawley, Nahlen & Ter Kuile, 2005; Lwambo, Brooker, Siza, Bundy & Guyatt, 2000) and is associated with long term consequences of poor school performance and productivity (Partnership for Child Development, 1999), and adult work capacity (Haas, Murdoch, Rivera & Martorell, 1996). The etiology of reduced linear growth involves multiple causes related to malnutrition, such as diarrheal diseases and low dietary intakes (Partnership for Child Development, 1998; Adair & Guilkey, 1997). Environmental factors related to low socio-economic status, and not genetic or racial factors, account for most of the differences in linear growth between populations (Ndiaye Coly, Milet, Diallo, Ndiaye, Benefice, Simondon, Wade & Simondon, 2006; Martorell, Kettal Khan & Schroeder, 1994). Though stunting mainly occurs during early childhood (Adair & Guilkey, 1997; Boersma & Wit, 1997) recent studies demonstrate the progression of stunting during adolescence (Martorell, 2010; Friedman *et al*., 2005; Lwambo *et al*., 2000). Some suggest that children in developing countries do not experience significant catch-up growth during adolescence (Friedman *et al*., 2005; Martorell *et al*., 1994), while others suggest that catch-up growth is possible even during late adolescence (Martorell, 2010; Stolzfus, Albonico, Tielsch, Chwaya & Savioli, 1997). During school years, linear growth of stunted children can develop in any of three patterns, namely catch-up growth, stable growth or progression of stunting. With progression of stunting, a child grows at a rate below the limits of normality for age and maturity (Friedman *et al*., 2005). The opposite pattern, namely catch-up growth is defined as height velocity above the statistical limits of normality for age and maturity (Boersma & Wit, 1997). Over time, a previously undernourished and stunted child may reach normal height according to international standards (Stolzfus *et al*., 1997).

New approaches that improve linear growth during the adolescent period can provide new evidence for intervention programmes in developing countries. The effect of physical activity on linear growth has been studied in 2 to 4-year-old undernourished children (Torun & Viteri, 1994) and in well-nourished adolescents (Matthews, Bennell, McKay, Khan, Baxter-Jones, Mirwald & Wark, 2006; Beunen, Malina, Renson, Simons, Ostyn & Lefevre, 1992). There were no significant differences between linear growth of healthy adolescent boys participating in physical activity for five hours per week, compared to similar adolescents participating in physical activity for 1.5 hours per week (Beunen *et al*., 1992). In female dancers compared to a control group there were no differences in absolute growth or linear growth velocity over three years (Matthews *et al*., 2006). In a randomised controlled trial, Torun and Viteri (1994) found that physical activity can enhance linear growth in previously stunted preschool children if combined with a good diet. Ecological studies indicate that stunted children are at increased risk for overweight (Popkin, Richards & Montiero, 1996). Hoffman, Sawaya, Verreschi, Tucker and Roberts (2000) showed that childhood stunting is associated with impaired fat oxidation.

Sedentary lifestyles of adolescents contribute to obesity and increase the risk for chronic diseases of lifestyle (Bradner Jasik & Lustig, 2008). If physical activity can help to improve linear growth and decrease fat deposition in stunted school-age children, activity based interventions during adolescence could help in reducing stunting and chronic disease. Previous physical activity based interventions have shown no effect on linear growth, or even inhibition of growth through high energy expenditure (Matthews *et al*., 2006; Rogol, Clark & Roemmich, 2000; Beunen *et al*., 1992). No interventions have tested the combination of physical activity plus a dietary supplement on linear growth in relatively undernourished adolescents. Therefore, the purpose of this study was to assess the role of physical activity and a snack together on linear growth velocity of black adolescents in a low-income shanty town in the North-West Province, South Africa. An after-school activity programme together with a snack was provided to children from an intervention school and their linear growth was compared with that of children from a reference school.

Methods

Study design and participants

A physical activity intervention was carried out in 2004 and 2005, in high school students from Ikageng shanty town in the North-West Province of South Africa with final measurements taken in 2006, the third year of the study. The two schools selected represented the most disadvantaged of the five available shanty town schools. The school with the larger number of children was chosen as the intervention group (n=250) and the other formed a reference group (n=66). Due to practical considerations the study design was quasi-experimental with a convenience sample. The study design has been described in more detail elsewhere (Mamabolo, Kruger, Lennox, Monyeki, Pienaar, Underhay & Czlapka-Matyasik, 2007). Demographic data were collected at baseline and anthropometric measurements and Tanner staging of physical maturation were done (Mamabolo *et al*., 2007). Height was measured with the children barefeet and the head in the Frankfort plane, using calibrated stadiometers. Duplicate measurements were taken by trained postgraduate students to minimize the possibility of inaccurate measurements. Height for age z-scores (HAZ) were calculated using SAS (SAS Institute Inc., 2003) based on the WHO criteria (WHO, 2007) and stunting was defined as an age and sex specific HAZ < -2 (Boersma & Wit, 1997). The protocol was approved by the Ethics Committee of the North-West University and the parents or guardians of the children signed informed consent. The children also gave assent to participate in this study.

Physical activity intervention

The physical activity intervention was carried out over two years only in the intervention school. The reference school received no intervention. The end measurements in both schools were done at the end of the third year. Two 1-hour sessions were presented weekly for 19 weeks by trained postgraduate Biokinetics students during the first year. The programme is comparable to a high school physical education programme. The programme was repeated during the second year, but increased to three sessions per week. Within the hour, activities rotated between aerobic exercise, ball games, strength and flexibility exercises. After the exercise, children received a snack of 25g dry breakfast cereal and artificially flavoured cold drink providing 400-500kJ, 2.5g vegetable protein, 8mg ascorbic acid, 33mg calcium, 1.4mg iron and 0.9mg zinc. The snack was given in response to requests by parents and the children for refreshment after the exercise session and before they walk home. Energy expenditure during the intervention was measured using Actical (Minimitter, Bend OR) accelerometers. Adherence to the programme was measured as attendance (number of exercise sessions attended) and group leaders encouraged all children to participate at the same intensity.

In order to control for differences between the intervention and reference school, habitual physical activity was measured using Previous Day Physical Activity Recall (Weston Petosa & Pate, 1997). Participants were categorized into three physical activity levels of habitual physical activity (Weston et al. 1997). Trained interviewers administered both physical activity and multiple-pass 24-hour dietary recall questionnaires using face-to-face interviews at the beginning, middle and end of each study year (Jonnalagadda, Mitchell, Smiciklas-Wright, Meaker, Heel van, Karmally, Ershow & Kris-Etherton, 2000). Snacks provided after exercise sessions were included in these dietary recalls. The dietary data were computerised and analysed using the Foodfinder computer programme (Medical Research Council, 1993) based on SA food composition tables. Means of repeated energy and nutrient intake data were calculated to represent intake over the study period. Intakes of total energy, protein, calcium, iron and zinc were considered as possible determinants of growth velocity. Means of physical activity category was calculated and rounded to categories 1, 2 or 3 to represent inactive, moderate or vigorous activity level.

Statistical analysis

Statistical analyses were done using Statistica version 9.0, 2010 for Windows (Statsoft, Tulsa, OK). Each child had multiple HAZ measurements, with measurements at the beginning and end of each of the study years and an additional measurement in the middle of 2005. Children were included in the analysis if they were present on at least three of the measurement days. Repeated measurements of each participant in this study were checked for outliers to minimize recording errors. The maximum number of data points was 7 for those present on all measurement days. The available measurements, ranging between 3 and 7, were plotted taking into account the time interval between measurements. Regression lines were fitted and slopes of the HAZ regression lines for each child were used to represent the child's linear growth velocity over the study period. This approach was followed to indicate linear growth over the total study period, instead of only at baseline and end. Chi square tests were used to assess the differences between categorical variables, analysis of variance (ANOVA) was used to test for difference between three groups of children at baseline and dependent t- tests were used to test for differences within the same groups between baseline and end. Mean growth velocity of children from the intervention versus the reference school was compared using analysis of covariance (ANCOVA), with habitual physical activity, Tanner stage of physical maturation, and dietary energy (MJ), protein, zinc and iron intakes and HAZ at baseline as covariates, and growth velocity (slope of the regression line) as dependent variable. Results with $p<0.05$ were considered statistically significant. All analyses retained the original intervention and reference group assignments based on the principles of intention to treat.

Results

The number of children present for three or more measurement days was 293, 229 (91.6%) from the intervention and 64 (97%) from the reference school. Table 1 shows the characteristics of all children at baseline, compared to children who were not present at three or more measurement days. The majority of children lived in brick houses and had a television (86%), but few had computers at home (3%). Parents or caregivers generally had low-income occupations and mostly had high school education. There were no physical education classes in high schools in the shanty town. Comparisons of demographic variables between children in intervention and reference groups showed no statistically significant differences. In addition, there were no statistically significant differences in anthropometric characteristics and dietary intakes of children in intervention versus those in the reference group at baseline or during the intervention period (Tables 1, 2 and 3). The children in the intervention group were significantly older than those in the reference group. However, there were no differences in Tanner stage between the two groups (Table 2). Overall, 16.1% of the children were stunted at baseline (20.1% of boys, 13.1% of girls). Nine percent of girls in the intervention school, and 10% in the reference school respectively, and 17% of boys in the intervention school were at Tanner stage 5, indicating physical maturation.

The children's habitual physical activity measured by Previous Day Physical Activity Recall was categorized as inactive (1), moderately active (2) or vigorously active (3) (Weston *et al*., 1997).

Table 1: Descriptive characteristics and dietary intakes of the intervention and reference groups and children who dropped out at baseline

Characteristic	Intervention group (n=250)	Reference group (n=66)	Children not included in final measurements (n=23)*	P†
Age (years)	14.8±1.4	13.8±1.0	15.8±1.4	<0.001
Stunted‡	41 (16.4%)	10 (15.1%)	3 (13%)	
Height-for-age z-score	-1.13±1.0	-0.96±1.0	-1.06±0.9	0.09
Dietary energy (kJ)	8461±3520	8568±2641	8687±3418	0.75
Total protein intake (g)	63.5±27.2	63.5±19.4	66.4±29.4	0.73
Calcium intake (mg)	318.2±170	303.8±135.5	335±202	0.44
Iron intake (mg)	8.1±4.0	8.8±2.9	8.8±3.4	0.82
Zinc intake (mg)	8.1±3.7	8.3±2.9	8.4±4.2	0.88

*: Children with less than three height measurements over the study period not included in final analyses; †: Level of significance of differences between intervention, reference and dropout groups measured by ANOVA; ‡: Height-for-age z-score < -2, number (%).

In both schools more than 50% of girls (54% vs 60%, intervention and reference school, respectively) were inactive, whereas boys tended to be more active (29% vs 28% vigorously active in intervention and reference school, respectively). There were no differences in habitual physical activity levels between the two groups (Chi-square tests X^2=1.25, p=0.16, X^2=1.30, p=0.10 boys and girls, respectively). The mean dietary intakes of the children were assessed using ten repreated 24h recalls over the study period. There were no significant differences between the mean dietary intakes of the children in the intervention and reference groups and those children who dropped out of the study (Table 3). Addition of the snack did not change mean nutrient intakes of the intervention group significantly compared to the reference group or to their own baseline intakes (Table 3). Attendance of the physical activity intervention ranged from 0 to 98% over two years. Only 36 children attended more than 50% of the exercise sessions over two years, which is approximately equal to one session per week, 106 attended 20-50%, and 19 children in the intervention school did not attend any of the sessions. Hourly energy expenditure during the intervention measured by accelerometer ranged between 306 and 1051kJ.

The mean dietary intakes of the children were assessed using ten repreated 24h recalls over the study period.

Table 2: Descriptive characteristics of the intervention and reference groups and children who dropped out at baseline

Characteristic	Intervention group (n=250)		Reference group (n=66)		Children not in the final measurements (n=23)		p†
Tanner stage	Boys (n=121)	Girls (n=129)	Boys (n=18)	Girls (n=48)	Boys (n=13)	Girls (n=10)	
1.	0	0	0	1 (2.1%)	0	0	Boys:
2.	12 (9.8%)	10 (7.7%)	0	5 (10.4%)	1 (7.7%)	1(10%)	0.63
3.	22 (18%)	47 (36.4%)	8 (44.4%)	20 (41.7%)	5 (35.2%)	3(30%)	Girls: 0.78
4.	67 (54.9%)	60 (46.5%)	10 (55.6%)	17 (35.4%)	7 (53.8%)	5(50%)	
5.	21 (17.2%)	12 (9.3%)	0	5 (10.4%)	0	1(10%)	
Habitual physical activity(PDPARS) level							
1. Inactive	32 (26.2%)	70 (54.3%)	7 (38.9%)	29 (60.4%)	4 (30.8%)	6 (60%)	Boys: 0.16
2. Moderately active	55 (45.1%)	49 (38%)	6 (33.3%)	14 (29.2%)	5 (38.5%)	3(30%)	Girls:
3. Vigorously active	35 (28.7%)	10 (7.8%)	5 (27.8%)	5 (10.4%)	4 (30.8%)	1(10%)	0.10

†: Level of significance of differences between intervention, reference and dropout groups measured by Chi-square test
§: PDPAR = previous day physical activity recall

Changes in mean HAZ of the children in the intervention and reference groups are shown in Table 4. Mean HAZ of the two groups were not statistically significantly different after 30 months from baseline. Catch-up growth was defined as a positive slope of the regression line through all available HAZ values for each adolescent. There was a trend of a difference between the changes in HAZ from baseline to end between the two groups, i.e. +0.12 in the intervention group *vs* -0.02 in the control group (p=0.07). The mean slopes of the HAZ regression lines were used to represent each child's linear growth velocity over the study period. In the intervention school there was a weak and non-significant positive slope of increased growth velocity, whereas in the reference school there was a weak negative growth velocity. The difference in the slopes was statistically significant (p=0.009). More than half (52.7%) of participants in the intervention school had a positive slope indicating an increase in HAZ over time, compared to 41.8% of participants in the reference school. There was a significant positive correlation between the slope of the regression line and attendance of the physical activity programme over two years (r=0.22, p<0.0001), indicating a higher linear growth rate among those who attended most of the exercise sessions.

Table 3: Mean dietary intakes during the intervention period of the intervention and reference groups and children who dropped out over the study period (mean ± standard deviation of repeated 24h recalls).

Characteristic	Intervention group (n=250)	Reference group (n=66)	Children not in final measurement (n=23)[a]	p*	p†
Dietary energy (kJ)	9256±2447	8547±2341	8688±3907	0.06	Intervention group: 0.2, Reference group: 0.8, Dropout group: 0.6
Total protein intake (g)	68.9±18.6	64.4±16.2	66.2±28.9	0.20	Intervention group: 0.2, Reference group: 0.6, Dropout group: 0.9
Calcium intake (mg)	344±135	308±116	329±201	0.13	Intervention group: 0.2, Reference group: 0.6, Dropout group: 0.8
Iron intake (mg)	8.7±2.7	8.9±2.2	8.8±2.4	0.9	Intervention group: 0.1, Reference group: 0.8, Dropout group: 0.7
Zinc intake (mg)	8.7±2.7	8.4±2.8	8.4±4.0	0.6	Intervention group: 0.06, Reference group: 0.8, Dropout group: 0.9

* Level of significance of differences between intervention, reference and dropout groups measured by ANOVA

† Level of significance of differences between baseline and during the intervention within intervention, reference and dropout groups measured by dependent t-test

Table 4: Height-for-age z-score of the intervention and reference groups at pre- and post tests (mean ± standard deviation).

Characteristic	Intervention group (n=229)*	Reference group (n=64) *	p
Height-for-age z-score at baseline	-1.17±1.0	-0.94±1.0	p=0.19†
Height-for-age z-score after 30 months	-0.98±0.96	-0.86±0.86	p=0.39†
Change in height-for-age z-score after 30 months	+0.12±0.6	-0.02±0.4	p=0.07† Intervention group: baseline to end p=0.01‡ Reference group: baseline to end p=0.91‡
Slope of the HAZ regression line	+0.002±0.03	-0.007±0.03	0.009†

*Subject number varied due to missing values at each measurement point, only participants with baseline and at least three HAZ values included.

†Difference between intervention and reference groups, independent t-test

‡ Difference between baseline and end within intervention and reference groups respectively, dependent t-test

ANCOVA showed a significantly higher growth velocity (slope of the HAZ regression line) in the intervention group than in the reference group, with Tanner stage, habitual physical activity, dietary energy, protein, iron and zinc intakes and HAZ at baseline as covariates [$F(1,292)=3.87$, $p=0.05$] (Table 5).

Table 5: Comparison of mean growth velocity of children from the intervention versus the reference school by analysis of covariance*

Model: growth velocity (slope of the regression line) as dependent variable	Slope parameter	95% CI	Slope ß	95% CI of ß	t	p
Intercept (HAZ units/month)	0.0148	-0.008, 0.037			1.29	0.2
Mean dietary energy (MJ)	-0.0000	-0.000, 0.000	-0.007	-0.26, 0.24	-0.06	0.9
Mean dietary protein (g)	-0.0002	-0.65, 0.51	-0.099	-0.4, 0.2	-0.65	0.5
Mean dietary iron (mg)	0.0006	-0.002, 0.003	0.05	-0.18, 0.29	0.44	0.6
Mean dietary zinc (mg)	-0.0007	-0.002, 0.001	-0.07	-0.23, 0.10	-0.80	0.4
Baseline Tanner stage (1-5)	-0.003	-0.007, 0.001	-0.09	-0.22, 0.03	-1.44	0.15
Baseline height-for-age z-score	-0.004	-0.008, -0.001	-0.14	-0.26, -0.02	-2.28	0.02
Mean physical activity score (1-3)	0.0002	-0.004, 0.004	0.007	-0.11, 0.12	0.11	0.9
School (grouping variable)	0.0044	0.0004, 0.008	0.12	0.01, 0.24	2.14	0.03

*Habitual physical activity, Tanner stage, and dietary energy (MJ), protein, zinc and iron intakes and HAZ at baseline as covariates; Whole model $F(1,292)=3.87$, $p=0.05$

Discussion

An important finding from the present study is the confirmation that catch-up growth can occur, but height deficit accrual can also progress during adolescence. The results indicate that the trend of a decline in growth rate found in the reference group was halted in the intervention group. Presently, in South Africa, stunting is a common nutritional disorder in children. For instance, the 2008 Youth Risk Behaviour Survey showed that 13.1% of 8-11 graders are stunted (Reddy, James, Sewpaul, Koopman, Funani & Sifunda, 2010). Until recently most research on catch-up growth has focused on young children and interventions have been targeted at feeding schemes (Black, Allen, Bhutta, Caulfield, Onis de, Ezzati, Mathers & Rivera, 2008). Adolescence is clearly an important period in development, and the possibility of catch-up growth or progression of stunting during middle childhood might give opportunities for successful interventions (Friedman *et al*., 2005; Stolzfus *et al*., 1997). The longitudinal design of this study allows us to investigate differences in linear growth velocity and the effect of a physical activity intervention plus a snack on linear growth. The results also indicate that even low-intensity physical activity interventions may have a beneficial effect on the growth rate of adolescents living in low-income areas. Our study's demographic data show that most of the children lived in poor socio-economic circumstances. Furthermore, the prevalence of stunting in our sample was 16.1% at baseline, which is consistent with other findings in the North West Province (Mukuddem-Petersen & Kruger, 2004) but higher than the overall level of stunting in South Africa (Reddy *et al.*, 2010) for this age group. The higher prevalence of stunting in this study, as compared to other populations in South Africa, is likely to be related to the children's low socio-economic status (Travill, Cameron & Kemper, 2008).

An important question is whether the snack taken by the children contributed to the observed beneficial effects on their growth velocity. Therefore, the dietary intakes of the children were assessed as a possible confounding factor in the relationship between the physical activity programme and growth velocity. The mean energy intakes were slightly below the estimated energy requirements (EER) for the age group in this study (8600kJ for girls, 12600kJ for boys) (National Academy Press, 2002), but no significant differences in energy or any nutrient intakes between the children in the intervention school and those in the reference school were found at baseline or with repeated measurements, even with inclusion of the snack given to children in the intervention school. The dietary intake results were consistent with findings of other studies in South Africa (Schutte, Rooyen van, Huisman, Kruger, Malan & De Ridder, 2003). Zinc, iron and calcium are important factors for growth (Bhutta, 2008; Allen, 1994). In our study there were no significant differences between zinc, iron or calcium intakes of children in the two groups. Overall mean calcium, zinc and iron intakes were below the adequate intake (AI) and estimated average requirements (EARs) (IOM, 2001). Although these low micronutrient intakes may have contributed to stunted growth in the children in this study and may sustain suboptimal linear growth of these children (Bhutta, 2008; Allen, 1994), there were no significant differences between the micronutrient intakes of the two groups which could explain the differences in linear growth.

Although the greatest degree of stunting occurs in the first two years of life (Martorell *et al.*, 1994), findings of the present study and other recent studies suggest that linear growth failure can progress during middle childhood, and some children might also display an improved growth velocity during adolescence (Ndiaye Coly *et al.*, 2006; Friedman *et al.*, 2005; Lwambo *et al.*, 2000). A study of Friedmann *et al*. (2005) suggests that children in less privileged environments do not experience complete catch-up growth, but may become even more stunted over time. In a cohort of Senegalese children, improved growth occurred, though the children remained short as adults (Ndiaye Coly *et al.*, 2006). Several studies provide observational support that children can catch up on linear growth via a maturational delay of 1.5-2 years allowing a prolonged growth period (Martorell, 2010; Ndiaye Coly *et al.*, 2006). The duration of the present study was too short to assess whether the children could have reached the end of a prolonged growing period via such a maturational delay.

Girls reach their pubertal growth spurt typically during Tanner breast stage 3, whereas boys attain peak height velocity during Tanner genital stage 4 (Rogol *et al*., 2000). A large percentage of the adolescents in the present study did not reach the end of their linear growth phase, because 46.9% of girls were still in Tanner stages 1-3 and 85% of boys were in Tanner stages 1-4. Studies in which the linear growth of stunted children is followed over a longer period of time are necessary to determine if physical activity in adolescence can reverse the effects of stunting.

The girls in the study population were generally inactive, possibly due to few opportunities for recreational physical activity in their environment (Mamabolo *et al*., 2007). The results indicate that the physical activity intervention had a significant influence on the growth status of the children. Limited research has been done on the relationship between physical activity and linear growth and the studies showed mixed results. Travill (2007) concluded in a study on adolescents in a shanty town near Cape Town that physical activity levels of these adolescents were poor compared to those of children in developed countries. The same study also reported impaired growth in comparison to adolescents from more developed countries. In a study by Gouthon *et al*. (2007) significant differences were found in physical activity levels between children living in rural, suburban and urban areas in Benin Republic, with children in rural areas being more physically active. In the same study significant differences were found in height between suburban and urban boys with suburban boys being taller, and between urban and rural girls with rural girls being taller, but without any significant relationship between height and physical activity.

Studies in intensively trained child athletes showed delayed linear growth during periods of intense training due to high energy expenditure. There are, however, indications that linear catch-up growth takes place after the competition season and no permanent consequences on adolescent growth were found (Gouthon *et al*., 2007; Matthews *et al*., 2006; Rogol *et al*., 2000). Conversely, increased physical activity did not improve linear growth of well-nourished adolescents in comparison to controls (Matthews *et al*., 2006; Beunen *et al*., 1992). The only study that showed improved linear growth in stunted children after a physical activity intervention was by Torun and Viteri (1994) who compared two groups of 24-48 months old children. The children were treated for severe protein energy malnutrition and received nutritional and medical treatment. The control group followed the routine programme involving rest-and-play in the rehabilitation centre, while the intervention group was encouraged to participate in games and heart rate of both groups were monitored. The intervention group had significantly higher heart rate and displayed significantly greater linear growth than the control group. The authors proposed that enhanced linear growth could be mediated through promotion of the growth of long bones by endocrine factors, such as growth hormone and insulin-like growth factor-1.

The results of this study suggest that higher physical activity in the children in the intervention school did not inhibit their linear growth, but may have contributed to stimulation of growth. Growth is a multi-dimensional phenomenon; therefore a cause-and-effect relationship between physical activity and growth is difficult to proof. A possible mechanism of a stimulatory effect of physical activity on growth is proposed to be increased secretion of growth hormone, insulin and insulin-like growth factor-1 in response to increased physical activity (Torun & Viteri, 1994). The children in the study of Torun and Viteri (1994) were, however, more undernourished than those in the present study and also much younger, making comparison difficult. Other studies of the effects of physical activity on growth often did not take inter-individual variation in biological maturity and dietary intake into account. Shorter and thinner girls who mature later are more successful in esthetic sports, such as gymnastics. These factors make it difficult to interpret the results of studies of physical activity and linear growth (Rogol *et al*., 2000). However, increased physical activity in adolescents with adequate energy intakes may not only favour linear growth, but also an increase in lean body mass and prevent excessive fat deposition (Watts, Jones, Davis & Green, 2005).

The findings of the present study should be interpreted in the light of a number of limitations. First, some children were lost during follow-up measurements, mainly due to absence from school on measurement days, or the fact that they changed schools. In order to ensure a similar level of data quality, we only included children in which three or more measurements were taken. The children who dropped out were not substantially different from those that stayed in the study. Secondly, the information on nutritional and activity status was collected using 24-hour recall methods, which may be subjected to error, because the method relies on the memory of the participants. Results regarding the mean energy and nutrient intakes of our subjects were however, consistent with other findings in the North West Province (Schutte *et al*., 2003). We were not able to retrieve information about HIV status or other infectious diseases in our sample, although it is known that HIV status goes hand in hand with growth failure in children (Arpadi, 2000). In South Africa, approximately 13.7% of children below the age of 20 are HIV infected (DOH, South Africa, 2008). However, none of the children of which serial height measurements could be done over the three years, had clearly visible signs of severe illness. There were only two schools recruited for study, and the larger school was allocated to the intervention group. There may have been differences between the two schools that influenced the way the intervention altered outcome measures, but we found no major differences between the schools. The setting of the present study, in which a quasi-experimental design was used could not be avoided, is also a limitation. A similar study may be repeated in settings where it is possible to do a cluster randomized trial to confirm the present results. Finally, the general compliance of the children with the physical activity intervention was poor. This was due to factors beyond the control of the children or researchers. Despite the poor compliance a significant effect on linear growth rate was found, which shows that regular physical activity of moderate intensity did not limit linear growth due to an energy deficit.

In conclusion, the present study, together with other recent studies, shows that stunting can progress or be reversed during middle childhood. This implies that more public health interventions are needed targeted at this age group. The fact that our physical activity intervention made a significant difference in growth status might stimulate future interventions. Our study showed that an activity intervention may have had a beneficial effect on the growth rate in adolescents. The impact of such an effect on long term school performance and productivity, as well as chronic disease risk is unknown and should be explored.

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