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Predictors of Differences in Vitamin D Levels in Children and Adolescents and Their Relation to Endurance Performance

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Key Words

Adolescents · Body mass index · Children · Endurance performance · 25-Hydoxyvitamin D · Sociodemographic factors

Abstract

Aims: The present study investigated whether sociodemographic factors and physical activity (PA) are associated with differences in serum 25-hydroxyvitamin D [25(OH)D] levels and whether these differences are associated with varying levels of endurance performance and body mass index (BMI) in children and adolescents. ***Subjects and Methods:*** Path analyses were based on data of a nationwide, cross-sectional German Health Interview and Examination Survey for Children (KiGGS; 2003 until 2006) for 25(OH)D and the embedded 'motor function module' for PA and endurance performance. The data were collected from 3,437 children and adolescents aged 6–17 years clustered in three age groups: 6–10, 11–13 and 14–17 years. ***Results:*** PA is affected by socioeconomic status and (non-)immigration background, 25(OH)D is only affected by (non-)immigration background and only in childhood. PA and 25(OH)D were not associated in those aged 11–13 years. In adolescence, lower 25(OH)D levels are associated with lower endurance performance and a higher BMI. ***Conclusions:*** Our results did not reveal a universally significant effect of sociodemographic factors on 25(OH)D. The association between 25(OH)D and endurance performance might reflect the effects of 25(OH)D on muscle function. Predictors of 25(OH)D status other than sunlight exposure and its health effects in the pediatric age group should be explored further.

Introduction

The impact of 25-hydroxyvitamin D [25(OH)D]) not only on bone health but also on other health outcomes is increasingly recognized [1–3]. Several studies in adults have found relationships between 25(OH)D and muscle function, an increased risk of falls [4, 5] as well as gastrointestinal disorders [6] and malignancies [7]. Little is known on the health effects of vitamin D in children and adolescents beyond the association of higher 25(OH)D levels with better bone health [8]. This question is of considerable interest given that numerous studies reported far less than optimal 25(OH)D levels in children and adolescents in different populations [9–18]. In the present study, we aimed to characterize not only the causes but

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also the consequences of differences in 25(OH)D levels in German children and adolescents. We aimed at exploring associations of sociodemographic factors [socioeconomic status (SES) and (non-)immigrant background] as well as physical activity (PA) with 25(OH)D levels, and potential relationships of 25(OH)D with endurance performance and body mass index (BMI). We considered different pediatric age groups separately because of previously reported age differences for PA, endurance performance [19] and 25(OH)D [20].

Methods

Subjects

The subjects studied represent a subgroup of the 'German Health Interview and Examination Survey for Children and Adolescents' (KiGGS) conducted between May 2003 and May 2006. The KiGGS survey is a nationwide, cross-sectional study on the health status of children and adolescents aged 4–17 years which was conducted by the Robert Koch Institute in Berlin and funded by the federal government [21]. A stratified two-stage probability sampling procedure was applied to select the subgroup participating in the 'motor function module' with detailed measurements of PA and endurance. The primary sample units were research sites in 150 communities throughout Germany. Subsequently, children and adolescents aged 4–17 years were randomly selected from the official registers of local residents' registration offices of these communities [22]. Participation was voluntary. The response rate was 66.6% with 5.3% quality-neutral dropouts, and 4,529 children and adolescents (2,244 girls and 2,285 boys) aged 4–17 years (mean ± SD: 9.45 ± 4.01 years) participated [23]. In consideration of seasonal variations in 25(OH)D levels, equal random samples were drawn over the four seasons of the year. Therefore, the analyses presented here are thus based on a sample of 3,437 children and adolescents. Participants were categorized into three age groups: 6–10 years (primary school), 11–13 years (lower secondary school) and 14–17 years (upper secondary school). Children were helped to fill out the questionnaires described below [22].

Socioeconomic Status

SES information was based on the unweighted mean score of the parents' information on their school education and professional qualifications, occupation and net household income. Each scale ranged from 1 to 7 points. Data on the parent with the higher status or, in case of divorced parents, the status of the parent the child lived with was used [24]. Migrants were defined as children born outside Germany, or with at least one parent born outside Germany, or with both parents having non-German citizenship.

Physical Activity

PA was assessed with a questionnaire containing 35 previously validated items involving the duration, intensity and frequency of PA in leisure time, school and sport clubs in the past year based on existing questionnaires [22]. The test-retest reliability in the previous 7-day longitudinal study ranged from r_{tt} = 0.72 (PA in leisure time) to r_{tt} = 0.93 (PA in sport clubs). Construct validity-related evidence was gathered by looking at the correlation with a multisensory electronic monitor including a biaxial accelerometer measuring PA (SenseWear Pro 2). Results have shown higher correlations with this monitor and the regarded types of PA (r_{min} = 0.56, r_{max} = 0.66) than with other PA questionnaires [25].

In accordance with international recommendations (President's Council on Physical Fitness and Sports 2008 [26, 27]) for activity guidelines with at least 60 min of moderate to vigorous activity daily, a PA parcel was built. For school, leisure time and sport club activity, only time spent from at least moderate PA (in min) was considered: number of school sport hours × 30 min + frequency of first sport × duration of first sport × number of months first sport is undertaken/12 (months a year) + frequency of second sport × duration second sport × number of months second sport is undertaken/12 (months a year) + frequency of third sport × duration third sport × number of months third sport is undertaken/12 (month a year) + frequency of fourth sport × duration fourth sport × number of months fourth sport is undertaken/12 (months a year). Sustained moderate to vigorous PA which was associated with positive health outcome was documented [28].

Endurance

A bicycle ergometer test was used to assess fitness performance and heart rate response. The test starts with a calculated initial load of 0.5 $W \cdot kg^{-1}$ body weight. This is then followed by an increase in load of a further 0.5 $W \cdot kg^{-1}$ body weight every 2 min. The test is then discontinued for any of the following three reasons: (1) when heart rate load reaches 190 (6–10 years) or 180 (11–17 years) b.p.m.; (2) when the frequency of rotation decreases below 50 rpm for a period of at least 20 s, or (3) when the subject stops due to exhaustion. The variable used for analysis is the wattage associated with a heart rate of 170 divided by the body weight (relative PWC 170). Since the health-related physical fitness should be assessed, PWC 170 was chosen as an internationally established endurance criterion and not the maximum heart rate load [29].

Body Mass Index

Height (stature) was measured in the standing position with a calibrated portable Holtain stadiometer and an accuracy of 0.1 cm. Body weight (mass) was assessed with participants in their underwear on a calibrated scale with an accuracy of 0.1 kg. BMI was calculated as body weight (kg)/height (m^2).

Serum 25(OH)D

Venous blood samples were collected from non-fasting participants and serum 25(OH)D (nmol/l) was assessed using the LIASON chemiluminescence immunoassay method (CLIA/DiaSorin) [30]. Severe vitamin D deficiency was defined as 25(OH)D concentration <12.5 nmol/l, moderate deficiency as 12.5 to <25 nmol/l, mild vitamin D deficiency as 25 to <50 nmol/l, and sufficiency as ≥50 nmol/l [31]. As expected, serum 25(OH)D concentrations were highest in summer (66 nmol/l), followed by autumn (54 nmol/l), spring (37 nmol/l) and winter (33 nmol/l). The lowest serum 25(OH)D concentrations were found in 11- to 13-year-old females in winter (mean 29 nmol/l) and 14- to 17-year-old male adolescents in spring (mean 32 nmol/l). The frequency distribution in the 25(OH)D classification – in categories of serious/moderate, mild and no deficiency – demonstrated that a total of 22% of subjects had moderate (or serious) deficiency, 42% a mild deficiency and 36% no vitamin D deficiency (table 1). In the 11- to 13-year-old group, only 30% showed a value >50 nmol/l.

Statistical Analysis

Descriptive statistics and regression analyses were calculated using IBM SPSS Statistics 19.0 (New York, N.Y., USA). The significance level was set at $p \leq 0.05$. As seasonal influences were treated as covariates in this study, regression analyses with seasonal influences as predictors for each measure considered as criterion were conducted and the standardized residuals were saved and used for path analyses. Path analyses to examine the interplay of all considered variables and bivariate correlations and to explore moderation or mediation effects were conducted with IBM SPSS AMOS 19.0 using a robust maximum likelihood algorithm. Because of missing data, the assumption of multivariate normality could not be tested. Cutoffs used to assess the model fit in addition to the significance of the χ^2 value were based upon the suggestions by Hu and Bentler [32] and Beauducel and Wittmann [33]. Consequently, we looked at the root mean square error of approximation (RMSEA), as recommended by Hu and Bentler [32], and, additionally, on the comparative fit index (CFI), as recommended by Beauducel and Wittmann [33]. According to Hu and Bentler [32], approximate cutoff values of RMSEA ≤ 0.08 and CFI ≥ 0.95 are appropriate. Missing data were imputed with the full information maximum likelihood algorithm [34]. Even when the assumption of multivariate normality is violated, the full information maximum likelihood algorithm provides relatively good estimations compared to deletion or mean imputation methods [35]. The proportion of missing item responses for each scale ranged from 0.0 to 1.0%. Overall lack of response was 1.7% (409 of 24,059 responses). Multigroup analyses were calculated for children and adolescents. A change in CFI >0.002 was regarded as a significant difference between the groups considered [36].

Table 1. Descriptive statistics (age and gender) for SES and immigration status, PA, 25(OH)D, BMI and endurance

	Mean ± SD or %		
	6–10 years	11–13 years	14–17 years
Age, years	8.31 ± 1.47	12.5 ± 0.88	15.79 ± 1.08
Gender			
male/female	51/49	53.4/46.6	49.5/50.5
SES	2.03 ± 0.71	1.93 ± 0.71	2.02 ± 0.70
(N-)IB			
IM/NIM	10.2/89.1	10.5/89.5	10.5/89.4
PA, min	141.54 ± 90.78	182.45 ± 116.57	180.95 ± 143.54
25(OH)D, nmol/l	50.54 ± 33.94	44.61 ± 25.63	47.07 ± 31.73
BMI	16.86 ± 2.64	19.47 ± 3.62	21.68 ± 3.81
Endurance,			
$W\cdot kg^{-1}$	1.94 ± 0.48	2.02 ± 0.48	2.10 ± 0.50

The SES scale ranged from 1 to 7 points. (N-)IB = Immigrant (IM)/nonimmigrant (NIM) background.

Table 2. Bivariate correlations for SES and immigration status, PA, 25(OH)D, BMI and endurance

	Bivariate correlations				
	(N-)IB	PA	25(OH)D	BMI	endurance
SES	–0.19[a]	0.10[a]	0.08[a]	–0.12[a]	0.11[a]
(N-)IB		–0.07[a]	–0.10[a]	0.02	–0.07[a]
PA			0.04[b]	0.17[a]	0.32[a]
25(OH)D				–0.10[a]	0.03
BMI					0.18[a]

The SES scale ranged from 1 to 7 points. (N-)IB = (Non-)immigrant background. [a] $p < 0.001$; [b] $p < 0.05$.

Results

Descriptive Statistics and Bivariate Path Correlations

Tables 1 and 2 provide descriptive statistics and bivariate correlations for the underlying variables of the path analyses. SES and (non-)immigrant background were similar for all age groups. Adolescents were more active than children and consequently revealed higher endurance performances, but also higher BMI scores. 25(OH)D levels were lowest for adolescents aged 11–13 and highest for children. SES and (non-)immigrant background correlated significantly with PA, 25(OH)D, BMI (only SES) and endurance performance. PA showed significant correlations to all body measures. 25(OH)D correlated significantly with BMI but not with endurance performance. A significant association between BMI and endurance was observed.

Model Fit

Multigroup analyses (fig. 1; statistical analysis) revealed differences for the three age groups, with an acceptable model fit [χ^2 (15) = 81.589, $p < 0.001$, RMSEA = 0.045 (90% confidence interval: 0.036–0.055), CFI = 0.90, ΔCFI = –0.051].

Correlations

Ages 6–10. Rates of PA are higher for both non-immigrant children background (a = –0.09, p = 0.001) and those with higher SES (a = 0.14, $p < 0.001$). Similarly 25(OH)D levels for non-immigrant children were higher (a = –0.12, $p < 0.001$), but no associations were found with SES (a = 0.05, p = 0.10). Higher PA was associated with

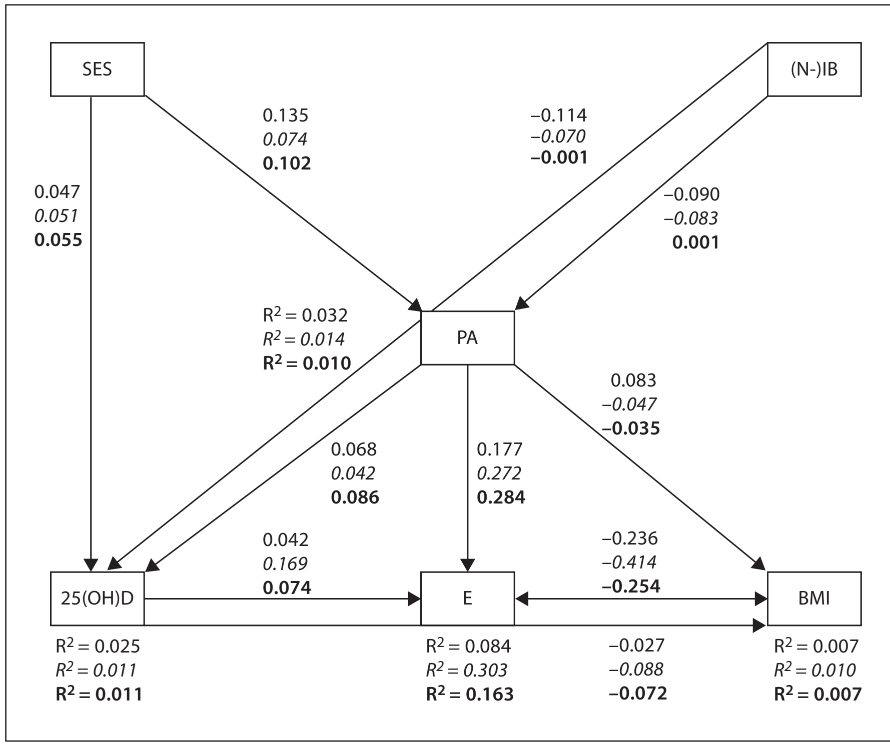

Fig. 1. Path model to describe the relationship between measured variables (compare text). Explained variance (R^2) and path values (a) are shown. Unstandardized solution. E = Endurance; (N-)IB = (non-) immigrant background. Standard = 6–10 years of age; italicized = 11–13 years of age; bold = 14–17 years of age.

higher BMI (a = 0.08, $p < 0.01$), with higher 25(OH)D levels (a = 0.07, $p < 0.05$) and with a higher level of endurance (a = 0.18, $p < 0.001$), which was also directly associated with a higher BMI (a = –0.24, $p < 0.001$). 25(OH)D was neither associated with BMI (a = –0.03, p = 0.33) nor with endurance (a = 0.04, p = 0.15). SES and (non-)immigrant background explained 3.2% of the PA variance and 2.5% of the 25(OH)D level variance was explained by sociodemographic variables and PA. PA explained 0.8% of the variance in BMI. PA, 25(OH)D and BMI explained 8.4% of the variance of endurance. The specific, explained variance of 25(OH)D on endurance performance amounts to 0.4%.

Ages 11–13. The PA of younger adolescents aged 11–13 years is associated with higher SES (a = 0.07, $p < 0.05$) and non-immigrant background (a = –0.08, $p < 0.05$). 25(OH)D was neither associated with (non-)immigrant background (a = –0.07, p = 0.06) nor with SES (a = 0.05, p = 0.15) and PA (a = 0.04, p = 0.26). BMI was unrelated to PA (a = –0.05, p = 0.20) but correlated with 25(OH)D [with a lower BMI for higher 25(OH)D levels; a = –0.09, $p < 0.05$]. Endurance performance was positively associated with PA (a = 0.27, $p < 0.001$) and 25(OH)D (a = 0.17, $p < 0.001$) and inversely with BMI (a = 0.41, $p < 0.001$). SES and (non-)immigrant background explained 1.4% of the PA variance, and 1.1% of the 25(OH)D level variance were explained by sociodemographic variables and PA. PA and 25(OH)D explained 1% of the variance of BMI [with 0.8% for 25(OH)D]. PA, 25(OH)D and BMI explained 29.9% of the variance in endurance. The specific, explained variance of 25(OH)D on endurance performance amounts to 4.9%.

Ages 14–17. In common with the other age groups, adolescents aged 14–17 with a higher SES were more physically active. Migration status was not associated with PA. The 25(OH)D levels were neither predicted by SES nor by migration status, but were predicted by PA [with a higher 25(OH)D level for more PA (a = 0.09, $p < 0.05$)]. BMI was not affected by PA, but a higher BMI was related to a lower 25(OH)D level. Endurance performance was greater with higher levels of 25(OH)D and PA but lower BMI. SES and (non-)immigrant background explained 1% of the PA variance, and 1.1% of the 25(OH) D level variance was explained by sociodemographic variables and PA. 25(OH)D explained 0.6% of the variance in BMI (the variance explained by PA is 0). PA, 25(OH)D and BMI explained 16% of the variance in endurance. The specific, explained variance of 25(OH)D on endurance performance amounts to 1.3%.

Discussion

This study shows that 25(OH)D levels are affected by (non-)immigrant background in children whereas PA is affected by SES in children and adolescents and by (non-) immigrant background in children and younger adolescents but not in those aged 14–17 years. Bivariate analysis showed an association between SES and 25(OH)D in children as well as of (non-)immigrant background with 25(OH)D in adolescents aged 11–13, which seems to result from multicollinearity. Thus, the specific effect sizes of SES or (non-)immigrant background on 25(OH)D seemed smaller than suggested by bivariate findings, emphasizing the need to consider both sociodemographic factors jointly. PA and 25(OH)D were not associated among adolescents aged 11–13 years. Thus, we cannot explain differences in 25(OH)D levels by (non-)immigrant background, SES or PA in adolescents aged 11–13 years. Of interest, associations of 25(OH)D with BMI and endurance performance were only observed in adolescents; however, in the bivariate analysis (but not in the path analysis) there was an association of 25(OH)D and endurance performance in children aged 6–10 years, which again seems to result from multicollinearity. Thus, the specific effects of 25(OH)D on endurance performance seem smaller than suggested by the bivariate correlations after controlling for BMI.

In addition to the known effect of the seasons on 25(OH)D levels [37], we found (non-)immigrant background to affect 25(OH)D levels in children but not in adolescents, which is of interest for future intervention studies. The impact of sociodemographic factors on 25(OH)D levels has been addressed only in a few studies, and findings were inconsistent [37–39]. For example, Räsanen et al. [38] found that sociodemographic factors, especially the number of children in the family and maternal age at child birth, were associated with total vitamin and vitamin D supplement intake. A seasonally adjusted multivariate analysis by Houghton et al. [37] showed higher levels of caregivers' education to be independently associated with lower 25(OH)D concentrations, possibly due to greater attempts to prevent unprotected sun exposure in their children. In the present analysis, we found no such associations between SES and 25(OH)D irrespective of age. However, there also seem to be effects of multicollinearity for SES and (non-)immigrant background on 25(OH)D suggesting that there is a need to consider both sociodemographic factors jointly. Of importance, such effects might explain the inconsistent findings of previous reports.

The impact of (non-)immigrant background on children's PA levels observed in the present study was also reported by Green et al. [40], who found the greatest cross-cultural diversity within three generations among children. Other studies reported a higher prevalence of physical inactivity for certain groups of immigrants, which was also associated with socioeconomic differences [41, 42]. Studies on the sole effect of SES on PA in children and adolescents revealed contradictory findings. However, more recent research has suggested lower levels of PA in families with lower SES [43, 44], which is in accordance with the present findings.

A previous study found PA to be related to 25(OH)D in children and adolescents [20]. In our study, higher levels of 25(OH)D were linked to higher levels of PA in children and adolescents aged 14–17 years, but not in those aged 11–13 years, which is difficult to explain but might be related to the many transitions occurring around puberty.

Hanson et al. [43] concluded that higher PA levels are correlated with higher levels of endurance. In contrast to our results, a lower BMI was previously found to be associated with higher PA levels in younger children [44]. A possible explanation is that not only PA level but also the extent of sedentary behavior and physical inactivity has a marked impact on BMI in children and adolescents [45]. In agreement with our findings, Deforche et al. [46] found a lower BMI associated with higher endurance levels in adolescents.

Besides PA, 25(OH)D also impacted on endurance of adolescents aged 11 years or older, with higher endurance levels for a more adequate supply of serum concentrations of 25(OH)D. This agrees with earlier findings where schoolgirls aged 9–15 years with severe vitamin D deficiency had a significantly lower level of fitness (VO_{2max}) than the non-deficient group [47]. Another study revealed that among 54 healthy young females better cardiorespiratory fitness (VO_{2max}) was associated with higher serum 25(OH)D level [39]. Ardestani et al. [48] concluded that serum 25(OH)D levels predict VO_{2max} in adults, with the greatest effects in those with low PA levels.

In line with the previously reported inverse relationship of 25(OH)D and BMI [49], we also found such a relationship in adolescents but not in children. The underlying mechanisms are not fully known, but it is assumed that sequestration of vitamin D in body fat stores may be a contributing factor along with lower sunlight exposure among obese people [50]. Another reason for the positive association between 25(OH)D and physical endurance as well as lower BMI levels could be the presence of vitamin D receptors in the muscle fibers, which makes a physiological impact of vitamin D supply on muscle activity plausible. Randomized controlled trials in elderly people showed vitamin D to significantly reduce the number of falls, apparently due to enhanced neuromuscular function [4, 51]. In a double-blind, placebo-controlled trial in Lebanese girls, vitamin D supplementation (2,000 IU/day) showed a significant effect on musculoskeletal parameters and muscle mass especially during the premenarchal period [52]. Since a correlation between muscle function, muscle mass and bone mass is well documented across age groups [48, 53–55], it is tempting to speculate that part of the benefits of vitamin D on bone health might be mediated by its effects on musculoskeletal function. This conclusion has to be treated with caution, because there is an ongoing debate as to whether relevant vitamin D receptor-related genetic influences are also associated with physical performance [56, 57].

A limitation of our study is that analyses are not based on longitudinal data, hence no inferences on causality or development over time are possible. Furthermore, we did not consider various 25(OH)D-related behaviors, such as dietary choices or use of sun blockers.

In summary, our findings reveal that while PA is affected by sociodemographic factors of SES and (non-)immigrant background [except for (non-)immigrant background for adolescents aged 14–17 years], 25(OH)D levels are only affected by (non-)immigrant background and only in childhood. There seemed to be multicollinearity for SES and (non-)immigrant background on 25(OH)D, therefore the commonalities among SES and (non-)immigrant background seem relevant for 25(OH)D concentrations. We cannot explain differences in 25(OH)D for adolescents aged 11–13 years with the specific amounts of the sociodemographic correlates and also not with PA, which might be due to puberty-related changes in physiology and behavior. The health benefits of adequate endurance [58] and normal BMI [59] are well known. Future interventions aiming at improving 25(OH)D levels, endurance and BMI should focus on children with (non-) immigrant background and lower SES, who bear an increased risk. The association of serum 25(OH)D with endurance might have effects on muscle function with great importance for public health and physical performance. Therefore, this question needs to be explored in further detail both in mechanistic and in human intervention studies.

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Disclosure Statement

None of the authors reports any conflict of interest according to the standards of the International Committee of Medical Journal Editors.

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