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ORIGINAL ARTICLE

Blood pressure tracking in children and adolescents

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Abstract
Background High blood pressure is a major risk factor for cardiovascular disease. Blood pressure tracking could help to identify individuals with potential hypertension. Therefore, we have asked whether or not tracking was of predictive value for the development of hypertension in early life.
Methods Blood pressure was routinely measured in 13,261 children and adolescents in outpatient clinics as well as during hospitalization. In one analysis, 568 individuals with elevated and normotensive blood pressure values were evaluated after 2, 4, and 6 years of follow-up. In a second analysis, 2,157 individuals with normotensive blood pressure were examined in a paired *t* test.
Results The follow-up analysis showed a significant tracking effect. However, the Pearson correlation coefficients of the systolic and diastolic blood pressure standard deviation scores (SDS) decreased over time. Upon the follow-up after 6 years, 35.6 % of the children and adolescents with elevated blood pressure values remained in the elevated range group. Of the children within the normotensive blood pressure range, 80.4 % remained normotensive after 6 years. Children with normotensive blood pressure showed a stronger tracking than those who had had one hypertensive blood pressure reading. Children with higher body mass index (BMI) at follow-up changed blood pressure SDS track from initially normal to higher blood pressure values.
Conclusions Blood pressure tracking in children and adolescents is moderate. We conclude that the predictive power of a single hypertensive blood pressure measurement during a single visit is rather small, and thus repetitive measurements across several consecutive visits are necessary.

Keywords Hypertension · Central Europe · Pediatric blood pressure measurements · CrescNet · Risk analysis

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Introduction

Hypertension is a risk factor for coronary heart disease, peripheral artery occlusive disease, stroke, and even chronic kidney disease [1–3]. However, the prevalence of hypertension in children is low: for example, a study conducted in Switzerland suggests a prevalence of only 2 % [4]. Nevertheless, it is recommended that children over the age of 3 years should have their blood pressure measured during every medical visit [5], as serial blood pressure measurements allow for a more accurate blood pressure assessment. Results of blood pressure measurements are highly variable and sensitive to internal influences such as age, gender, height [5], and body mass index (BMI) [6]. Tracking of blood pressure can be useful in identifying individuals with potential hypertension later in life. Tracking is defined as the extent of retaining an individual ranking over time relative to others [7]. Meta-analysis of blood pressure measurements has found significant tracking [8, 9] and there seems to be familial aggregation of blood pressure early in life [10]. The correlation coefficients of blood pressure tracking are smaller than those of more stable values, such as height (correlation coefficients between 0.3 and 0.45 over 10-year periods for blood pressure, compared to 0.70 and 0.80 for height [11]). In a large retrospective trend analysis, we asked whether and to what extent there was tracking of blood pressure measurements in children and adolescents in Central Europe.

Subjects and methods

Study population

CrescNet is an auxologic network for the early detection of children's growth disorders and overweight children in Germany [12–15]. Currently, the network connects more than 300 German pediatricians in practice and more than 20 centers for pediatrics and pediatric endocrinology [16]. Since 1999, CrescNet has monitored around 654,983 children (337,904 boys and 317,079 girls) with 3,047,706 measurements of growth and the cardiovascular system by May 2013. The pseudonymized data is collected during routine medical check-ups of healthy and sick children in outpatient clinics or inpatient wards: for example, on wards of the University Children's Hospital of Leipzig [14]. Until May 2013, blood pressure values had been recorded in only 13,261 children (6,853 boys and 6,408 girls), with 42,528 blood pressure values (Fig. 1). Criteria for inclusion were the age of the children (between 3 and 21 years) and a logical dataset of systolic and diastolic blood pressures. Children younger than 3 years were excluded from analysis in our study, owing to the difficulties in precisely measuring blood pressure in this age group. According to pilot studies in our cohort, blood pressure data in children younger than 3 years is unreliable and often not reproducible. The measurements for the follow-up groups were mainly taken between 2007 and March 2011 (97.4 %), with one healthcare visit per child selected randomly. The follow-up groups were not dependent on one another. For the retrospective follow-up analysis, a total of 568 children and adolescents out of a pool of 13,261 were available. After a follow-up period of 2 years, data involving 568 children (255 boys and 313 girls) could be retrieved. After 4 years, only 377 children (167 boys and 210 girls) could be included in the analysis and 217 children (100 boys and 117 girls) after 6 years (Tables 1 and 2). The children in each follow-up group were

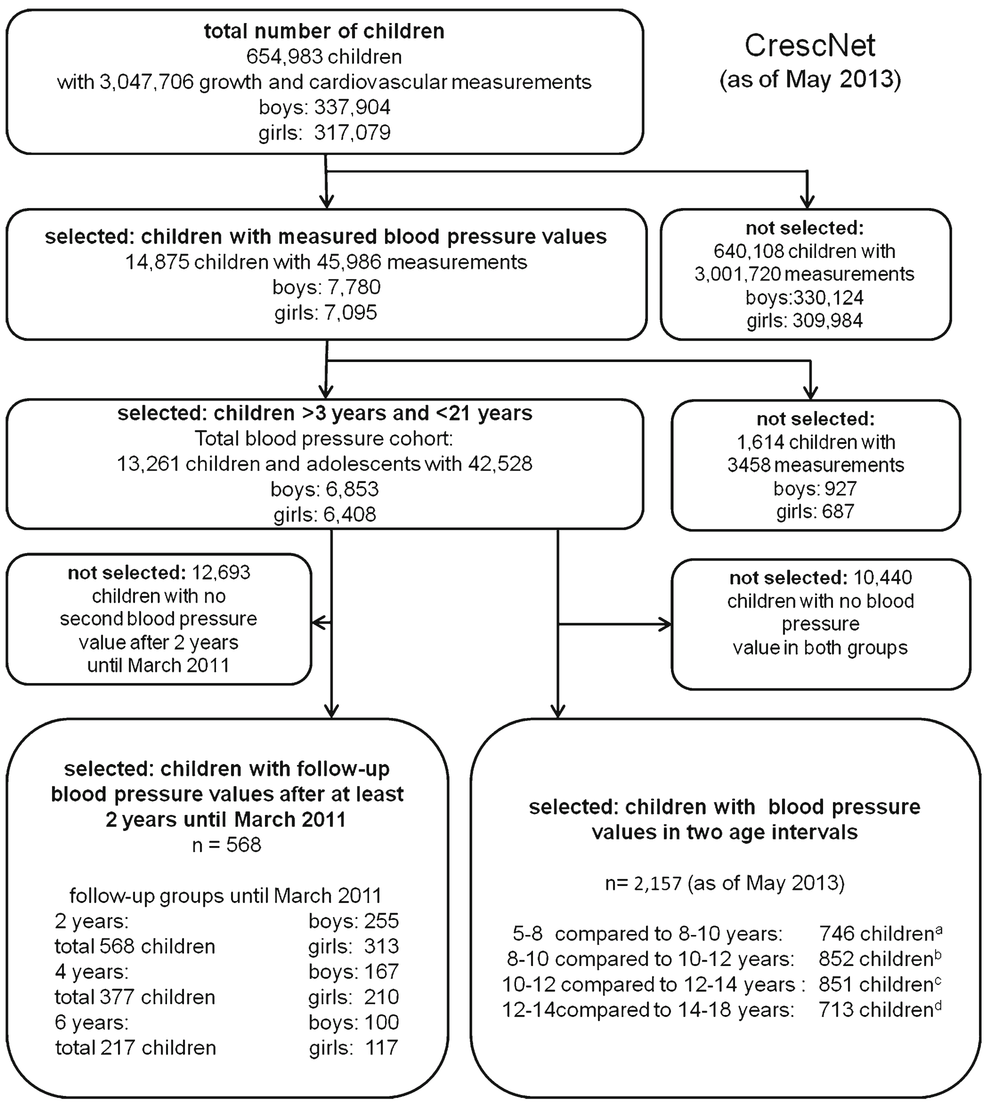

Fig. 1 CrescNet is an anonymous public health database, initially founded to collect up-to-date growth data of children in Germany. Since 2007, blood pressure measurements of children have also been registered. At present, some pediatricians still only use CrescNet to evaluate growth. Therefore, only a small yet increasing number of children and adolescents are registered with blood pressure measurements. Furthermore, only few of the older children have follow-up data and the numbers are undergoing permanent changes. **a** See Fig. 3a. **b** See Fig. 3b. **c** See Fig. 3c. **d** See Fig. 3d

Table 1 Clinical characteristics of study subjects

	Complete blood pressure cohort as of May 2013		Sample for follow-up analysis until March 2011	
	Boys (n=6,853)	Girls (n=6,408)	Boys (n=255)	Girls (n=313)
Clinical features				
Age, years*	10.5±4.2	10.7±4.2	9.9±3.6	9.1±3.5
Systolic BP, SDS*	0.764±1.1	0.794±1.2	0.614±1.0	0.617±1.2
Diastolic BP, SDS*	0.447±1.1	0.458±1.2	0.387±0.8	0.349±0.8
Elevated BP, %	31.1	32.6	23.1	27.5

BP, blood pressure; SDS, satandard deviation score

divided according to the blood pressure measurement of the first visit, into a subgroup with elevated systolic blood pressure (systolic blood pressure at the 90th centile or higher [standard deviation scores (SDS) of 1.2816]) and a subgroup with normal systolic blood pressure (systolic blood pressure below the 90th centile). Follow-up measurements in a second visit were sub-grouped into hypertensive range blood pressure (systolic blood pressure at the 95th centile or higher [SDS 1.6449]), prehypertensive range blood pressure (systolic blood pressure at 90th centile or higher and below the 95th centile) and normal range blood pressure measurements (systolic blood pressure below the 90th centile).

Furthermore, 2,157 children and adolescents were analyzed for tracking in different age intervals in an additional *t* test, with only children with normotensive blood pressure included in the analysis. A total of 746 children and adolescents were included in the paired *t* test comparing the age intervals of 5–8 and 8–10 years. In the paired *t* test comparing the age intervals of 8–10 and 10–12 years, 852 children and adolescents were included. In the paired *t* test comparing the age intervals of 10–12 and 12–14 years, 851 children and adolescents were included. Finally, 713 children and adolescents were included in the paired *t* test comparing the age intervals of 12–14 and 14–18 years.

Measurements

All measurements were performed by pediatricians in practice or trained staff in pediatric practices. During pediatric consultations, height, weight, and vital parameters such as the pulse or blood pressure of the children and adolescents were collected according to standardized procedures, and were subsequently transferred into the database of CrescNet [12, 13]. All pediatricians were supplied with a stadiometer of the same type to ensure identical conditions. For measuring body weight, the children were only wearing light underwear [15]. In all departments of the University Hospital of Leipzig (80 % of the blood pressure measurements), blood pressure is measured with an oscillometric device (DINAMAP Pro300V2), according to the latest studies of the National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents [5]. The remainder of the measurements were obtained using comparable devices that we cannot specify in each individual case. All measured values underwent plausibility tests [14].

Statistical analysis

All measurements were transferred into standard deviation scores (SDS) to avoid a bias concerning the influence of different heights and ages on blood pressure, and render measurements comparable. SDS defines the deviation of the measurement referred to height and age from the median given by the "National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents" [5]. A Pearson's correlation analysis was performed to investigate the blood pressure tracking in our cohort, comparing the systolic and diastolic blood pressure for both sexes and in total, as well as elevated and normal range systolic blood pressure measurements in each follow-up group (see Tables 3, 4 and Fig. 2). In order to compare the tracking in more detail, the outcome in the subgroups with elevated and normal range blood pressure measurements at baseline were tested against each other using Fisher's exact test, with the

Table 2 Characteristics* of the study subgroups

Follow-up groups	Age*[a]	Systolic BP at baseline SDS*	Sex			At baseline	
			Boys	Girls	Boys (%)	Elevated	Normal
2 years	9.45±3.55	0.615±1.12	255	313	44.9	145	423
4 years	8.29±3.18	0.650±1.11	210	167	55.7	96	281
6 years	7.64±3.03	0.646±1.30	100	117	46.1	59	158

*Values are mean ± SD or percentages. BP indicates blood pressure. For the sample that was used for trend analyses, characteristics are from the date of the first initial measurement

[a] The average age of the groups decreases in the follow-up years because the date of the initial measurement was earlier in the life of children with long follow-up as compared to many children with short follow-up who had dropped out after 4 years

Table 3 Tracking correlation coefficients for systolic and diastolic blood pressure SDS and both sexes

Follow–up group	Systolic blood pressure SDS			Diastolic blood pressure SDS		
	Boys	Girls	Total	Boys	Girls	Total
2 years	$n=255$	$n=313$	$n=568$	$n=255$	$n=313$	$n=568$
	$r=0.412$	$r=0.418$	$r=0.414$	$r=0.330$	$r=0.306$	$r=0.314$
	$p<0.0005$	$p<0.0005$	$p<0.0005$	$p<0.0005$	$p<0.0005$	$p<0.0005$
4 years	$n=167$	$n=210$	$n=377$	$n=167$	$n=210$	$n=377$
	$r=0.362$	$r=0.373$	$r=0.368$	$r=0.270$	$r=0.255$	$r=0.258$
	$p<0.0005$	$p<0.0005$	$p<0.0005$	$p<0.0005$	$p<0.0005$	$p<0.0005$
6 years	$n=100$	$n=117$	$n=217$	$n=100$	$n=117$	$n=217$
	$r=0.379$	$r=0.155$	$r=0.269$	$r=0.043$	$r=0.037$	$r=0.039$
	$p<0.0005$	$p=0.096$	$p<0.0005$	$p=0.668$	$p=0.692$	$p=0.569$

All results were calculated with SPSS 17.0. *SDS* indicates standard deviation score; *r* indicates the correlation coefficient according Pearson; *n* indicates the number of children

calculations completed in SPSS and Excel. We chose a similar approach to the German study of Briedigkeit [17] to gain more detailed information about tracking in our sample, albeit with higher case numbers (see Table 5).

A paired *t* test was performed in order to observe the individual blood pressure change with increasing age (see Fig. 3) with a specific age interval was tested against the subsequent interval. In Fig. 3a–d, two horizontal and two vertical lines mark the blood pressure SDS for normal range blood pressure (−1.28 and 1.28), with all children in the middle square normotensive in both age intervals. The diagonal line is the line of zero blood pressure SDS changes with the distance to the diagonal line indicating the power of the tracking. The closer the values are to this line, the lower the blood pressure SDS change and the stronger the tracking. We also analyzed the blood pressure changes in relation to BMI. The blood pressure changes in their dependence upon BMI are shown in Fig. 4, which is organized in the same way as Fig. 3 (see the legend to Fig. 3). The shape of the points indicates the BMI in the first age interval (10–12 years), while the color indicates the BMI in the second age interval (12–14 years).

Table 4 Tracking correlation coefficients for elevated or normal blood pressure value at baseline

Follow-up group	Systolic blood pressure SDS at baseline		
	Elevated	Normal	Total
2 years	$n=145$	$n=423$	$n=568$
	$r=0.265$	$r=0.295$	$r=0.414$
	$p<0.01$	$p<0.001$	$p<0.0005$
4 years	$n=96$	$n=281$	$n=377$
	$r=0.148$	$r=0.284$	$r=0.368$
	$p=0.151$	$p<0.001$	$p<0.0005$
6 years	$n=59$	$n=158$	$n=217$
	$r=0.084$	$r=0.165$	$r=0.269$
	$p=0.527$	$p=0.039$	$p<0.0005$

All results were calculated with SPSS 17.0. *SDS* indicates standard deviation score; *BP* indicates blood pressure; *r* indicates the correlation coefficient according Pearson; *n* indicates the number of children and adolescents

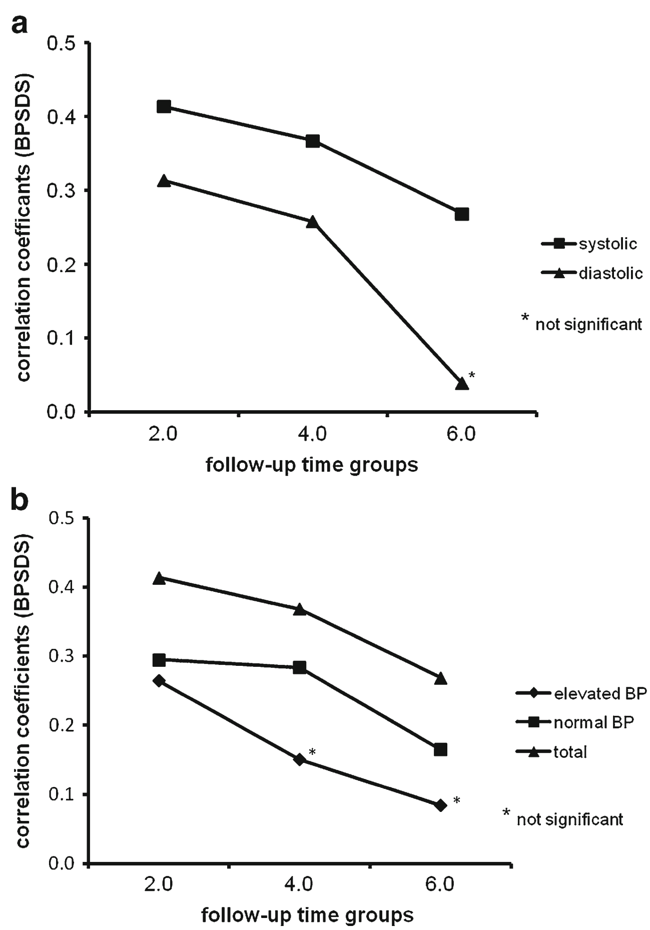

Fig. 2 Pearson's auto correlation analysis. BP SDS indicates blood pressure standard deviation score. BP indicates blood pressure. **a** Systolic and diastolic correlation coefficients over follow-up time groups in years according to Table 3. The diastolic correlation coefficients are only significant for 2 to 4 years follow-up time. **b** Correlation coefficients for children and adolescents with elevated systolic or normotensive blood pressure measurement at baseline over follow-up time groups in years, according to Table 4

Table 5 Follow-up analysis of single blood pressure measurements

Follow-up time in years	Initial systolic blood pressure SDS[a]	*n*	Systolic blood pressure SDS after observation period[b]						Significance
			Normal		Prehypertensive		Hypertensive		Fisher's exact test
			n	%	*n*	%	*n*	%	
2	Elevated	145	77	53.1	22	15.2	46	31.7	$p<0.001$
	Normal	423	351	83.0	33	7.8	39	9.2	
4	Elevated	96	61	63.5	9	9.4	26	27.1	$p<0.001$
	Normal	281	230	81.9	21	7.5	30	10.7	
6	Elevated	59	38	64.4	4	6.8	17	28.8	$p=0.014$
	Normal	158	127	80.4	9	5.7	22	13.9	

Values are absolute (n) or relative (%) numbers of children. *SDS* indicates the standard deviation score. The Fisher's exact test was calculated in SPSS 17.0

[a] For the initial systolic blood pressure SDS, the children were divided into groups of elevated (above or at the 90th centile [SDS 1.2816]) and normal (below the 90th centile) blood pressure SDS

[b] According to the second blood pressure measurement at the end of the follow-up time the children were grouped into: normal (below the 90th centile), prehypertensive (over or at the 90th centile and below the 95th centile) and hypertensive (at or above the 95th centile [SDS 1.6449])

The small light grey points symbolize the lean children or adolescents who remained lean, while the big dark points symbolize the obese children who remained obese over time. The small dark points represent children or adolescents who developed a higher BMI compared to other children in their age. Regarding the middle square, lean children are more in the left lower corner and closer to the diagonal line, whereas obese children are more in the right upper corner and more distant from the diagonal line. These statistical analyses were undertaken in R, a language for statistical computing (version 2.13.0) [18]. The level of significance was set at $\alpha=0.05$.

Results

Characteristics

The characteristics of the study population are compared to all children with blood pressure values in Tables 1 and 2. The distribution of blood pressure measurement SDS in the follow-up cohort is equal to the distribution of blood pressure measurement SDS in the complete blood pressure cohort. The average age was similar for boys and girls. The complete sample with measured blood pressure showed more cases with elevated blood pressure readings. The percentage of children or adolescents with elevated blood pressure measurements was 25.3 % (23.1 % boys; 27.5 % girls) in the follow-up sample and 31.9 % (31.1 % boys; 32.6 % girls) in the complete sample. These relatively high percentages are presumably due to the "white coat" effect, involving a higher inclusion of children with chronic disorders in the hospital sample, as well as the reliance on a single blood pressure reading during each visit.

Pearson's correlation analysis

We performed a Pearson's product–moment correlation to investigate the tracking phenomena in 568 children with follow-up data shown in Tables 3 and 4. After 2 and 4 years' follow-up time, there was a moderate decrease in the correlation coefficients for both boys and girls. The total (boys and girls) significant correlation coefficients for the systolic blood pressure SDS were $r=0.414$ ($p<0.001$) after 2 years, $r=0.368$ ($p<0.001$) after 4 years and $r=0.269$ ($p<0.001$) after 6 years (see Fig. 2a and Table 5). A similar trend was found in the diastolic blood pressure SDS, with a decrease of 0.314 ($p<0.001$) after 2 years and 0.258 ($p<0.001$) after 4 years (see Fig. 2a). After 6 years, there was no significant correlation. Comparing both sexes, the tracking seemed to be slightly higher in male children and adolescents.

Furthermore, comparing the correlation coefficients in Fig. 2b, the tracking of children and adolescents within the elevated range was weaker than the tracking of children and adolescents with normotensive range blood pressure measurements. After 2 years, the correlation coefficients of the group within the elevated blood pressure range were lower compared to the group with normotensive blood pressure range (0.030 points lower after 2 years). The correlation coefficients for the subgroup with elevated blood pressure measurements were not significant after 4 and 6 years of follow-up. Each subgroup showed a decline of the correlation coefficients, and the decline of the follow-up groups with elevated blood pressure measurements was even stronger.

Table 5 presents the allocation of the groups as well as the assignment into the three subgroups at the end of each follow-up time group. After 2 years of follow-up time, 46.9 % of the children (31.7 % hypertensive and 15.2 % prehypertensive)

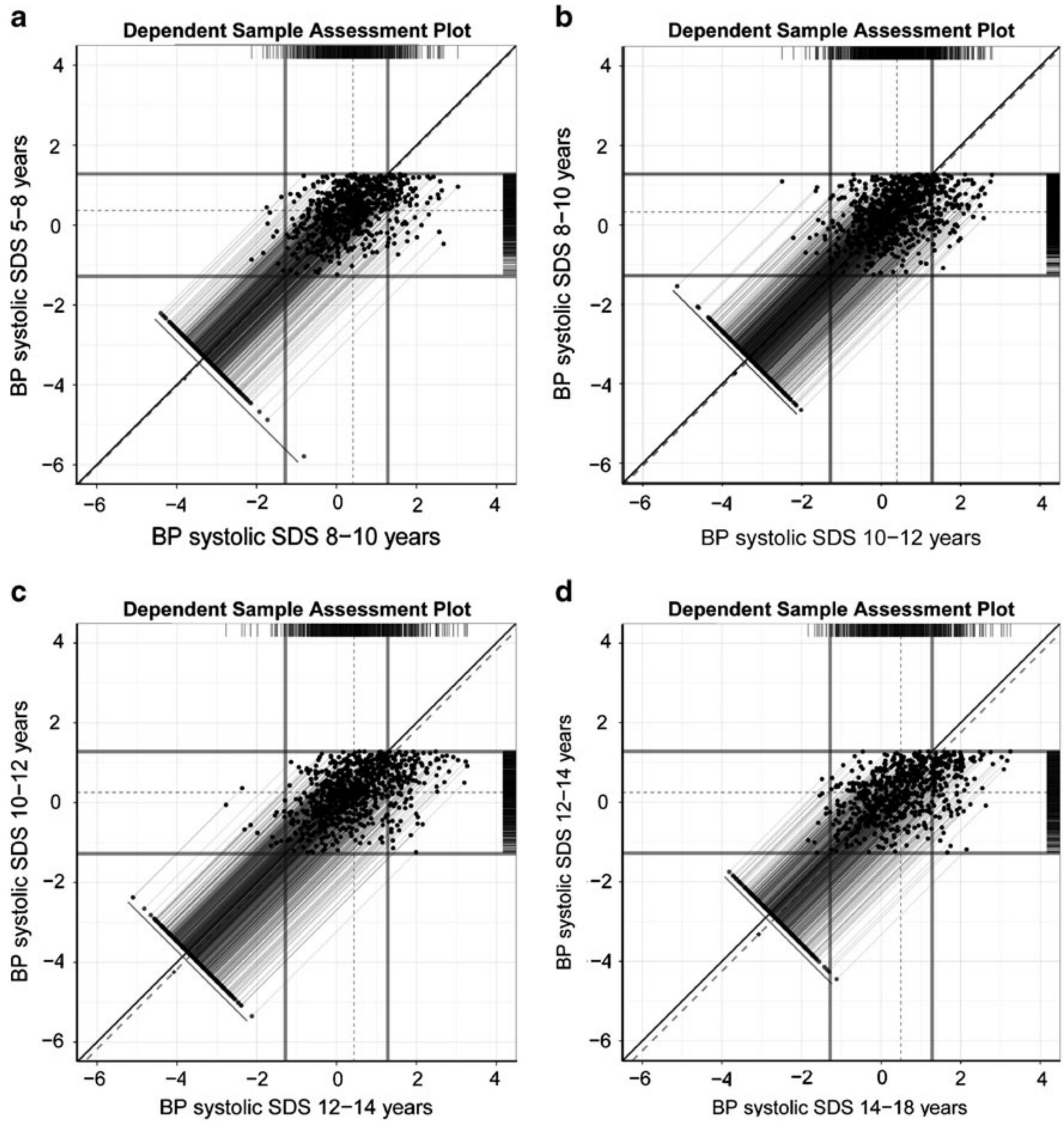

Fig. 3 Paired t test comparing age intervals listed in Fig. 1. The *horizontal and vertical lines* mark the normotensive range in each age interval. *Points in the middle square* symbolize children and adolescents with normotensive blood pressure (BP) measurements at both age intervals. The *middle diagonal lin*e is the zero line, marking no blood pressure standard deviation score (SDS) changes over time. Each point is projected in one vertical line to illustrate the deviation to the zero line. **a** Paired t test of the age interval of 5–8 years over the age interval of 8–10 years (r= 0.437, p=0.127, mean difference=0.04). **b** Paired t test of the age interval of 8–10 years over the age interval of 10–12 years (r=0.396, p =0.012, mean difference=0.07). **c** Paired t test of the age interval of 10–12 years over the age interval of 12–14 years (r=0.479, p<0.001, mean difference=0.18). **d** Paired t test of the age interval of 1–14 years over the age interval of 14–18 years (r=0.469, p<0.001, mean difference=0.24)

remained in their systolic blood pressure SDS range (elevated blood pressure above the 90th centile). After 4 years, 36.5 % (27.1 % hypertensive and 9.4 % prehypertensive) and after 6 years, 35.6 % (28.8 % hypertensive and 6.8 prehypertensive) remained in the elevated SDS range. Interestingly, only 83.0 % of the children and adolescents retained their normotensive range blood pressure value after 2 years, 81.9 % after 4 years and 80.4 % after 6 years. However, 50–60 % of the children with initially elevated blood pressure measurement had achieved normal range values upon the follow-up time.

In the paired t test, the mean difference of each individual to the zero line was used to describe the tracking behavior of the whole age group. The lower the mean difference, the higher the mean tracking of the blood pressure measurements. The mean difference to the zero line increases from 0.04 at an age interval from 5 to 10 years continuously up to 0.24 at an age from 12 to 18 years. In all age intervals, the correlation

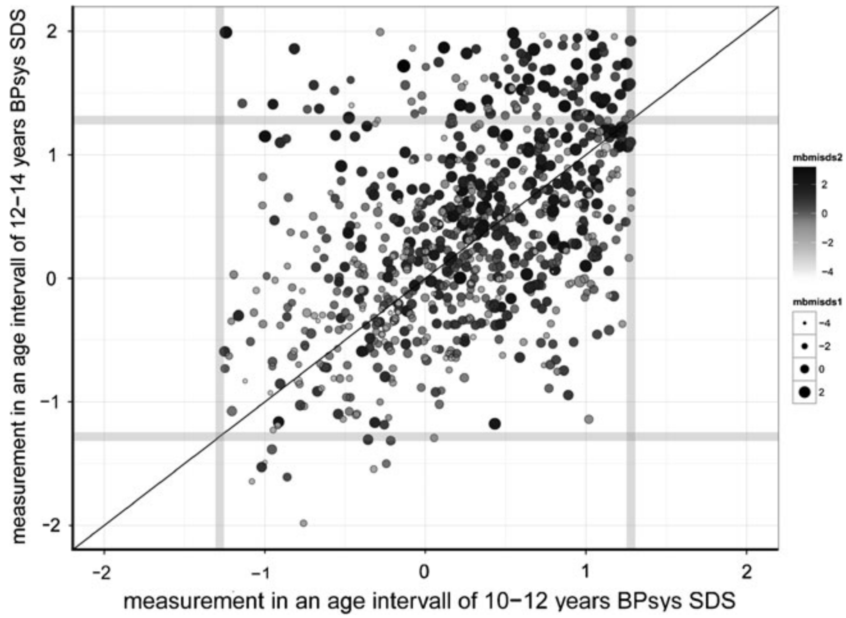

Fig. 4 Individual paired *t* test comparing the age interval of 10–12 years and the age interval of 12–14 years in their dependence upon body mass index (BMI) change. *Points in the middle square* symbolize children and adolescents with normotensive blood pressure measurements in both age intervals. The *middle diagonal line* is the zero line with a maximum tracking. On this line, each child has the same standard deviation score (SDS) in both age groups. The size of the points indicates the BMI of each child or adolescent in the first age interval and the color indicates the BMI in the second time interval. "mbmisds" indicates mean BMI SDS

coefficients varied from 0.396 (age interval 5–8 years compared to 8–10 years) to 0.479 (age interval 12–14 years compared to 14–18 years). The correlation is not significant for the comparison of age intervals of 5–8 years and 8–10 years (see legend to Fig. 3a). In this analysis, 51.1–62.1 % of the children and adolescents with an elevated blood pressure measurement in the first age interval had a second elevated blood pressure measurement in the subsequent age interval. Furthermore, 80.2–86.7 % of the children and adolescents with normotensive blood pressure measurement in the first age interval had a second normotensive measurement in the next following age interval.

Figure 4 shows the relationship of blood pressure SDS changes to the BMI of the children and adolescents. Children with higher BMI at follow-up often changed their blood pressure SDS track from initially normal to higher blood pressure values.

Discussion

Elevated blood pressure is associated with an increased risk of cardiovascular diseases, stroke, and mortality. Many covariates such as age, gender, height, BMI nutrition during pregnancy, and smoking parents influence blood pressure, even in early life [5, 6, 19, 20].

The tracking phenomenon is known as an autocorrelation of a measured value in a defined corridor of percentiles. Understanding this phenomenon is important to estimate the predictive power of measured blood pressure values in children and the strategy of treating hypertension in children according to their future risk. This study examined the tracking behavior of elevated and normal blood pressure data in children and adolescents in Central Europe. Furthermore, we also examined the predictive power of a single blood pressure reading.

Pearson's correlation analysis revealed a moderate tracking in the systolic and diastolic blood pressure SDS groups, which was stronger in the former than the latter, while the power of tracking decreases over time. These effects are also described in other studies [8, 9]. We found that the effect of tracking is also smaller in the cohort with elevated blood measurements at baseline. Figure 2 shows the correlation coefficients over time for children and adolescents with normotensive and elevated blood pressure measurements. The differences in tracking could refer to successful treatment of children or adolescents with hypertensive blood pressure, which may reduce the power of tracking. Further reasons for single or repetitive elevated blood pressure values could include the "white coat" effect, false measurement technique, or the reliance on single blood pressure measurements.

At follow-up, 46.9 % (after 2 years) and 35.6 % (after 6 years) of the children and adolescents with elevated blood pressure measurement retained an elevated blood pressure. The paired *t* test showed similar results: 51.1 % and 62.1 % of the children and adolescents with elevated blood pressure retained the elevated blood pressure. However, 80.4 % and 83.05 % of the children and adolescents with normotensive blood pressure measurements retained the normotensive value at follow-up, with the same results seen in the *t* test: 80.2 % and 86.7 % remained normotensive. The mean difference given in the legend to Fig. 3 describes the mean distances of each point to the diagonal zero line. By comparing the age intervals in a paired *t* test, an increase of the mean difference from 0.04 in an age interval from 5 to 10 years up to 0.24 in an age interval from 12 to 18 years was observed. The relevance of the mean difference is limited by the wide spread of the points in terms of distance to the zero line. The correlation coefficients from this analysis increased from 0.396 in children to 0.479 in adolescents. The BMI of many children changed at the start of puberty (Fig. 4). As is already known, BMI strongly influences blood pressure, with many of the children and adolescents with higher weight gain leaving their SDS track to higher blood pressure values. Accordingly, an increase in BMI negatively influenced the power of tracking.

Current studies showed that the influence of hypertension on the risk of cardiovascular disease in obese children is not reversible through losing weight as an adult [21, 22]. Therefore, an increasing BMI and hypertension during childhood represents a serious problem. We conclude that patients with a single normotensive blood pressure measurement will most likely remain normotensive, whereas the predictive power of a single elevated blood pressure reading is relatively small. We recommend repetitive blood pressure measurements during all health care visits.

Conclusions

Blood pressure measurements in children and adolescents show a moderate tracking phenomenon. The systolic and normotensive blood pressure tracking is stronger than that of the diastolic and of elevated blood pressure. Upon follow-up over 6 years, only 35.6 % of the children and adolescents with elevated blood pressure retained elevated blood pressure. Almost 20 % of the children with normal blood pressure values showed elevated blood pressure values later on. Children with higher BMI tend to leave the SDS track to higher blood pressure values. Consequently, we conclude that the predictive power of an elevated blood pressure measurement during a single visit is rather small, and thus repetitive measurements are necessary.

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