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Independent and Combined Effects of Physical Activity and Changes in Body Mass on Long-Term Changes in Blood Pressure among Adolescents:

The HUNT Study, Norway

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Abstract

Background: The association between overweight or obesity and blood pressure is well established among adolescents. Also the beneficial effect of physical activity on reduction in body mass is well known. However, studies done on the possible effect of physical activity on blood pressure are limited. Thus, the purpose of this study is to examine the independent and combined effect of baseline physical activity and changes in body mass on change in blood pressure in a population of Norwegian adolescents.

Methods: Weight, height, waist circumference (WC), hip circumference (HC), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured, and body mass index (BMI) and waist-hip ratio (WHR) were calculated among 1814 adolescents (777 males and 1037 males) aged 13-19 years, who participated in a population based study in 1995-1997 (Young-HUNT 1), and a follow-up study in 2006-2008 (HUNT 3), in the county of Nord-Trøndelag, Norway. Internationally accepted cut-off points were used to classify the subjects as underweight, normal weight, overweight or obese, and changes between the body mass variables from baseline to follow-up was calculated. The adolescents completed a detailed questionnaire including physical activity and smoking habits. We calculated changes in mean SBP and DBP within categories of changes in body mass and level of physical activity score (PAS) at baseline, and examined the crude and adjusted differences in change in mean SBP and DBP between the categories.

Results: An increase in either of the body mass variables resulted generally in a higher change in mean SBP and DBP among both males and females, compared to those who were stable, whereas there was no evidence of an independent effect of baseline PAS on changes in SBP or DBP. Analysis of the combined effect showed that those who had a stable BMI had approximately similar changes in SBP and DBP, irrespective of their baseline PAS level. Moreover, those who increased their BMI had a higher change in both SBP and DBP than those with a stable BMI, with no evidence of any modifying effect of PAS.

Conclusion: In this population-based study of Norwegian adolescents, we found that an increase in body mass from Young-HUNT 1 to HUNT 3 was associated with a higher change in mean SBP and DBP, compared to those who were stable, but that baseline level of physical activity seemed to have no influence on these associations. Thus, avoiding weight gain seems to be the key factor to prevent unfavorable BP levels.

Introduction

The World Health Organization (WHO) [1] states that overweight and obesity among children and adolescents have become one of the most serious public health challenges in the 21st century. Additionally, Salvadori and colleagues [2] have predicted that the current generation of children may be the first to have poorer health outcomes than their parents.

Numerous studies [3-5], have shown that the prevalence of overweight and obesity among adolescents is rapidly increasing worldwide. WHO [6] states that worldwide, 1.6 billion people aged 15 years or older were overweight and 400 million were obese in 2005, and if the development continues to the same extent, they project that approximately 700 million will be obese in 2015. A survey done by the Norwegian Directorate of Health [7] in 2005-2006, showed that 11.6 % of 15 year old Norwegian girls were overweight, and that 1.3 % were obese. Correspondingly, 9.2 % of 15 year old boys were overweight and 4.4 % were obese. Increased body mass index (BMI) is strongly associated with cardiovascular risk factors such as elevated blood pressure (BP) in adolescents; the higher the increase in BMI, the higher is the increase in risk factor levels [8, 9]. This underscores the fact that millions of children and adolescents worldwide are at risk for chronic illnesses, notably hypertension [5, 10].

It is well known that physical activity has a beneficial effect on weight control, and on the prevention of overweight and obesity in adolescents [11 -13]. Reduction in daily physical activity among adolescents is believed to be one of the main reasons for the increasing prevalence of overweight and obesity, and of obesity related diseases [10]. The Norwegian Institute of Public Health [14] recommends that children and adolescents should participate in varied physical activities in at least 60 minutes per day, but a recent Norwegian study showed that only 54 % of 15 year old boys and 50 % of 15 year old girls met these recommendations [7]. Concurrently, time spent in sedentary lifestyle leisure time activities, like watching TV and playing computer games, increased among the same population. This tendency is also reported elsewhere [15].

In order to classify children and adolescents as underweight, normal weight, overweight or obese, standardized classifications of BMI based on age and gender has been developed and later referred to as the International Obesity Task Force (IOTF) cut-off points [16]. A study by Barba and colleagues [17] indicates that the IOTF criteria are sufficiently accurate to characterize individuals in terms of blood pressure (BP), among other physical mechanisms and conditions. They found that high BP is unlikely to occur in children falling into the “normal weight" IOTF category, and that this is a relevant outcome for recommending the use of IOTF classifications in future epidemiological settings.

Until recently, elevated BP and hypertension was considered a rare condition in young people. However, this seems to have become an increasingly larger health problem in adolescence concurrent to the increase in inactivity, overweight and obesity [18-20]. Engeland and colleagues [21], suggest that high BMI in adolescence tends to persist into adulthood, and it may also be predictive of adult overweight, obesity and associated diseases like cardiovascular diseases and metabolic syndrome. This is also reported elsewhere [22]. Additionally, Falkner and colleagues [23] showed that elevated BP may be predictive of future hypertension already in adolescence, and that preventive interventions like lifestyle changes including increased levels of physical activity, are highly needed. Other studies have shown that childhood BP and increase in BMI were consistently the two most powerful predictors of adult BP across all ages and both genders [24]. Additionally, it is suggested that physical activity patterns have a tendency to track from childhood to adulthood [13]. Thus, the need for early prevention strategies in childhood and adolescence is increasing.

Numerous studies [15, 19, 25] have suggested that increased regular physical activity can decrease the risk of elevated BP in overweight adolescents, both directly through physiological changes, and indirectly through the control of body weight. Torrance and colleagues [10] tried to explore if physical activity could have a potential role as a countermeasure against the development of high BP in an overweight pediatric population. Their results showed that 40 minutes of moderate to vigorous aerobic-based physical activity 3-5 days a week is required to reduce BP in obese children through improvements in vascular function. However, more knowledge is still needed on this issue. It appears that the evaluation of how physical activity can control changes in BP in overweight adolescents over time is challenging. First of all, there is currently little evidence describing the potential protective effect of physical activity in adolescents. Secondly, an important question, for further studies, is whether or not one should assess factors like diet in order to examine the effect of physical activity and BMI on BP. Fagard [26] conducted a study on adults on in order to evaluate the effect of exercise and diet on BP, and the results showed that exercise appeared to be less effective than diet in lowering BP, and that the effect of exercise was found to be more pronounced in hypertensive persons than in those who are normotensive.

Only few studies have had an appropriate design to address the long term effects of physical activity and BMI on BP in adolescents [15, 19, 27]. Thus, the purpose of this longitudinal study of Norwegian adolescents was to examine the independent and combined effects of physical activity and changes in measures of body mass on long-term changes in blood pressure. More specifically, we would assess if a high level of physical activity could compensate for the potentially adverse effects of increased body mass on blood pressure.

Methods

Study population

The Nord-Trøndelag Health Study (the HUNT Study) is one of the largest health studies ever performed. The HUNT Study has been carried out in Nord-Trøndelag County, Norway. Up to present, three cross-sectional waves have been conducted; HUNT 1 (1984-86), HUNT 2 (1995-97) and HUNT 3 (2006-08). All men and women aged 20 years or older receding in the county of Nord-Trøndelag at the different time periods were invited to participate in the studies. At HUNT 2 and HUNT 3, a youth part (the Young-HUNT Study) was also included, inviting all adolescents between 13 and 19 years. The population of Nord-Trøndelag is considered to be fairly representative because it reflects the total Norwegian population in most respects [28].

This study is a prospective longitudinal study that is based on data on those who participated on the first Young-HUNT Study, also called Young-HUNT 1 (1995-1997), and who also participated at HUNT 3 in 2006-2008. This provides a unique opportunity to analyze changes in different variables in the same population over a period of 11 years.

A total of 9917 adolescents were invited to participate in Young-HUNT 1, and 8950 (91%) of these accepted the invitation and completed a self-administered questionnaire that provides information about physical activity, life style habits, and health. Additionally, 8408 (85%) chose to participate in a clinical examination that included measurements on height, weight, waist and hip circumference, and blood pressure, performed by specially trained nurses [29].

Subsequently, 1920 of those who participated in Young-HUNT 1 also chose to participate at the HUNT 3 study 11 years later, in 2006-2008. We excluded 106 (5%) of these adolescents due to incomplete data on blood pressure from either of the two studies (52 males and 54 females). The remaining 1814 adolescents comprise the study population in this study.

Outcome measure – blood pressure

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) in Young-HUNT 1 was measured manually by trained nurses. The adolescents were sitting comfortably in a chair during the measurements. Their upper arm circumference was measured to the closest centimeter. A small cuff was used if the circumference was 24 cm or less. If it was between 25 cm and 34 cm, a medium cuff was used. A large cuff was used for those who had a circumference of 35 cm or more. The adolescents rested for two minutes before the first measurement, which was done by using an automatic oscillometric, upon inflation technique (Criticare 507 N monitor, Criticare System Inc., Waukesha, Wisconsin, USA) [30]. The second and third measurements were done with one-minute intervals, and we used the mean value of the last two measurements of SBP and DBP in the analyses.

BP in HUNT3 was also measured by using an automatic oscillometer, but with a different monitor (Dinamap 845XT Critikon). Unfortunately, some of the participant in HUNT 3 (n=170 missing on the third measure of SBP, n=168 missing on the third measure of DBP) had their BP measured twice instead of three times. Consequently, we used the second measure in the analyses instead of the mean value of the second and third measures [31].

Study variables

Height and weight was measured by trained nurses, and internally standardized meter measures and weight scales were used. The participant wore light clothes like T-shirts and trousers/shorts, and without shoes. Height was measured to the nearest 1.0 cm, and weight to the nearest 0.5 kg. BMI was calculated as kg/m^2, and in order to classify the subjects in Young-HUNT 1, we used BMI cut-off points, developed and described in detail by Cole and colleagues [16]. They were developed after recommendations from an International Obesity Task Force (IOTF) Working Group [32]. These IOTF Reference cut-off points are supposed to reflect the health-related BMI cut-off points for adults, defined by WHO [3]; underweight $<18.5\ kg/m^2$, normal weight $18.8\text{-}24.9\ kg/m^2$, overweight $25.0\text{-}29.9\ kg/m^2$, and obese $\geq 30\ kg/m^2$.

The subjects in this study were classified into these four BMI categories based on BMI in both Young-HUNT 1 and HUNT 3. To identify the changes in BMI category between the surveys, we subtracted the BMI category in HUNT 3 from the BMI category in Young-HUNT 1 for each subject. This resulted in a new variable called “Changes between BMI categories”, with values from -1 to 2. If the subjects had decreased their BMI with one category, they were categorized with a “Decrease” in BMI. Those who had increased their BMI with one category were categorized with “Moderate increase”, and those who had increased their BMI with two categories were categorized with “High increase”.

Waist circumference (WC) and hip circumference (HC) were measured in both Young-HUNT 1 and HUNT 3. The measures were done using a steel band, and both circumferences were measured to the nearest 1.0 cm with the participant standing with their arms hanging relaxed. The waist circumference was measured horizontally at the height of the umbilicus, and the hip circumference was measured likewise at the thickest part of the hip [29]. We calculated waist-hip ratio (WHR) as HC/WC. Changes in BMI, WC, HC and WHR were calculated as the difference between values from HUNT 3 and the values from Young-HUNT 1. All measures of changes in body mass were classified according to the level of change and grouped into five categories: decrease, stable, some increase, moderate increase, and high increase.

At baseline, the subjects were asked to indicate the amount of physical activity that they usually engage in during one week (Appendix 1). The first question was “Not during the average school day: How many days a week do you play sports or exercise to the point where you breathe heavily and/or sweat?” The response alternatives were “every day”, “4-6 days a week”, “2-3 days a week”, “1 day a week”, “not every week, but at least one day every two weeks”, “not every 14th day, but at least once a month”, “less than once a month” or “never”. The next question was “Not during the average school day: How many hours a week do you play sports or exercise to the point where you breathe heavily and/or sweat?” The response alternatives were “none”, “about half an hour”, “about 1 hour”, “about 2-3 hours”, “about 4-6 hours” or “7 hours or more”. For the purpose of this thesis, we calculated a physical activity summary score by multiplying each individual response option on these two questions after recoding the variable “days per week” (“every day” were defined as 7, “4-6 day a week” as 5, “2-3 days a week” as 2.5, “once a week” as 1, and “not every week, but at least one day every two weeks” were defined as 0.5. The last three response options got the value 0. The subjects were then classified into three equal groups (thirds) based on the age and sex specific distribution of score values; inactive/ low PA, moderate PA and high PA – resulting in a new variable called “Physical activity score” (PAS).

Ethics

All participants signed a written consent upon participation in the study. For adolescents who were under the age of 16, their parents had to sign as well. The study has been approved by the Regional Committee for Medical Research Ethics.

Statistical analyses

The characteristics of the study population were analyzed in a descriptive analysis, and presented as frequencies and means with standard deviations (SD).

We calculated the mean change in SBP and DBP from Young-HUNT 1 to HUNT 3 with 95% confidence interval (CI) within each category of BMI, weight, WC, HC, WHR and PAS. The categories were defined by the size of the change from Young-HUNT 1 to HUNT 3.

We used a general linear model to examine the crude differences in mean change in SBP and DBP within each category. Additionally, we calculated adjusted differences in order to evaluate if smoking (daily, sometimes, previous sometimes, previous daily, not smoking), level of PAS (inactive or low PAS, moderate PAS, high PAS), age at baseline (continuous) could have a potential confounding effect on the associations. Trend tests across categories of PAS and body mass variables were conducted by treating the categories as an ordinal variable in the regression model.

A multivariable analysis was conducted in order to examine the combined effect of PA level at baseline and changes between BMI categories from Young-HUNT 1 to HUNT 3, and their combined effect on the mean change in SBP and DBP. We divided the subjects into12 categories based on the combination of three categories of baseline PAS and the four categories of change in BMI classification from Young-HUNT 1 to HUNT 3. Additionally, mean SBP and DBP at HUNT 3 was calculated for each of these groups.

All statistical tests were two-sided, and all analyses were conducted using SPSS 15.0 for Windows (© SPSS Inc., 1989-2006).

Results

Baseline characteristics

At baseline, 39.9% of the females and 38.2% of the males reported no or little PAS. Also the percentages of those who reported moderate or high level of PAS were quite similar between males and females (Table 1). For body mass, defined by BMI, 14.4 % of the females and 13.0 % of the males were overweight, and 1.5 % of the females and 3.1 % of the males were categorized as obese (Table 1).

Moreover, 19.3% of the girls and 18.5% of the boys smoked daily or occasionally at baseline, whereas 33.6% of the girls and 31.3% of the boys reported that they were not smoking at present, or that they had previously smoked daily or occasionally. However, 47.1% of the females and 50.2% of the males did not answer the question about smoking (Table 1).

For boys, the mean baseline SBP and DBP was 125.0 mm Hg (SD 13.2) and 64.7 mm Hg (SD 8.2), respectively, and in girls it was 119.3 mm Hg (D 10.3) and 63.4 mm Hg (SD 7.9). The mean SBT in females had declined by 4 mm Hg (SD 11.8) from Young-HUNT 1 to HUNT 3, while it had increased by 2.3 mm Hg (SD 13.2) among males. Mean DBP had increased in both males and females; 3.5 mm Hg (SD 9.7) and 1.6 mm Hg (SD 9.2), respectively. Overall, there was an increase in all of the body mass variables among both sexes from Young-HUNT 1 to HUNT 3.

Table 1: Baseline characteristics of the study population.

Variables	Females	Males
No. of participants	1091	829
No. of cases excluded[a]	54	52
Inactive/low level of PAS (%)	39.9	38.2
Moderate level of PAS (%)	22.3	18.3
High level of PAS (%)	37.8	43.5
Smoking status (%)[b]	19.4	18.5
BMI[c] Underweight (%)	5.2	6.4
BMI[c] Normal weight (%)	78.9	77.5
BMI[c] Overweight (%)	14.4	13.0
BMI[c] Obese (%)	1.5	3.1

[a]Cases excluded due to missing data on mean systolic and diastolic blood pressure in both Yong-HUNT 1 and HUNT3.
[b]33.6 % of the girls did not smoke, 47.1 % did not answer. 31.3 % of the boys did not smoke, 50.2 % did not answer.
[c]Body mass index categories defined by IOTF classifications [16].
Abbreviations: PAS=physical activity score.

Table 2: Selected characteristics[a] of the study population

	Young - HUNT 1 (1995-1997)		HUNT 3 (2006-2008)		Difference	
	Girls	Boys	Women	Men	Women	Men
Age, years	15.9 (1.8)	15.9 (1.8)	27.2 (1.9)	27.2 (1.9)	11.2 (0.5)	11.2 (0.5)
Systolic blood pressure, mmHg	119.3 (10.3)	125.0 (13.2)	115.3 (10.9)	127.5 (11.4)	-4.0 (11.8)	2.3 (13.2)
Diastolic blood pressure, mmHg	63.4 (7.9)	64.7 (8.2)	65.0 (8.3)	68.3 (9.0)	1.6 (9.2)	3.5 (9.7)
Height, cm	165.2 (6.5)	173.6 (9.5)	166.9 (6.0)	180.0 (6.4)	1.6 (3.0)	6.5 (8.0)
Weight, kg	58.6 (9.8)	63.9 (13.4)	70.4 (13.8)	84.8 (14.7)	11.8 (10.4)	20.8 (11.9)
Body mass index (kg/m^2)	21.4 (3.2)	21.0 (3.2)	25.3 (4.8)	26.2 (4.3)	3.9 (3.6)	5.1 (3.0)
Waist circumference	70.3 (7.5)	75.4 (8.4)	85.8 (13.0)	91.5 (11.4)	15.5 (11.1)	16.0 (9.2)
Hip circumference	93.5 (7.5)	93.7 (7.9)	102.3 (9.4)	103.3 (7.6)	8.8 (8.3)	9.5 (7.4)
Waist-hip ratio	0.7 (0.05)	0.8 (0.05)	0.8 (0.08)	0.9 (0.06)	0.08 (0.07)	0.08 (0.06)

[a]Mean values with standard deviation (SD) in parentheses.

Body mass variables and changes in mean systolic and diastolic blood pressure

The associations between body mass variables and the changes in mean SBP and DBP are presented in Table 3a and 3b.

Males, who had a decline in either of the body mass variables except from WC and HC, tended to have a lower change in mean SBP and DBP, compared to the reference category of those who were stable. On the other hand, we found that an increase in either of the body mass variables resulted generally in a larger change in mean SBP and DBP. The change in mean SBP was highest among males who had the highest increase in weight (≥25 kg), with a 10 mm Hg (95% CI, 5.7-14.2) higher SBP, compared to the reference category. An increase in BMI units was also statistically significantly associated with a larger change in mean SBP and DBP. Males with a high increase in BMI units had a 8.4 mm Hg (95% CI, 4.0-12.8) higher change in mean SBP compared to those who were stable, and a 4.9 mm Hg (95% CI, 1.4-8.4) higher change in mean DBP (P-trend = <0.001).

Among females, we found a similar statistically significant association between a high increase in BMI and larger change in mean SBP (5.2 mm Hg (95% CI, 2.2-8.2)) and DBP (2.6 mm Hg (95% CI, 0.2-5.0)), compared to those who had a stable BMI. A high increase in weight resulted in a 6.2 mm Hg (95% CI, 3.6-8.7) higher change in SBP compared to those with a stable weight. WC, HC, and WHR seemed to have a weak association with changes in DBP. On the other hand, we found that an increase in WC and HC showed a statistically significantly higher change in mean SBP (P-trend = 0.005 and <0.001, respectively). Similar to the results among males, the results from our analyses of females showed that a decrease in any of the body mass variables, except from WHR, was associated with a lower change in SBP. In the analysis of DBP, a similar effect was only observed for a decrease in weight and BMI.

Table 3a: The effect of changes in different anthropometrical measures on mean change in systolic and diastolic blood pressure among males

		SBP, mmHg					DBP, mmHg				
Variables	N	Mean change	Crude Diff.	Adjusted[a] Diff.	95% CI	P. trend[b]	Mean change	Crude Diff.	Adjusted[a] Diff.	95% CI	P. trend[b]
Males											
Change in weight (kg)											
Decrease < -5.0 kg	4	-14.1	-6.9	-7,5	-19.5 - 4.5		-5.1	-4.8	-5.1	-14.6 - 4.5	
Stable +/- 5.0 kg	41	-7.2	0.0	0.0	Reference		-0.4	0.0	0.0	Reference	
Some increase 5.0-14.9 kg	216	-3.6	3.5	2.2	-1.8 - 6.1		0.2	0.6	0.3	-2.8 - 3.5	
Moderate increase 15.0-24.9 kg	264	1.2	8.3	4.9	0.9 - 8.9		3.1	3.5	3.0	-0.2 - 6.2	
High increase ≥25 kg	252	8.5	15.7	10.0	5.7 - 14.2	<0.001	4.7	5.1	4.5	1.1 - 7.9	<0.001
Change in WC (cm)											
Decrease < -5.0 cm	7	-0.4	4.3	2.4	-6.9 - 11.6		-0.9	-1.7	-2.2	-9.5 - 5.0	
Stable +/- 5.0 cm	62	-4.7	0.0	0.0	Reference		0.9	0.0	0.0	Reference	
Some increase 5.0-9.9 cm	108	-1.8	2.9	2.5	-1.2 - 6.2		0.6	-0.2	-0.2	-3.2 - 2.7	
Moderate increase 10.0-19.9 cm	343	1.4	6.1	3.3	0.1 - 6.5		1.9	1.0	0.5	-2.1 - 3-0	
High increase ≥ 20.0 cm	250	5.4	10.2	6.4	3.1 - 9.8	<0.001	5.0	4.1	3.3	0.7 - 6.0	<0.001
Change in HC (cm)											
Decrease < -5.0 cm	16	-8.9	-5.0	-5.7	-11.8 - 0.3		1.5	0.4	0.1	-4.8 - 4.9	
Stable +/- 5.0 cm	167	-3.9	0.0	0.0	Reference		1.1	0.0	0.0	Reference	
Some increase 5.0-9.9 cm	197	-1.2	2.8	1.2	-1.2 - 3.7		1.2	0.1	-0.4	-2.4 - 1.5	
Moderate increase 10.0-19.9 cm	326	5.3	9.3	5.0	2.6 - 7.5		3.6	2.5	1.4	-0.6 - 3.3	
High increase ≥ 20.0 cm	64	9.9	13.8	8.1	4.5 - 11.8	<0.001	5.9	4.7	3.4	0.5 - 6.3	0.05
Change in WHR[c]											
Decrease < -0.05	15	3.7	2.0	-0.4	-6.7 - 5.8		2.3	0.1	-0.2	-5.1 - 4.7	
Stable +/- 0.05	241	1.6	0.0	0.0	Reference		1.5	0.0	0.0	Reference	
Some increase 0.05-0.09	226	1.1	-0.5	-0.1	-2.2 - 2.1		2.6	1.1	1.2	-0.5 - 2.9	
Moderate increase 0.10-0.19	267	2.3	0.7	1.6	-0.5 - 3.7		3.4	1.8	2.1	0.5 - 3.7	
High increase ≥ 0.20	21	2.4	0.8	0.8	-4.6 - 6.1	0.14	5.7	4.1	3.8	-0.5 - 8.0	0.005
Change in BMI (kg/m^2)											
Decrease < -2.0 kg/m^2	3	-6.0	-1.2	-2.9	-16.5 - 10.7		-1.2	-1.9	-2.6	-13.3 - 8.2	
Stable +/- 2.0 kg/m^2	91	-4.8	0.0	0.0	Reference		0.8	0.0	0.0	Reference	
Some increase 2.0-5.9 kg/m^2	436	0.5	5.3	2.6	-0.2 - 5.3		1.6	0.8	0.2	-1.9 - 2.3	
Moderate increase 6.0-9.9 kg/m^2	205	5.7	10.6	6.4	3.4 - 9.4		4.7	3.9	3.0	0.6 - 5.4	
High increase ≥ 10.0 kg/m^2	42	9.0	13.9	8.4	4.0 - 12.8	<0.001	6.8	6.0	4.9	1.4 - 8.4	<0.001

[a] Adjusted for age (continuous), physical activity (inactive, low PA, moderate PA, high Pa, unknown) and smoking status (daily, occasionally, previous occasionally, previous daily, not smoking, unknown).
[b]P-value from linear trend test when exposure categories were treated as an ordinal variable in a generalized linear model.
[c]WHR is calculated as hip circumference/waist circumference.
Abbreviations: SBP = systolic blood pressure, DBP= diastolic blood pressure, WC = waist circumference, HC = hip circumference, WHR = waist-hip Ratio, BMI = body mass index.

Table 3b: The effect of changes in different anthropometrical measures on mean change in systolic and diastolic blood pressure in females

		SBP, mmHg					DBP, mmHg				
Variables	N	Mean change	Crude Diff.	Adjusted Diff.[a]	95% CI	P. trend[b]	Mean change	Crude Diff.	Adjusted Diff.[a]	95% CI	P. trend[b]
Females											
Change in weight (kg)											
Decrease < -5.0 kg	30	-12.3	-3.8	-4.3	-8.5, -0.1		-2.2	-2.5	-2.6	-5.9 - 0.8	
Stable +/- 5.0 kg	239	-8.5	0.0	0.0	Reference		0.3	0.0	0.0	Reference	
Some increase 5.0-14.9 kg	420	-4.4	4.0	3.5	1.7 - 5.2		1.3	1.0	0.5	-0.9 - 1.9	
Moderate increase 15.0-24.9 kg	236	-1.1	7.4	6.4	4.4 - 8.5		1.7	1.5	0.7	-0.9 - 2.3	
High increase ≥25 kg	108	-1.3	7.2	6.2	3.6 - 8.7	<0.001	3.8	3.6	2.8	0.7 - 4.8	0.003
Change in WC (cm)											
Decrease < -5.0 cm	14	-14.0	-8.4	-8.4	-14.5, -2.2		0.2	-2.5	-2.6	-7.4 - 2.1	
Stable +/- 5.0 cm	136	-5.6	0.0	0.0	Reference		2.7	0.0	0.0	Reference	
Some increase 5.0-9.9 cm	157	-4.2	1.4	1.2	-1.4 - 3.7		0.9	-1.8	-2.1	-4.1, -0.1	
Moderate increase 10.0-19.9 cm	357	-5.2	0.4	0.1	-2.1 - 2.3		0.8	-1.9	-2.0	-3.8 , -0.3	
High increase ≥ 20.0 cm	320	-2.6	2.9	2.4	0.2 - 4.7	0.005	2.2	-0.5	-0.8	-2.6 - 1.0	0.94
Change in HC (cm)											
Decrease < -5.0 cm	42	-10.7	-4.1	-3.8	-7.4, -0.2		1.1	0.2	0.4	-2.5 - 3.2	
Stable +/- 5.0 cm	247	-6.7	0.0	0.0	Reference		0.8	0.0	0.0	Reference	
Some increase 5.0-9.9 cm	255	-4.9	1.7	1.6	-0.4 - 3.5		1.1	0.3	0.3	-1.3 - 1.8	
Moderate increase 10.0-19.9 cm	353	-2.5	4.1	3.7	1.9 - 5.5		1.9	1.0	0.9	-0.6 - 2.3	
High increase ≥ 20.0 cm	91	-0.9	5.7	4.6	1.9 - 7.3	<0.001	3.3	2.5	2.1	-0.1 - 4.2	0.10
Change in WHR[b]											
Decrease < -0.05	41	-2.7	1.9	1.3	-2.4 - 4.9		3.0	0.9	0.5	-2.3 - 3.4	
Stable +/- 0.05	295	-4.6	0.0	0.0	Reference		2.1	0.0	0.0	Reference	
Some increase 0.05-0.09	238	-5.1	-0.6	-0.5	-2.4 - 1.4		0.6	-1.6	-1.7	-3.2, -0.2	
Moderate increase 0.10-0.19	341	-3.5	1.0	1.2	-0.5 - 2.9		1.6	-0.1	-0.5	-1.8 - 0.9	
High increase ≥ 0.20	69	-6.3	-1.8	-1.8	-4.7 - 1.1	0.92	0.9	-1.2	-1.3	-3.5 - 1.0	0.28
Change in BMI (kg/m^2)											
Decrease < -2.0 kg/m^2	26	-13.7	-6.1	-6.1	-10.5, -1.7		-2.5	-3.0	-2.9	-6.4 - 0.6	
Stable +/- 2.0 kg/m^2	298	-7.6	0.0	0.0	Reference		0.5	0.0	0.0	Reference	
Some increase 2.0-5.9 kg/m^2	478	-3.4	4.2	3.5	1.9 - 5.1		1.4	1.0	0.4	-0.8 - 1.7	
Moderate increase 6.0-9.9 kg/m^2	168	-1.7	5.9	5.0	2.9 - 7.2		2.4	1.9	1.4	-0.2 - 3.1	
High increase ≥ 10.0 kg/m^2	63	-1.6	6.0	5.2	2.2 - 8.2	<0.001	3.5	3.1	2.6	0.2 - 5.0	0.003

[a] Adjusted for age (continuous), physical activity (inactive, low PA, moderate PA, high Pa, unknown) and smoking status (daily, occasionally, previous occasionally, previous daily, not smoking, unknown).
[b]P-value from linear trend test when exposure categories were treated as an ordinal variable in a generalized linear model.
[c]WHR is calculated as hip circumference/waist circumference.
Abbreviations: SBP = systolic blood pressure, DBP= diastolic blood pressure, WC = waist circumference, HC = hip circumference, WHR = waist-hip Ratio, BMI = body mass index.

Body mass index categories and changes in mean systolic and diastolic blood pressure

The results from our analyses of baseline BMI categories and changes BMI categories from Young-HUNT 1 to HUNT 3, and their independent associations with mean SBP and DBP, are presented in Table 4.

The most consistent results from these analyses were the statistically significant associations between changes in BMI categories and changes in mean SBP among both males and females

(P-trend = ≤0.001 for both sexes). The associations with DBP were also clear, but somewhat weaker (P-trend = 0.001 for males and 0.02 for females). Although not statistically significant, males, who decreased their BMI-category had a 3.7 mm Hg (95% CI, -10.6-3.1) lower change in mean SBP, and a 0.8 mm Hg (95% CI, -6.2-4.7) lower change in mean DBP, compared to those who were stable. A high increase in BMI resulted in a 6.8 mm Hg (95% CI, 3.5-10.1) higher change in SBP, and a 5.3 mm Hg (95% CI, 2.7-7.8) higher change in DBP, compared to those who were stable. Females who had increased their BMI classification with two categories had a 3.3 mm Hg (95% CI, 0.5-6.1) larger change in mean SBP compared to those with a stable BMI. A one category decrease in BMI classification was associated with a smaller change in mean SBP (-6.8 mm Hg; 95% CI, -10.8- -2.8) compared to those who were stable.

Moreover, the results show an inverse association between baseline BMI and change in mean SBP among males (P-trend = 0.006). Those who were categorized as obese at baseline had a 4.6 (95% CI, -9.5-0.3) mm Hg lower change in SBP than those with a normal weight. For the remainder of the analysis of baseline BMI, we found no clear trend in the data.

Table 4: The effect of baseline body mass index categories and changes in body mass index categories on mean change in systolic and diastolic blood pressure

		SBP, mm Hg					DBP, mm Hg				
Variable	N	Mean change	Crude Diff.	Adjusted Diff.[c]	95% CI	P. trend[d]	Mean change	Crude Diff.	Adjusted Diff.[c]	95% CI	P. trend[d]
Males											
Baseline BMI categories[a]											
Underweight	50	5.4	3.5	2.0	-1.4 - 5.5		3.3	0.7	0.4	-2.3 - 3.1	
Normal weight	602	1.9	0.0	0.0	Reference		2.6	0.0	0.0	Reference	
Overweight	101	-0.3	-2.2	-2.1	-4.6 - 0.5		2.9	0.3	0.3	-1.7 - 2.3	
Obese	24	-2.8	-4.7	-4.6	-9.5 - 0.3	0.006	0.5	-2.0	-2.0	-5.9 - 1.6	0.54
Changes between BMI categories[b]											
-1 (Decrease)	12	-1.7	-1.9	-3.7	-10.6 - 3.1		1.4	-0.3	-0.8	-6.2 - 4.7	
0 (Stable)	362	0.2	0.0	0.0	Reference		1.7	0.0	0.0	Reference	
1 (Moderate increase)	344	2.6	2.5	2.6	0.8 - 4.3		2.8	1.1	1.0	-0.4 - 2.4	
2 (High increase)	59	6.5	6.3	6.8	3.5 - 10.1	<0.001	6.9	5.1	5.3	2.7 - 7.8	0.001
Females											
Baseline BMI categories[a]											
Underweight	54	-5.1	-0.9	-2.3	-5.4 - 0.9		-0.4	-1.9	-2.5	-4.9 - 0.1	
Normal weight	818	-4.2	0.0	0.0	Reference		1.5	0.0	0.0	Reference	
Overweight	149	-4.9	-0.7	-0.9	-2.8 - 1.1		1.4	-0.1	-0.1	-1.6 - 1.5	
Obese	16	-10.0	-5.8	-5.8	-11.3, -0.2	0.40	-4.4	-5.9	-6.2	-10.5, - 1.9	0.77
Changes between BMI categories[b]											
-1 (Decrease)	31	-11.6	-6.2	-6.8	-10.8, -2.8		-0.4	-1.3	-1.6	-5.0 - 1.6	
0 (Stable)	568	-5.5	0.0	0.0	Reference		1.0	0.0	0.0	Reference	
1 (Moderate increase)	368	-2.8	2.6	2.5	1.0 - 3.9		1.8	0.8	0.7	-0.4 - 1.9	
2 (High increase)	66	-2.3	3.2	3.3	0.5 - 6.1	<0.001	2.7	1.7	1.9	-0.3 - 4.1	0.02

[a] BMI categories defined by IOTF classification; under weight, normal weight, overweight and obese.
[b]BMI category in HUNT 3 - BMI category in Young-HUNT 1. Crossing between categories of BMI classification.
[c] Adjusted for age (continuous), physical activity (inactive, low PA, moderate PA, high Pa, unknown) and smoking status (daily, occasionally, previous occasionally, previous daily, not smoking, unknown).
[d]P-value from linear trend test when exposure categories were treated as an ordinal variable in a generalized linear model.
Abbreviations: SBP = systolic blood pressure, DBP = diastolic blood pressure, BMI = body mass index.

Physical activity score and changes in mean systolic and diastolic blood pressure

The associations between PAS at baseline and changes in mean blood pressure were examined, and the results are presented in Table 5.

The results indicate no clear association between PAS and changes in mean SBP (P-trend = 0.86 for males and 0.46 for females) or changes in DBP (P-trend = 0.60 for males and 0.10 for females).

Table 5: The effect of physical activity score at baseline (Young-HUNT 1) on change in mean systolic and diastolic blood pressure

	SBP, mm Hg						DBP, mmHg				
Variables	N	Mean change	Crude Diff.	Adjusted[a] Diff.	95% CI	P. trend[b]	Mean change	Crude Diff.	Adjusted[a] Diff.	95% CI	P. trend[b]
Males											
PAS											
Inactive	293	1.3	0.0	0.0	Reference		2.5	0.0	0.0	Reference	
Moderate	140	3.0	1.7	0.6	-1.8 - 3.1		2.7	0.2	-0.2	-2.5 - 2.2	
High	334	1.5	0.2	0.2	-1.7 - 2.1	0.86	2.7	0.2	0.2	-2.5 - 2.0	0.60
Females											
PAS											
Inactive	409	-4.3	0.0	0.0	Reference		0.9	0.0	0.0	Reference	
Moderate	229	-4.6	-0.3	-0.7	-2.5 - 1.1		1.2	0.3	0.3	-1.2 - 1.7	
High	387	-4.4	-0.2	-0.6	-2.2 - 1.0	0.46	2.0	1.1	1.0	-0.2 - 2.3	0.10

[a] Adjusted for age (continuous) and smoking status (daily, sometimes, previous sometimes, previous daily, not smoking, unknown).
[b]P-value from linear trend test when exposure categories were treated as an ordinal variable in a generalized linear model.
Abbreviations: SBP = systolic blood pressure, DBP = diastolic blood pressure, PAS = physical activity score.

The combined effect of physical activity score and change in body mass index on changes in mean systolic and diastolic blood pressure

The reference category in this analysis represents the anticipated most beneficial development regarding a stable and healthy BP; subjects who reported a high level of PAS at baseline in combination with a stable BMI. All the results are presented in Table 6.

Overall, the results of this analysis indicate that the largest effect on change in blood pressure is mediated by change in weight, and that physical activity is of marginal importance. Compared to the reference category of highly active subjects with a stable BMI, we found that those who were stable in BMI but inactive had almost similar change in SBP (0.5mm Hg (95% CI -2.2 – 3.3) in males and -0.5 mm Hg (95% CI, -2.7 – 1.7) in females) and DBP (0.3 mm Hg (95% CI, -1.8 – 2.4) in males and -1.2 mm Hg (95% CI, -3.8 – 0.1) in females). On the other hand, those who had increased their BMI classification with two categories had overall a higher change in both SBP and DBP irrespective of their activity level. However, these associations were stronger and more consistent among males that among females. For instance, we found that males who increased their BMI classification with two categories had a 6.7 (95% CI, 1.9 – 11.6), 9.3 (95% CI, 1.3 – 17.3), and 6.8 (95% CI, 1.6 – 12.1) mm Hg higher change in SBP than the reference group if they were inactive, moderately active, or highly active, respectively. The corresponding results for females were 4.2 (95% CI, -0.1 – 8.4), 2.7 (95% CI, -3.0 – 8.4), and 2.2 (95% CI, -2.6 – 7.0). Thus, there was no evidence that a high increase in BMI resulted in a larger change in BP among inactive subjects compared to highly active subjects.

Table 6: The combined effect of physical activity score at baseline (Young-HUNT1), and changes in body mass index categories from Young-HUNT 1 to HUNT 3 on systolic and diastolic blood pressure.

		SBP, mm Hg				DBP, mm Hg			
Variables	N	Mean Change	Crude Diff.	Adjusted[a] Diff.	95% CI	Mean Change	Crude Diff.	Adjusted[a] Diff.	95% CI
Males									
Inactive									
Decrease in BMI category	5	-8.6	-8.2	-8.6	-19.1 - 1.9	1.4	-0.4	-0.7	-9.0 - 7.6
Stable BMI category	121	0.1	0.6	0.5	-2.2 - 3.3	1.5	-0.3	-0.5	-2.7 - 1.7
Moderate increase in BMI categories	140	1.9	2.3	2.4	-0.3 - 5.1	2.4	0.6	0.4	-1.7 - 2.5
High increase in BMI categories	27	5.4	5.8	6.7	1.9 - 11.6	7.8	6.0	6.1	2.2 - 9.9
Moderate PAS									
Decrease in BMI categories	4	7.6	8.1	2.0	-9.8 - 13.7	5.8	4.0	1.9	-7.3 - 11.2
Stable BMI category	68	1.4	1.8	1.2	-2.1 - 4.5	1.9	0.1	-0.1	-2.8 - 2.5
Moderate increase in BMI categories	59	3.4	3.8	2.8	-0.7 - 6.3	3.3	1.6	1.0	-1.8 - 3.8
High increase in BMI categories	9	9.9	10.3	9.3	1.3 - 17.3	3.1	1.3	1.0	-5.3 - 7.3
High PAS									
Decrease in BMI categories	3	-2.7	-2.2	-1.4	-14.9 - 12.1	-4.3	-6.1	-5.5	-16.2 - 5.1
Stable BMI category (reference)	169	-0.4	0.0	0.0	Reference	1.8	0.0	0.0	Reference
Moderate increase in BMI categories	140	3.1	3.5	3.6	0.9 - 6.2	3.2	1.4	1.3	-0.8 - 3.4
High increase in BMI categories	22	6.5	6.9	6.8	1.6 - 12.1	7.7	5.9	5.7	1.6 - 9.8
Females									
Inactive									
Decrease in BMI categories	17	-11.4	-6.3	-6.3	-11.8, -0.9	-1.0	-3.0	-3.1	-7.4 - 1.2
Stable BMI category	200	-5.2	-0.1	0.3	-1.8 - 2.4	0.7	-1.2	-1.2	-2.8 - 0.5
Moderate increase in BMI categories	161	-2.9	2.2	2.5	0.3 - 4.8	1.2	-0.8	-0.7	-2.5 - 1.1
High increase in BMI categories	29	-1.6	3.5	4.2	-0.1 - 8.4	1.5	-0.5	-0.2	-3.5 - 3.2
Moderate PAS									
Decrease in BMI categories	3	-4.3	0.8	-0.5	-13.0 - 12.0	6.3	4.4	3.8	-6.1 - 13.7
Stable BMI category	126	-6.1	-1.0	-0.8	-3.2 - 1.6	-0.1	-2.1	-1.9	-3.8, - 0.1
Moderate increase in BMI categories	85	-2.8	2.3	2.2	-0.5 - 4.9	2.1	0.2	0.2	-2.0 - 2.3
High increase in BMI categories	15	-2.5	2.6	2.7	-3.0 - 8.4	5.4	3.5	3.4	-1.1 - 7.9
High PAS									
Decrease in BMI categories	11	-13.9	-8.8	-9.4	-16.1, -2.8	-1.2	-3.2	-3.9	-9.1 - 1.4
Stable BMI category (reference)	234	-5.1	0.0	0.0	Reference	1.9	0.0	0.0	Reference
Moderate increase in BMI categories	118	-2.6	2.6	2.6	0.1 - 5.0	2.4	0.4	0.4	-1.5 - 2.4
High increase in BMI categories	22	-2.9	2.1	2.2	-2.6 - 7.0	2.4	0.5	0.5	-3.3 - 4.3

[a] Adjusted for age (continuous) and smoking status (daily, sometimes, previous sometimes, previous daily, not smoking, unknown).
Abbreviations: SBP = systolic blood pressure, DBP = diastolic blood pressure, BMI = body mass index, PAS = physical activity score.

Mean systolic and diastolic blood pressure at follow-up (HUNT 3) within groups of physical activity score and changes in body mass index

We calculated mean SBP and DBP within each group of subjects defined by baseline PAS and change in BMI category (Table 7). Males who had a high increase in BMI categories had the highest mean SBP, independent of their level of PAS at baseline. Those who reported a high level of PAS at baseline in addition to a high increase in BMI categories had the highest mean SBP and DBP. On the other hand, the general tendency was that the mean SBP within each group increased along with an increase in BMI category.

Females, who were inactive and had a high increase in BMI category, had the highest mean SBP. Additionally, a dose-response association between increase in BMI category and mean SBP was only observed for those who were inactive. We observed no large differences in DBP between categories of PAS and change in BMI.

Table 7: Mean[a] systolic and diastolic blood pressure within groups of physical activity score and changes in body mass index classifications

	Males			Females		
Variables	N	Mean SBP, mm Hg	Mean DBP, mm Hg	N	Mean SBP, mm Hg	Mean DBP, mm Hg
Inactive						
Decrease in BMI categories	5	120.5 (9.5)	64.5 (5.0)	17	111.3 (11.1)	66.2 (6.3)
Stable BMI category	121	124.6 (10.9)	66.1 (8.9)	200	113.4 (9.7)	64.7 (8.1)
Moderate increase in BMI categories	140	127.6 (11.3)	67.8 (8.8)	161	117.2 (10.6)	65.9 (7.8)
High increase in BMI categories	27	131.2 (10.4)	67.6 (10.1)	29	118.2 (10.4)	66.7 (7.2)
Moderate PAS						
Decrease in BMI categories	4	123.1 (7.3)	67.6 (6.1)	3	117.2 (14.3)	68.2 (3.5)
Stable BMI category	68	126.6 (10.5)	67.7 (8.8)	126	112.7 (10.3)	63.1 (7.9)
Moderate increase in BMI categories	59	128.8 (11.2)	67.7 (10.1)	85	118.9 (8.2)	66.3 (9.5)
High increase in BMI categories	9	130.1 (6.9)	66.5 (6.5)	15	118.0 (8.2)	67.8 (11.9)
High PAS						
Decrease in BMI categories	3	120.2 (7.8)	62.7 (9.7)	11	107.5 (11.3)	61.0 (9.1)
Stable BMI category	169	125.1 (11.1)	66.7 (8.6)	234	113.1 (8.6)	63.7 (6.3)
Moderate increase in BMI categories	140	128.3 (10.9)	67.3 (8.2)	118	116.6 (10.0)	64.5 (8.2)
High increase in BMI categories	22	131.9 (8.9)	71.5 (9.7)	22	116.3 (9.3)	66.3 (6.2)

[a]Unadjusted mean values with standard deviation (SD) in parenthesis.
Abbreviations: BMI = body mass index, PAS = physical activity score.

Discussion

In this population-based study of Norwegian adolescents, we found that an increase in measures of body mass from Young-HUNT 1 to HUNT 3 was associated with a higher change in mean SBP and DBP, compared to those who were stable, and that participants who increased their BMI category had a larger change in SBP and DBP compared to those who were stable, irrespective of their level of PAS at baseline. Similarly, mean SBP and DBP at HUNT 3 were highest among those who had the highest increase in BMI, whereas the baseline PAS level seemed to be of marginal importance

Strengths and limitations

This study has several strengths, including the longitudinal study design and the large sample size that makes chance an unlikely explanation for the observed associations. There is a high participation rate, and together with the thorough administration of the questionnaires and the clinical examinations, the possibilities of selection and information bias are reduced. Body mass variables were measured objectively by trained personal, and the analyses of different body mass variables confront the problem with using only BMI [33]. However, potential misclassification of physical activity cannot be ignored, and could potentially have distorted our results. It has been shown that adolescents may report higher level of physical activity than they actually have when the level of physical activity is self reported [13]. Additionally, we have only used data on baseline level of physical activity in this study, and changes in physical activity level could therefore not be detected. The reason for this is that the questionnaires on physical activity were different between Young-HUNT 1 and HUNT 3, and it was thus not possible to compare self reported level of PAS at baseline with the same calculation of level of physical activity in HUNT 3. Although the questions used about PA that was used in this study have been used in previous studies [12], they have not been formally validated.

The homogeneity of the study population makes confounding of ethnicity unlikely. Additionally, we have treated smoking status as a possible confounder. However, diet and other possible confounding life style related factors, which could have affected the results, have not been considered.

Despite the different BP measure-monitors used in Young-HUNT 1 and HUNT 3, it has been shown that the mean BP for 18 year old adolescents in Young-HUNT 1 (1995-97) and 19-21 year old adults, who participated in HUNT 2 in the same period, were similar. However, it should be considered that several studies have found higher SBP values among children and adolescents than adults when oscillometric methods have been used, compared with manual methods [30].

Mechanisms underlying the development of elevated blood pressure in overweight adolescents

Torrance and colleagues [10] have suggested that the root cause of high BP in overweight and obese youth is a combination of factors that raise the systemic vascular resistance. They present a figure illustrating how weight gain may contribute to the increased vascular tone in obese individuals, including: (1) activation of the sympathetic nervous system, (2) insulin resistance and (3) vascular dysfunction, which further may lead to increased heart rate, systemic vascular resistance, and eventually elevated BP. Further on, they suggest that increased physical activity may attenuate the three mechanisms underlying increased vascular tone (1, 2 and 3), and that this will prevent a rise in BP by reducing resting heart rate and systemic vascular resistance.

Association between body mass index and blood pressure

Since BMI cut-off points for children and adolescents are developed [16], we chose BMI as the body mass measure of greatest interest in this study. It has been reported that the cut-off points are sufficiently accurate in studies of the association between blood pressure and BMI, and in predictions of obesity-related diseases in adulthood [17, 34].

The associations between overweight and BP in adolescents is well documented in previous studies [2, 18, 33, 35]. Additionally, previous studies have also shown that level of BP is strongly predicted by BMI, and that a high BMI may predict a high level of BP [2, 9, 17, 19, 34]. This association is supported by the results in our study, which showed that an increase in both BMI units and BMI categories was associated with higher change in SBP and DBP among both males and females, compared to those who had a stable BMI.

On the other hand, we found that the magnitude of change within each category of change in BMI categories were not very large. Thus, it is difficult to decide whether it is a result of a natural development, or in fact a result of an increased BMI. The results also revealed that the association between BMI and SBP tended to be stronger than the association between BMI and DBP. Similar results are also supported by a study done by Sugiyama and colleagues [36], which argued that adiposity is a strong predictor of SBP in youth, independent of PA, while BMI, alone, was negatively associated with DBP. Thus, these arguments may contribute to the explanations of the stronger association between BMI and SBP found in our study, compared to the association between BMI and DBP. Anyhow, our findings support the fact that an increase in body mass indeed may have an unfavorable effect on BP in general, whether it is SBP or DBP. Being overweight or obese in adolescence may result in an early onset of elevated BP, which can also persist into adulthood and contribute to the development of hypertension or other cardiovascular diseases [21, 24].

Further on, the analysis of BMI at baseline showed that both males and females who were categorized as overweight or obese had a lower change in SBP and DBP, compared to those who were normal weight at baseline. This tendency was also present among both males and females who decreased their BMI classification with one category after the period between Young-HUNT 1 and HUNT 3. This could mean that the adolescents who were overweight and obese at baseline, or those have reduced their BMI classification by one category, have been advised to lose weight, or have suffered from a disease, and a consequence of this could have affected their change in SBP and DBP. This is supported by a previous study that found weight control to be strongly associated with a decreased risk of elevated BP and hypertension [23].

Among those who were overweight or obese at baseline, the decrease in BP could be affected by the fact that BP values, especially SBP values, tend to be higher among adolescents compared to adults, due to the BP measure methods used in Young-HUNT 1 [30]. In the analyses of change in BMI categories, it should be considered that it is difficult to tell from and to which category the adolescents have moved. This challenge is also reported elsewhere, correspondingly to the use of similar crossings between categories [37]. However, the analyses of changes in BMI categories still gives an indication of the direction and size of the change in BMI among the subjects during the period. Still, it is difficult to detect the actual cause of this tendency, although the analyses were adjusted for PAS level at baseline in order to consider a possible confounding effect of physical activity. Additionally, the level of PAS may have changed during the period between Young-HUNT 1 and HUNT 3 as well, which could also be an explanatory factor for the findings in this study.

It is often debated if BMI is an adequate measure of body mass, especially among children and adolescents, because the sensitiveness for changes in body composition is low [33]. However, the use of IOTF standardized cut-off points [16], which considers age and height, deals with these concerns, and have also been recommended in studies which’s aim is to examine a possible association with BP [17]. Additionally, the effect of other body mass variables was examined in this study as well. The results showed that an increase in any of these had a statistically significant effect on the changes in BP, and these results were fairly similar to those of changes in BMI (units, or changes in categories). Thus, the associations between BMI and BP in this study are considered trustworthy.

Association between physical activity score and blood pressure

The results from our study revealed no association between PAS and SBP, or between PAS and DBP. These findings were quite surprising, regarding previous studies, which have suggested that physical activity was inversely associated with both SBP and DBP, and that increased levels of physical activity may prevent cardiovascular diseases in adolescents [2, 10, 12, 15, 19, 23, 25, 27, 38].

More specifically, previous studies, done on adults, have been reviewed in order to examine the effect of physical activity alone on the reduction of BP, and the effect of physical activity in combination with diet and weight control [26]. The results from this review showed that physical activity was less effective than diet in lowering BP, and that the effect of diet in combination with physical activity did not seem to further reduce BP. It also showed that the effect of physical activity on BP was more pronounced in hypertensive than in normotensive individuals. On the other hand, Hu and colleagues [39] showed, in their study, that a protective effect of physical activity indeed was observed in both male and female adults. Apparently, the association between physical activity and BP is still inconclusive in adults. These uncertainties are also found in adolescents [5, 10]. Twisk [40] reported that there was only marginal evidence that physical activity could be beneficial for health in this age group, which this study also suggests. Still, Falkner and colleagues [23] suggested that increased physical activity indeed could be preventive for developing hypertension.

It is well known that a moderate to high level of physical activity has a positive effect on weight control and a strong association with a reduction in body fat and body weight [11, 41]. Additionally, studies have shown that 40 minutes of moderate to vigorous aerobic-based physical activity 3-5 days a week is required to reduce BP in obese children through improvements in vascular function [10]. Paradoxically, the results in our study showed that males who reported a moderate or high level of PAS, in addition to a high increase in BMI categories, had a higher change in SBP compared to the reference category of highly active adolescents with a stable BMI, but also compared to those who were inactive in combination with a high increase in BMI. It could be speculated that even though we found that PAS did not affect the change in BP directly, it may have an effect indirectly through body mass regulation. Torrance and colleagues [10] suggested that increased physical activity could attenuate the development of weight gain and elevated BP through reduction of undesirable vascular mechanisms. Hypothetically, the prevention of elevated BP could merely be a result of the stable weight, which again could have been a result from regularly physical activity. Then, the stable body mass would be the main preventive factor for elevated BP, and physical activity would only help to control body mass.

Overall, the challenge of body mass attenuating the association between physical activity and BP is also considered elsewhere [15]. However, the results from that study claimed that BMI did not attenuate the association between physical activity and BP at all. Thus, the strong associations between increases in body mass variables and BP, and the non-existing association between PAS and BP, that are found in this study, are highly debatable. Anyhow, the results from our study strengthen the suggestions about an association between BMI and BP. However, the effect of physical activity, or PAS in this matter, remains uncertain, but it may have had an effect indirectly through body mass regulation.

Independent of previous findings, the assessment of physical activity is often strongly debated. In this study, the amount of physical activity is self reported, and there is always an uncertainty when this method is used. Previous studies have shown that 60-70 % of children are considered sufficiently active when self-report methods are used. When more objective methods are used, like for instance an accelerometer or other methods which indicate a physical fitness level, the PA levels are significantly lower [13]. Thus, information bias about PAS may contribute to the explanation of the somewhat paradoxical findings in this study. Additionally, only baseline level of PAS has been used in this thesis and this gives no information about a possible change in level of PAS among the study population during the period between the two studies.

On the other hand, previous studies have suggested that childhood pattern of physical activity tends to persist into adulthood [13], and if this in fact is true, the results from this study are quite alarming. As much as 39.9% of the females and 38.2% of the males in our study reported little or no PAS at baseline. This high percentage reflects the world wide trend where time spent in sedentary activity is increasing rapidly among children and adolescents [3-5, 15]. And according to Torrance and colleagues [10] the consequence of low physical activity levels could be an increased prevalence of overweight and obesity, and obesity related conditions like elevated BP. As much as 14.4 % of the females and 13.0 % of the males in our study population were overweight at baseline. Thus, if physical activity in fact can protect overweight and obese adolescents from progressing elevated BP independent of other factors, like previous studies have suggested, still remains uncertain after this study, and this should be an area of future studies, perhaps with more objective measures of PA [25,26].

The combined effect of physical activity score and changes in body mass index

Maximova and colleagues [15] showed in their study that a decline in time spent in moderate-to-vigorous physical activity was inversely associated with SBP in adolescents, and that this association was not attenuated by changes in body mass. Additionally, numerous studies [13, 18, 25] have suggested that increased regular physical activity can decrease the risk of elevated BP in overweight adolescents, both directly through physiological changes, and indirectly through the control of body weight. However, these studies have only tried to predict the risk of developing elevated BP instead of examine changes in BP from one point to another. It appears that the evaluation of how physical activity can control changes in BP in overweight adolescents over time is challenging.

In this study, the effect of baseline level of PAS had no effect on changes in BP, neither independently or in combination with BMI. Thus, in order to shed new light on the association between the combined effect of PAS and changes in BMI on changes in mean BP, we calculated the mean SBP and DBP at follow-up (HUNT 3) within the categories of BMI change and PAS. This would give the opportunity to detect the mean BP level in each category instead of changes in BP. However, the results of this analysis revealed fairly the same findings as for change in BP; mean SBP and DBP was in general higher among males and females who had a high increase in BMI categories, independent of their self reported level of PAS.

Anyhow, high levels of physical activity may be a valuable intervention strategy in order to prevent increased BP among adolescents, but based on the results from this study, the effect of PAS is most likely mediated by a stable body mass.

Conclusion

An increase in body mass variables was associated with a larger change in both SBP and DBP, compared to those who had a stable body mass during the follow-up period, both in males and females, whereas subjects who decreased in body mass had a lower change in SBP and DBP. These associations were independent of baseline level of physical activity. Overall, the results indicate that the long term changes in blood pressure is largely mediated by change in body mass, and that physical activity is of marginal importance. The results of this study add to the limited literature on the long term association between BMI, physical activity and changes in BP among adolescents, and may be valuable for development and evaluation of different intervention strategies in order to prevent increases in BP among this age group.

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Appendix 1

50. Utenom skoletida: **Hvor mange <u>dager</u> i uka driver du idrett, eller mosjonerer du så mye at du blir andpusten og/eller svett?**
(Sett bare ett kryss)

- ☐ *Hver dag*
- ☐ *4-6 dager i uka*
- ☐ *2-3 dager i uka*
- ☐ *1 dag i uka*
- ☐ *Ikke hver uke, men minst en dag hver 14. dag.*
- ☐ *Ikke hver 14. dag, men minst en dag i måneden*
- ☐ *Sjeldnere enn en dag i måneden*
- ☐ *Aldri*

51. Utenom skoletida: **Tilsammen hvor mange <u>timer</u> i uka driver du idrett, eller mosjonerer du så mye at du blir andpusten og/eller svett?**
(Sett bare ett kryss)

- ☐ *Ingen*
- ☐ *Omtrent ½ time*
- ☐ *Omtrent 1 time*
- ☐ *Omtrent 2-3 timer*
- ☐ *Omtrent 4-6 timer*
- ☐ *7 timer eller mer*