

**Thesis**

**Changes in Pulse-Wave Velocity following a one-year  
Physical Activity Intervention**

submitted by

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in partial fulfillment of the requirements for the degree of

**Doktor der gesamten Heilkunde**

**(Dr. med. univ.)**

at the

**Medical University Graz**

executed at the

**Division of Physiology and Pathophysiology**

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Graz, 03.04.2025

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## **Acknowledgements**

I would like to express my sincere gratitude to my supervisors, Priv.-Doz. Mag. Dr. rer. nat. Karin Schmid-Zalaudek and Assoz. Prof. Priv.-Doz. Dr. med. Dr. med. univ. MMedSci PhD Nandu Goswami, for their patience, time, and invaluable guidance. Their expertise and support have been instrumental in shaping this work.

Furthermore, I would like to extend my appreciation to everyone who has supported me on this journey. Whether through insightful discussions, encouragement, or assistance, their contributions have been deeply meaningful.

Finally, I am profoundly grateful for the unwavering support of my family, without whom none of this would have been possible. Thank you.

## Zusammenfassung

**Hintergrund:** Die steigende Prävalenz von Übergewicht und Adipositas bei Kindern stellt ein wachsendes globales Gesundheitsproblem dar, trotz zahlreicher Bemühungen diesem Trend entgegenzuwirken. Viele Kinder und Jugendliche erfüllen nicht die Bewegungsempfehlungen der Weltgesundheitsorganisation (WHO), was mit negativen gesundheitlichen Folgen verbunden ist. Regelmäßige körperliche Aktivität wird mit einer verbesserten kardiovaskulären Gesundheit in Verbindung gebracht, dazu zählt eine Verringerung der arteriellen Steifigkeit, welche mittels der Pulswellengeschwindigkeit gemessen werden kann.

**Zielsetzung:** Diese Studie untersuchte, ob eine schulbasierte Intervention zur Förderung der körperlichen Aktivität einen positiven Einfluss auf die Pulswellengeschwindigkeit von Volksschulkindern haben kann. Die Hypothese dieser Studie war, dass der (physiologische) Anstieg der Pulswellengeschwindigkeit durch die Intervention in den Interventionsschulen geringer ausfallen würde als in der Kontrollschule.

**Methode:** Die Intervention wurde in zwei öffentlichen Volksschulen, in Graz, Österreich durchgeführt, in denen aktive Lernstrategien in den Lehrplan eingebaut wurden, um Bewegung in den täglichen Schulalltag zu integrieren. Eine dritte Schule diente als Kontrollgruppe. Zusätzlich zum regulären Lehrplan wurden verschiedene Unterrichtsinhalte bewegungsbasiert vermittelt, sodass jedes Kind die empfohlenen 45 Minuten mäßiger bis intensiver körperlicher Aktivität pro Tag erreichte. Die Pulswellengeschwindigkeit wurde zu Beginn des Schuljahres (Baseline) und am Ende des Schuljahres (Follow-up) mit dem Vicorder Gerät gemessen. Die Interventionsgruppe umfasste 102 Kinder in der IV-1 und 91 Kinder in der IV-2, während 32 Kinder die Kontrollgruppe in der CS bildeten. Insgesamt wurde die Pulswellengeschwindigkeit bei 225 Kindern gemessen (46,2% Mädchen, 53,8% Jungen; Durchschnittsalter:  $8,02 \pm 1,29$  Jahre).

**Ergebnisse:** Für diese Altersgruppe waren die Ausgangswerte der Pulswellengeschwindigkeit höher als erwartet und während der Studie zeigten Jungen höhere Werte als Mädchen. Die Ergebnisse zeigten keinen signifikanten Effekt der Intervention auf die Pulswellengeschwindigkeit in den Interventionsschulen im Vergleich zur Kontrollschule. Die durchschnittlichen Werte der Pulswellengeschwindigkeit veränderten sich von der Baseline Messung (IV-1:  $5,43 \pm 0,56$  m/s, IV-2:  $5,22 \pm 0,50$  m/s, CS:  $5,65 \pm 0,52$  m/s) zur Follow-up Messung (IV-1:  $5,96 \pm 0,61$  m/s, IV-2:  $5,67 \pm 0,59$  m/s, CS:  $5,98 \pm 0,54$  m/s). Die durchschnittliche Körpergröße änderte sich von der Baseline Messung (IV-1:  $1,36 \pm 0,11$  m, IV-2:  $1,31 \pm 0,08$  m, CS:  $1,35 \pm 0,10$  m) zur Follow-up Messung (IV-1:  $1,41 \pm 0,11$  m, IV-2:  $1,35 \pm 0,08$  m, CS:  $1,39 \pm 0,10$  m).

**Diskussion und Schlussfolgerung:** Trotz der bekannten gesundheitlichen Vorteile von körperlicher Aktivität konnte diese Studie keinen messbaren Einfluss einer schulbasierten Intervention auf die Pulswellengeschwindigkeit nachweisen. Angesichts der zunehmenden Prävalenz von Übergewicht und Adipositas im Kindesalter bleibt die Schule jedoch ein vielversprechender Ort für strukturierte Bewegungsprogramme. Weitere Forschung ist erforderlich, um die optimale Intensität, Dauer und langfristigen Auswirkungen solcher Maßnahmen auf die kardiovaskuläre Gesundheit von Kindern zu bestimmen.

## Abstract

**Background:** The rising prevalence of overweight and obesity among children is a growing global health concern, despite efforts to counteract this trend. Many children and adolescents fail to meet the World Health Organization's (WHO) recommendations for physical activity. Regular physical activity has been linked to improved cardiovascular health, including reduced arterial stiffness, which can be measured by pulse wave velocity (PWV).

**Objective:** This study aimed to assess whether a school-based physical activity intervention could positively influence PWV in primary school children. The hypothesis of this study was that, due to the intervention, the (physiological) increase in PWV would be smaller in the intervention schools, as compared to the control school.

**Methods:** The intervention was implemented in two public primary schools in Graz, Austria, where active learning strategies were integrated into the curriculum to incorporate movement into daily lessons. A third public school served as a control. In addition to the standard curriculum, various content was taught through movement-based activities to ensure that each child achieved the recommended 45 minutes of moderate to vigorous physical activity per day. PWV was measured at baseline, at the beginning of the school year, and at follow-up, at the end of the school year, using the Vicorder device. The intervention group included 102 children in the IV-1 and 91 children in the IV-2, while 32 children formed the control group in the CS. PWV was measured in 225 participants (46.2% girls and 53.8% boys, mean age:  $8.02 \pm 1.29$  years).

**Results:** For this age group, baseline PWV was higher than expected and throughout the study boys showed higher PWV values than girls. The findings did not show a significant effect of the intervention on PWV in the intervention schools compared to the control school. Mean PWV values changed from baseline (IV-1:  $5.43 \pm 0.56$  m/s, IV-2:  $5.22 \pm 0.50$  m/s, CS:  $5.65 \pm 0.52$  m/s) to follow-up (IV-1:  $5.96 \pm 0.61$  m/s, IV-2:  $5.67 \pm 0.59$  m/s, CS:  $5.98 \pm 0.54$  m/s). The mean height changed from baseline (IV-1:  $1.36 \pm 0.11$  m, IV-2:  $1.31 \pm 0.08$  m, CS:  $1.35 \pm 0.10$  m) to follow-up (IV-1:  $1.41 \pm 0.11$  m, IV-2:  $1.35 \pm 0.08$  m, CS:  $1.39 \pm 0.10$  m).

**Conclusion:** Despite the well-established benefits of physical activity, this study did not demonstrate a measurable impact on PWV through a school-based intervention. However, given the increasing prevalence of childhood overweight and obesity, schools remain a promising setting for structured physical activity interventions. Further research is needed to determine the optimal intensity, duration, and long-term effects of such programs on cardiovascular health in children.

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## List of abbreviations

AT	adipose tissue
aPWV	aortic pulse wave velocity
BAT	brown adipose tissue
BMI	body mass index
BP	blood pressure
CAD	coronary artery disease
cPWV	central pulse wave velocity
CO	cardiac output
CRF	cardiorespiratory fitness
CS	control school
CV	cardiovascular
CVD	cardiovascular disease
DBP	diastolic blood pressure
ECM	extracellular matrix
ET-1	endothelin-1
FMD	flow-mediated dilation
FU	follow-up
HIIT	high intensity interval training
ISH	isolated systolic hypertension
IV-1	intervention school 1
IV-2	intervention school 2
MAP	mean arterial pressure
MVPA	moderate to vigorous physical activity
NO	nitric oxide
NW	normal weight
OB	obesity
OW	overweight
PA	physical activity
PAAC	physical activity across curriculum
PAT	peripheral arterial tonometry
PP	pulse pressure

PPH	Private University College of Teacher Education Augustinum, Diocese Graz-Seckau
PVAT	perivascular adipose tissue
PWV	pulse wave velocity
ROS	reactive oxygen species
SBP	systolic blood pressure
SD	standard deviation
SEM	standard error of the mean
SES	socioeconomic status
SV	stroke volume
TPR	total peripheral resistance
VAT	visceral adipose tissue
VEGF	vascular endothelial growth factor
WAT	white adipose tissue
WHtR	waist-to-height ratio

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# 1 Introduction

## 1.1 The Arterial Vascular System

Arteries, with the exception of the pulmonary artery, distribute oxygenated blood to different tissues in the body. As the arterial tree travels through the body, the diameter of the vessels gets smaller. Arteries turn into arterioles, from which ultimately capillaries branch out and form the capillary bed, where an exchange of oxygenated blood coming from the arterial system and the deoxygenated blood, coming from the venous system, takes place (1).

Arteries can be histologically divided in three parts, with varying degrees of elastin and smooth muscle cells (2). Those parts are: the tunica intima, the tunica media and the tunica adventitia (2,6). Collagen and elastin are the two main components responsible for the properties of arterial walls (3). The tunica intima is an endothelial layer on the luminal side, consisting of a single sheet of endothelial cells, which sits on a basement membrane (2). The extracellular matrix (ECM) consists of elastin and collagen (4). It is involved in processes of coagulation and inflammation and in short term adaptations of the vascular tone, by signaling to the smooth muscle cells in the tunica media through vasoactive substances such as prostaglandins and nitric oxide (NO) (2,4).

The tunica media, separated from the tunica intima by the internal elastic lamina, consists of vascular smooth muscle cells, layers of elastin and fibrillar collagen and proteoglycans and glycoproteins (7). It is the layer responsible for the elastic properties of arteries and for maintaining the vessel's tone (4).

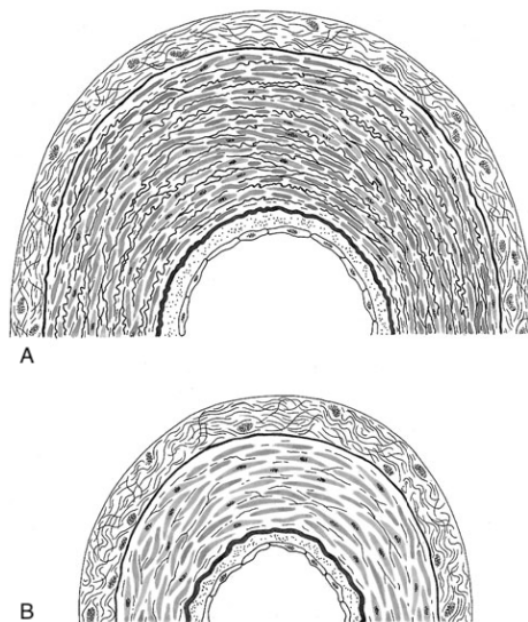
The adventitia, a layer rich in fibroblasts and collagen, allows the vessels to embed themselves into surrounding tissues (4). Vasa vasorum, nerve plexi and lymphatic tissue can be found in the adventitia (5). Adventitial fibroblasts also play a role in vascular remodeling and produce substances which influence vascular tone and the proliferation of cells. It is the outermost layer and is separated from the tunica media by the external elastic lamina (4).

Perivascular adipose tissue (PVAT), the adventitial fat, which is different from visceral fat, can be found around almost all blood vessels and plays a modulating role in the vasculature. Perivascular adipocyte-derived relaxation factors promote vascular relaxation,

whereas perivascular adipocyte-derived constricting factors lead to vasoconstriction as a consequence of the excitation of perivascular nerves. Furthermore, PVAT influences vessel tone through endothelium-dependent and endothelium independent release of vasoactive substances that contribute to the dilation of the blood vessel. An example for the latter would be vascular endothelial growth factor (VEGF) (45).

Arteries can be divided by the constitution of their walls and size, which influences their mechanical properties (5). Elastic arteries, also called conduit arteries, such as the aorta, are characterized by layers elastic fibers with smooth vascular muscle cells, which allows them to serve as a buffering structure (8). During a systolic contraction blood is ejected from the left ventricle into the aorta. The aorta can dilate to accommodate the bolus of blood, buffering the increase in systolic pressure. In diastole, the dilated wall will return to a more neutral position, limiting the diastolic drop in arterial pressure. This phenomenon, which results in a more even flow of blood, in comparison to the pulsatile flow caused by the systolic contraction, is called the Windkessel effect (8,9).

Muscular arteries, also called distributing arteries, are medium sized arteries with up to 40 layers of smooth muscle cells and a thick external elastic lamina (3). Due to their structure, muscular arteries show less arterial compliance and therefore more arterial stiffness than elastic arteries.



*Figure 1: A) Elastic artery & B) Muscular artery. Taken from: F. Anderhuber, F. Pera, J. Streicher, Waldeyer - Anatomie des Menschen, 19th Edition, De Gruyter 2012. Modified by the author.*

Arterioles are mainly composed of muscle and lack an external elastic lamina (3). Through autonomic regulation, the size of the lumen can change in order to ensure the tissues need for oxygenated blood. Furthermore, arterioles are the primary resistance vessels, as they provide 80% of the total peripheral resistance (TPR) and thus play an important role in maintaining the mean arterial pressure (MAP), as the MAP is a function of TPR and cardiac output (CO) (7,10). One way of describing MAP mathematically is:

$$\text{MAP} = \text{CO} \times \text{TPR} \quad (10)$$

This increase in resistance and subsequent decrease in flow is necessary to ensure that the capillaries are not damaged. The capillaries are formed by a single sheet of endothelial cells sitting on a basement membrane, with pericytes wrapping around the endothelial cells (2). The capillary network forms the transition between the arterial system and the venous system, where waste products and nutrients are exchanged (2,11).

## **1.2 Blood Pressure**

The high pressure system, which consists of the arteries and, during the systolic phase, the left ventricle, contains around 15% of the blood volume and is responsible for supplying different organs with blood (12).

As the left ventricle contracts, physiologically, around 70 ml of blood (Stroke volume (SV)) are ejected into the aorta, which leads to a pressure increase from 80 mmHg to 120 mmHg. The relaxation of the elastic fibers in the aorta, where, after the blood has left the left ventricle, around 50% of the stroke volume is stored, enables a continuous flow of blood. The pressure maximum in the aorta after a contraction is described as the systolic blood pressure (SBP). The pressure minimum, during the diastolic filling of the left ventricle, is called diastolic blood pressure (DBP). The difference between the two is the pulse pressure (PP) (12,13).

## **1.3 Arterial Compliance**

The ability of an artery to expand due to increasing pressure is called arterial compliance (11). Arterial compliance (C; in ml/mmHg) can be calculated by dividing the change in blood volume ( $\Delta V$ ; in ml) by the change in blood pressure (BP) ( $\Delta P$ ; in mmHg) (3,11).

$$C = \Delta V / \Delta P$$

The elastic resistance ( $E'$ ; in mmHg/ml) of the arterial wall can be described as the reciprocal of arterial compliance (9).

$$E' = 1 / C$$

Due to the fact that the ability to expand and accommodate an increase in blood volume is dependent on the arterial stiffness, the stiffer the wall of an artery, the lower the compliance (3). This means that arterial stiffness is proportional to  $E'$ , therefore,

$$\text{Arterial stiffness} \propto 1 / C \quad (3)$$

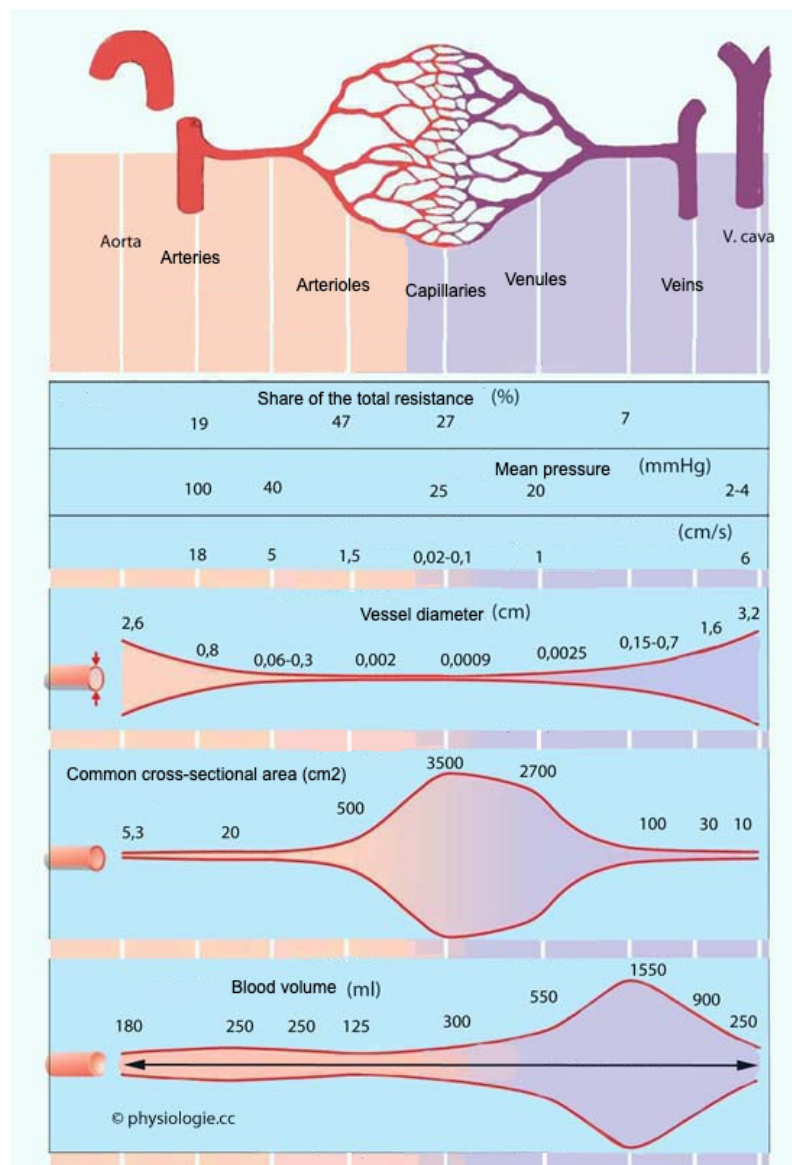


Figure 2: Influence of different types of vessels on different properties of the circulation. Taken from: <http://physiologie.cc/VII.1.htm>. Modified by the author.

## **1.4 Arterial Stiffening**

Arteries undergo constant remodeling processes which influence their morphology and function. As described by Lacolley P, Regnault V & Laurent S, arterial walls stiffen due to different factors including a “reduced elastin/collagen ratio, production of elastin cross-linking, reactive oxygen species–induced inflammation, calcification, vascular smooth muscle cell stiffness, and endothelial dysfunction“ (14). Due to a relative increase in collagen fibers and atherosclerotic plaques, the stiffening of arteries occurs as a part of the ageing process, which is how isolated systolic hypertension (ISH) in elderly patients can be explained (8,12). As a consequence, the pressure generated by the heart needs to increase (12). One non-invasive method of estimating the stiffness of arteries is measuring the pulse wave velocity (PWV) (15).

## **1.5 Pulse Wave Velocity**

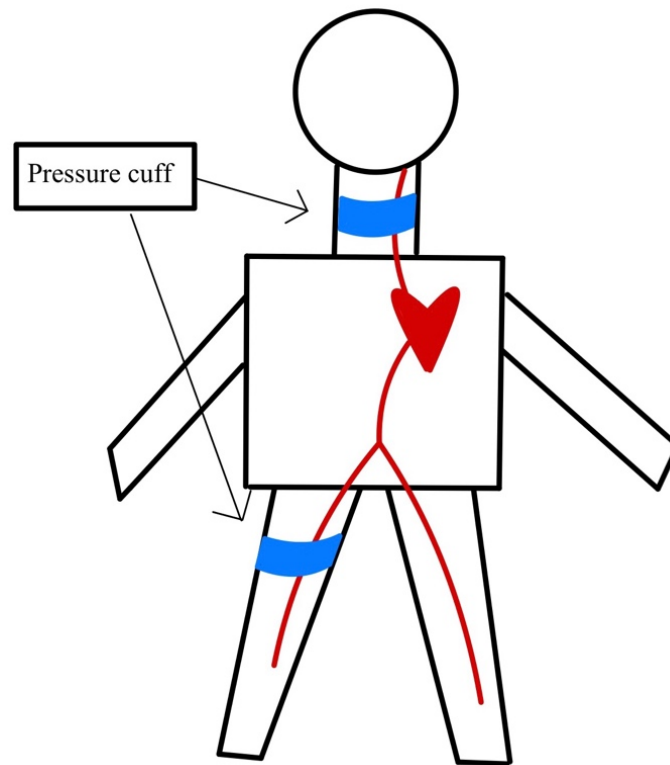
Through the systolic pressure generated, the aorta dilates to temporarily accommodate blood coming from the heart. As the pressure changes, the aorta relaxes and propels the blood to the periphery, where the process continuously repeats, which creates a pulse-wave travelling through the arterial vessels. The pulse wave moves faster than the blood and the PWV is influenced by the diameter and elasticity of the vessel (12).

In the peripheral arteries the pulse wave is reflected. Physiologically, the reflected pulse wave reaches the aorta during diastole, leading to a higher pulse pressure in the periphery (pressure amplification). However, with an increased PWV, the pulse wave returns during the systole, leading to an increase in systolic blood pressure (16). Therefore, PWV is used as a surrogate marker for the stiffness of the aortic wall (17).

## **1.6 Assessing Pulse Wave Velocity**

Since the thoracic and abdominal aorta are the two greatest contributors to the arterial buffering function (18) and the aorta is the main region of pathological arterial stiffening, aortic pulse wave velocity (aPWV) is regarded as the gold standard for assessing arterial stiffness, due to its lower sensitivity to cardiac function as compared to pulse pressure (17). The carotid-femoral PWV has shown to be a good proxy of the aPWV (17). It is a non-invasive method, whereby the pulse waveforms between the respective arteries are

determined and a gradient velocity is calculated (20). Due to the heterogeneity of arterial elasticity, the PWV increases from 4-5 m/s in the ascending aorta to 8-9 m/s in the femoral and iliac arteries (18).



*Figure 3: Schematic representation of the placement of the pressure cuffs when measuring PWV. Picture by the author.*

Different methods exist for assessing PWV. PWV measured by oscillometry and applanation tonometry are the two most commonly used noninvasive methods for assessing PWV in the pediatric population (70). While the tonometric measurement of PWV is considered the gold standard for noninvasively assessing PWV, oscillometric devices offer a good alternative in the general population. However, while cuff-based devices offer easier handling and have been described as easier to use in pediatric subjects, the assessment of PWV by oscillometry also tends to underestimate PWV in younger subjects. Considering the general population, those differences do not appear to be clinically significant (74, 75).

## **1.7 Consequences of Arterial Stiffening**

Aortic stiffness is associated with an elevated PWV, PP and SBP (16,19). Furthermore, aPWV and PP have been shown to be markers for cardiovascular (CV) events, and

elevated PP is associated with pathophysiological processes where microvascular dysfunction is a common element such as macular degeneration, strokes and kidney dysfunction (17,19).

An increase in arterial stiffness also leads to higher left ventricular afterload, due to a higher amplitude of the reflected wave, which increases the pressure in late systole (39). Another consequence of arterial stiffening is the development of isolated systolic hypertension, defined as a SBP > 140 mmHg and a DBP < 90 mmHg (22). ISH is the most common form of hypertension and typically affects elderly patients (22). However, ISH can also be found in young males (21). While the clinical significance is somewhat unclear, the scoping review by Scott H, Barton MJ, Johnston ANB suggests that the cardiovascular risk for young males (between the ages of 18 to 30 years) with ISH is dependent on modifiable risk factors such as being overweight and that “exceptionally healthy” young males did not seem to carry an increased cardiovascular risk, despite having ISH (21).

## **1.8 Obesity, Endothelial Dysfunction and Arterial Stiffness**

Overweight, defined by a body mass index (BMI) between 25 kg/m<sup>2</sup> and 29.9 kg/m<sup>2</sup>, and obesity, defined as a BMI of 30 kg/m<sup>2</sup> or greater, are global health problems with increasing prevalence (40). This trend can also be observed in children (41) and while the pathophysiology is complex, there are many factors contributing to the development of obesity, which results in significant mental as well as physical health consequences (41,42).

Adipose tissue (AT) can be categorized in white, brown and beige AT. Subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) on the inside of the abdomen, constitute the white adipose tissue (WAT). Besides WAT, mitochondria rich brown adipose tissue (BAT) and beige adipose tissue exist (46).

The accumulation of adipose tissue with endocrine properties creates a pro inflammatory milieu, leading to chronic low-grade inflammation, which ultimately promotes micro- and macroangiopathy (41). Especially the accumulation of visceral fat is problematic, since it is associated with endothelial dysfunction, chronic inflammation, and the development of insulin resistance, as well as cardiovascular disease (CVD), the leading cause of death

worldwide (43,44). It is important to note that a higher prevalence of cardiometabolic diseases can be observed in individuals with higher visceral and ectopic adipose tissue storage than individuals with equal BMI's, who carry a higher percentage of subcutaneous adipose tissue, relative to the overall adipose tissue (44).

Furthermore, sexual dimorphisms in fat distribution exist. While women generally have a higher body fat percentage, the distribution differs from those in males, with more fat accumulation in the femoral and gluteal areas, which may be a contributing factor to premenopausal women having a lower risk of developing cardiometabolic disorders (46).

Nevertheless, a high BMI has been described as a reliable factor for predicting endothelial dysfunction, the initial stage of atherosclerosis and permanent endothelial dysfunction can be induced by a high childhood BMI (43).

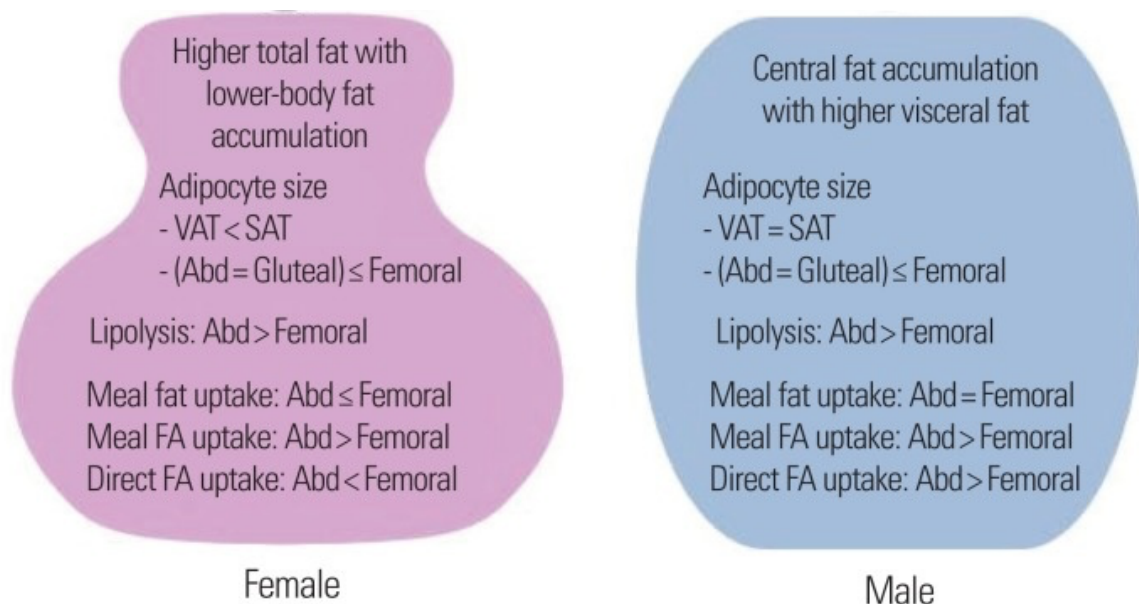


Figure 4: Fat distribution patterns in males and females. FA= Fatty acid; Abd = Abdominal. Taken from: Lee MJ, Fried SK. Sex-dependent Depot Differences in Adipose Tissue Development and Function; Role of Sex Steroids. *J Obes Metab Syndr.* 2017 Sep;26(3):172-180. doi: 10.7570/jomes.2017.26.3.172. Epub 2017 Sep 30. PMID: 31089514; PMCID: PMC6484911. Modified by the author.

Adipose tissue contains, beside adipocytes, different types of cells and is a metabolically active tissue. The process of obesity leads to processes that propagate a pro-inflammatory milieu with a dysfunction in adipocytes and lipolysis, stimulated by proinflammatory cytokines which leads to the development of insulin resistance (45). Furthermore, increased vascular endothelin-1 (ET-1) expression from the adipose tissue can be observed

in people with obesity, causing a decrease in NO release by a disruption in the ET-1/NO system (45). A higher ET-1 release, which is associated with obesity, is a contributing factor to the development of hypertension by disrupting the endothelial vasodilator function (45). As a result of obesity, inflammation of the PVAT occurs and leads to insulin resistance in the vasculature which compromises the vasodilation mediated by insulin (45).

Insulin resistance, as present in individuals with obesity, has been shown to be associated as an independent risk factor, with vascular stiffening in children as well as adults (44). The endothelial morphology can be changed by different stressors such as shear stress and blood lipid content, for example (45). Different risk factors contribute to the development of endothelial dysfunction which already begins early in life with a reduced NO bioavailability. This largely depends on the concentration of reactive oxygen species (ROS), preceding morphological changes in the vasculature (31,47).

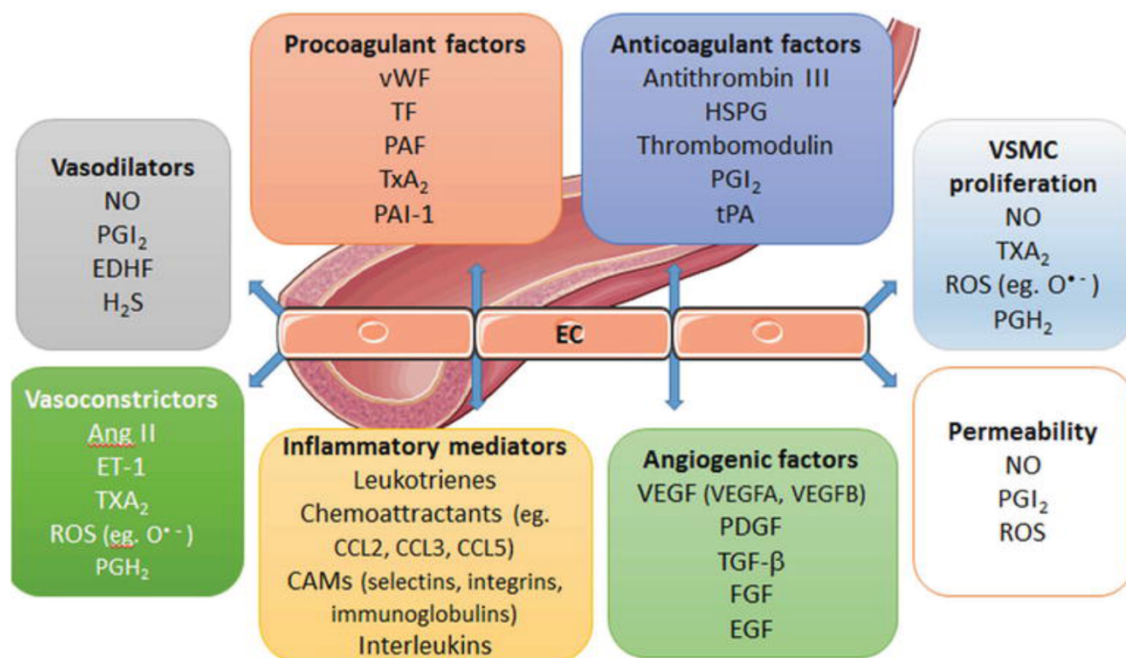


Figure 5: Showing the different functions of the endothelium. From: Sena CM, Carrilho F and Seica RM (2018) Endothelial Dysfunction in Type 2 Diabetes: Targeting Inflammation. Endothelial Dysfunction - Old Concepts and New Challenges. InTech. Available at: <http://dx.doi.org/10.5772/intechopen.76994>.

Chronic inflammation, which is related to CV-risk factors, can, in combination with intrinsic mediators, contribute to a dysfunction in the endothelium (31). As described by Hanssen H, Streese L & Vilser W. in: Retinal vessel diameters and function in cardiovascular risk and disease: "Small vessel disease is characterized by reduced functional vasodilation, structural remodeling, rarefaction as well as platelet activation

leading to increased peripheral vascular resistance and a reduced blood supply of end-organs (Brunner et al., 2005). This simplified cascade stretching from CV risk factors, intrinsic risk-mediators to microvascular dysfunction is the main mechanism responsible for the development of manifest CVD such as coronary artery disease (CAD) and stroke, but also chronic kidney disease as well as hypertensive and diabetic retinopathy (Brunner et al., 2005; Farrah et al., 2020).” (31).

While hypertension is much less common in children than in adults, an increase in hypertension has been observed simultaneously with the increase in obesity levels in children in the US (48).

Studies in children using peripheral arterial tonometry (PAT) have shown an improvement in endothelial function and a decrease in pathological conditions through pubertal changes and Physical activity (PA) (47). On a macrovascular level, endothelial changes measured by flow-mediated dilation (FMD) have already been found in children and adolescents who have been newly diagnosed with essential hypertension or white coat hypertension. Furthermore, early microvascular changes have been found in adolescents with newly diagnosed essential hypertension, using PAT, a biomarker for early vascular change. However, the clinical relevance of these findings remains to be seen (47).

## **1.9 Arterial Stiffness and Pulse Wave Velocity in Children**

While cardiovascular disease is a prevalent problem in adults, the pathophysiological changes and damaging of the vasculature already manifest in children and can predict CVD in adulthood (23,24,25). It has, for example, been shown that a higher central pulse wave velocity (cPWV) is associated with a higher SBP & DBP in children, which continue to persist in adulthood (23). Furthermore, changes preceding atherosclerosis such as fatty streaks have been described in young children (26).

Over the past decades obesity in children has increased while physical activity recommendations are not met by a large percentage of children and obesity is a key element in the development of arterial stiffness in children (20,27,28). While the pathophysiology of obesity is complex, the changes that accompany obesity lead to alterations that ultimately increase CV morbidity and mortality (29).

It is important to note that the physiological changes that occur as part of a child's development and later in puberty need to be accounted for when discussing vascular structure and changes (20,23).

Obesity is not only a risk factor for increased PWV but obesity and a related elevated BP can also lead to microvascular changes (23). A variety of conditions leading to CV-disease and atherosclerosis are associated with endothelial dysfunction, a systemic condition, where the function of the endothelium in the periphery correlates with that in the coronaries. It is important to note that pharmacological and lifestyle interventions in adults have been shown to, at least in part, reverse endothelial dysfunction. This has been shown, for example, with antihypertensive therapy, likely due to an increase in NO bioavailability. However, micro- and macrovascular endothelial function can be improved through PA, weight loss and dietary interventions as well (49).

### 1.10 Pulse Wave Velocity Reference Values in Children

Thurn et al. measured pulse waves in 1003 healthy children between the ages of 6 and 18 years in a multicenter study using the oscillometric Vicorder system (Skidmore Medical, Bristol, UK; Software Version 4.0). Age correlated significantly with PWV and they described sex differences already beginning at the age of 9 years, with boys showing a higher PWV (55).

*Table 1: PWV values for different age brackets in male (M) and female children (F). Taken from: Thurn D, Doyon A, Sözeri B, Bayazit AK, Canpolat N, Duzova A, Querfeld U, Schmidt BM, Schaefer F, Wühl E, Melk A; 4C Study Consortium. Aortic Pulse Wave Velocity in Healthy Children and Adolescents: Reference Values for the Vicorder Device and Modifying Factors. Am J Hypertens. 2015 Dec;28(12):1480-8. doi: 10.1093/ajh/hpv048. Epub 2015 May 5. PMID: 25944878.*

	<b>Age (years)</b>			
	6-8.99	9-11.99	12-14.99	15-18
<b>PWV (m/s)</b>				
M	4.3 ± 0.4	4.6 ± 0.5	5.0 ± 0.6	5.4 ± 0.6
F	4.3 ± 0.4	4.5 ± 0.4	4.8 ± 0.5	5.2 ± 0.5
<b>P</b>	0.35	0.023	.001	.003

The measurements were performed with a 30° inclination of the head and shoulders to prevent venous artifacts after a resting period of at least 5 minutes and standardized using the recommendations from the “Clinical applications of arterial stiffness, Task Force III: recommendations for user procedures” (55,56).

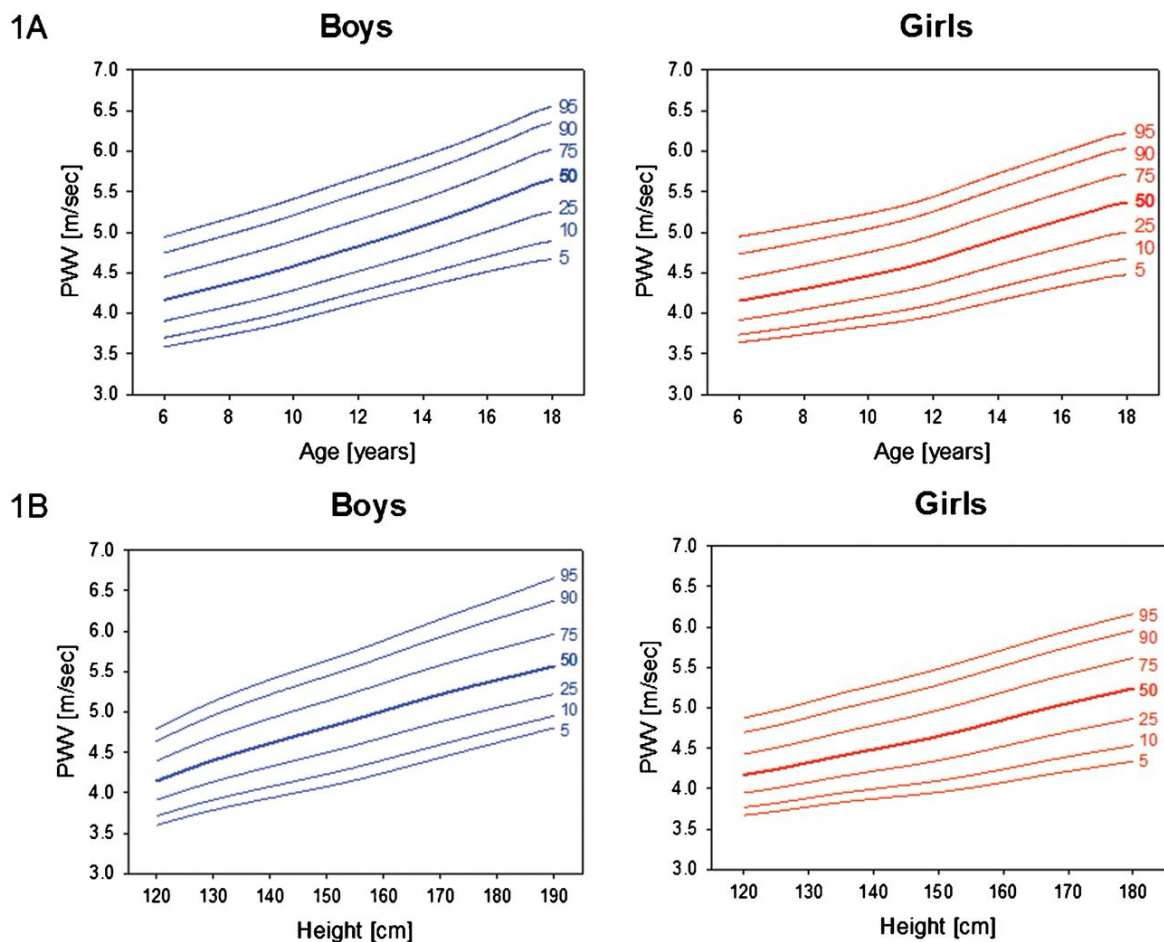


Figure 6: PWV percentiles in relation to age and height in boys and girls. Taken from: Thurn D, Doyon A, Sözeri B, Bayazit AK, Canpolat N, Duzova A, Querfeld U, Schmidt BM, Schaefer F, Wühl E, Melk A; 4C Study Consortium. Aortic Pulse Wave Velocity in Healthy Children and Adolescents: Reference Values for the Vicorder Device and Modifying Factors. *Am J Hypertens.* 2015 Dec;28(12):1480-8. doi: 10.1093/ajh/hpv048. Epub 2015 May 5. PMID: 25944878

## 1.11 The Influence of Physical Activity on Pulse Wave Velocity in Children

The WHO recommends that children and adolescents between the ages of 5 and 17 years do a minimum of 60 minutes of mostly aerobic physical activity with a moderate to vigorous intensity on average per day over the week. Additionally, at least 3 days a week

muscle and bone strengthening as well as vigorous intensity aerobic activities should be incorporated (32). However, those recommendations are not met by a majority of children and adolescents (28). With both obesity and PA levels persisting into adulthood, finding ways to increase PA in children can reap serious health benefits later in life (29,30,34).

In adults, aerobic endurance exercise has been described as the only intervention that can help mitigate arterial stiffening related to ageing (13). It has been shown that a higher level of cardiorespiratory fitness (CRF) correlates with a lower cPWV and that PA can improve PWV in overweight children (23,33).

Köchli et al. investigated the connection between PWV, obesity and PA in children. Cardiorespiratory fitness was assessed using the validated 20-meter shuttle run test, which required children to run between two 20-meter lines. The starting pace was set at 8.0 km/h, increasing incrementally by 0.5 km/h every minute. The test concluded when a participant failed to reach the line within 2 meters for two consecutive attempts. Results were recorded in stages, each equivalent to one minute, with half-stage increments noted for accuracy. Additionally, a 20-meter sprint test was performed. Data on physical activity and screen time were gathered through parent-completed questionnaires. PA was categorized into vigorous, indoor, and outdoor activities, recorded in minutes per day, while screen time included activities like watching television, playing video games, and using smartphones, also measured in daily minutes. The results show a correlation between increased PWV and higher BMI and BP, while PA correlated with a lower PWV (27).

Different studies have also investigated the relationship between PA and microvascular changes, namely the retinal vasculature, where it has been shown that PA positively influences the morphology of the retinal vessels (27,30,31,50).

## **1.12 School based Physical Activity Interventions**

Five days a week children spend a large part of their day in school, which provides a fantastic opportunity to increase PA. The school environment provides the opportunity to reach a large number of children with adequately trained staff to supervise and guide PA. School based PA interventions have led to significant improvements of various health metrics in children (35,36).

It has been shown that school-based PA interventions, which were integrated in the curriculum, and included PA specialists as well as family support, have led to significant increases in objectively measured PA (53).

In a parallel-arm cluster-randomized controlled trial Ketelhut et al. investigated the effects of a 9-month exercise intervention in two primary schools in socially disadvantaged areas in Düsseldorf, Germany on different cardiovascular parameters. In addition to following the weekly 3 x 45 minutes physical education classes of the curriculum, the intervention group performed 2 x 45 minutes of supervised PA in a relatively high intensity. With regard to aPWV, they showed that throughout the intervention, a lower PWV was observed in the intervention group (58).

Effects of school-based PA interventions on the microvasculature and cognitive function have been described in the literature as well (51, 52).

When discussing PA in children, environmental factors and parental socioeconomic status (SES) need to be taken into account. A review by Gautam et al. describes that a higher parental SES is associated with higher PA levels in children, while a lower SES is associated with unhealthy behaviors (37).

### **1.13 Health & Academic Performance with Happy Children**

Inspired by a Norwegian large scale, longitudinal, school based PA Intervention in elementary school children (The health oriented pedagogical program HOPP) (38), the project "Optimizing cardiometabolic Health, Cognition and Academic Performance with Happy Children using school-based physical activity" (HAPHC or „Happy children“), was started in 2021. It was part of the ERASMUS+ K201-Strategic Partnerships for school education projects: „Health & Academic Performance with Happy Children“ (Form ID: KA201-D9E80201), in cooperation with Norway, Belgium, Slovenia and Austria. The project aimed to promote the physical and psychological wellbeing of primary school children by integrating PA as a part of the learning process. In addition to the curriculum's physical education lessons, PA was integrated into other subjects in order to achieve an average of 45 minutes of moderate to vigorous physical activity (MVPA) daily (38,54).

PA has been shown to not only have a positive impact on cardiometabolic factors but also on academic performance and stress alleviation (54).

In order to incorporate physical activity (PA) into the daily school routine, an approach which has been referred to as Physical Activity Across Curriculum (PAAC) has been implemented. This approach aims to optimize the balance between the benefits of physical education and PA while minimizing the reduction in learning time due to the increased PA (54).

In Austria, elementary school children between the ages of 6 to 11 years, from different schools participated in the school-based PA intervention and teachers were trained on how to implement the program into the curriculum. This provided an opportunity to reach a large number of children from different socioeconomic backgrounds. The aim was to assess how daily MVPA integration would impact physical fitness, PA during leisure time, cardio-metabolic health of elementary school children, the children's mental health and quality of life as well as how PAAC would impact academic achievement (54).

## **2 Aims and objectives**

The aim of the present thesis was to assess the PWV of elementary school children at baseline and whether any changes can be observed one school year after implementing a PA intervention. In addition to the physical education classes prescribed by the curriculum, content from various subjects was taught and/or practiced through movement, ensuring that each child reached the recommended average of 45 minutes of MVPA per day.

We hypothesized that implementing 45 minutes of MVPA daily, for the duration of one school year, can positively influence the PWV.

### **2.1 Null hypothesis**

Main outcome parameter:

H0 [1]: There is no difference in the PWV changes as a result of a daily 45-minute exercise intervention in primary school children of the intervention schools compared to the changes in primary school children of the control school. The changes from baseline to follow-up are independent of the intervention.

### **2.2 Alternative hypothesis**

Main outcome parameter:

H1 [1]: There is a difference in the increase of PWV between the intervention schools and the control school. Specifically, a smaller increase of the expected, physiological increase in PWV from baseline to follow-up, as a function of a daily 45-minute physical activity intervention, can be observed in primary school children of the intervention schools, compared to primary school children of the control school.

## **3 Methods**

### **3.1 Study design**

This thesis was conducted as part of the project called “Optimizing cardiometabolic Health, Cognition and Academic Performance with Happy Children using school-based physical activity” (HAPHC or short „Happy children“). The project was inspired by a study, which was carried out in Norway in 2015, called “The health oriented pedagogical program HOPP” (38).

The “Happy children” project was conducted as an ERASMUS+ K201-Strategic Partnerships for school education project: „Health & Academic Performance with Happy Children“ (Form ID: KA201-D9E80201), in cooperation with partner institutions in Norway, Belgium and Slovenia, where the same study protocol was implemented.

In cooperation with the Styrian state directorate of education and the “Private University College of Teacher Education Augustinum, Diocese Graz-Seckau” (PPH), two intervention schools and a control school were recruited. Based on the Norwegian methods, teaching materials were translated and created by the PPH and teachers were trained in a two-day course for implementing PA into the curriculum. Additionally, before the start of the project, teachers of the intervention schools visited schools in Norway which were part of the HOPP project. Norwegian teachers that were part of the HOPP project visited and supervised the Austrian intervention school teachers during the project.

The project support for the schools, in terms of regular exchanges, was further provided by staff members of the PPH and/or the Medical University of Graz. The participating schools, as sub-partners, took responsibility for the implementation of the physical activity intervention and committed to weekly written documentation of the same.

In February of 2021, the Styrian Board directorate for Education sent out an invitation letter to all public primary schools of the city of Graz to participate in the project. Even though the disruption of school-life caused by the COVID-19 pandemic led to a smaller participation rate among the school’s leadership, three schools showed willingness to take part in the project. Two intervention schools and one school, which served as a control group were included. The schools differed largely regarding the parental SES and

household income, whereby only one intervention school and the control school were comparable.

Due to the high number of children with a migration background, the parent information, consent form, and parent questionnaire was made available on a platform called 'SchoolFox' in simple language. This platform allows parents to translate documents into their native language. Additionally, senior project staff attended the parent evenings in the fall of the school year 2021/22 to give parents ample opportunity to ask questions.

In addition to the physical education classes prescribed by the curriculum, 'active learning' was introduced and continuously taught with a daily 45-minute session of PA. Active learning means that, unlike traditional methods where learning is done while sitting, learning took place through movement. For example, in mathematics, addition is learned by hopping on numbers placed on the floor. To monitor implementation and ensure quality, teachers were required to keep a log (see supplementary material). Additionally, in the first year of the intervention, a designated contact person who supported the teachers in implementing the program regularly visited the intervention schools. Before the project's start, teachers from the two intervention schools received appropriate training through the PPH Graz as part of a teacher development program and were provided with teaching materials for implementing the movement intervention in classroom lessons. These materials had been developed by the PPH based on resources from Norway. At the end of each school year (in June), a new assessment of the medical-physiological health parameters and psychological test procedures was conducted. Additionally, feedback from students and teachers regarding the intervention was collected. The parameters collected in the "Happy children" study were as follows:

- Cardiovascular: Heartrate, Blood pressure, microcirculation (measured by a retina camera) and pulse wave velocity
- Physical fitness changes: strength, endurance, coordination, and stretching ability
- Changes in cognitive performance: attention, concentration, reading comprehension, mathematics
- Cardiometabolic changes: Metabolomics (parameters from urine)
- Changes in subcutaneous adipose tissue: Measurements using ultrasound
- Changes in psychological and social variables: Strengths and weaknesses, friendships, quality of life, joy of learning

The study was carried out over a period of 3 school years. **For the present thesis, only the PWV at baseline and after a one year follow up were analyzed.**

### **3.2 Ethical approval**

The ethical board of the Medical University of Graz (Graz, Austria), where the Happy Children study was conducted, approved of the study's research protocol and subsequent changes to it (EK-number: 33-488x 20/21). The trial was performed in accordance with the standards laid out by the Declaration of Helsinki and registered on clinicaltrials.gov (NCT-number: NCT04956003).

### **3.3 Recruitment**

All of the 41 public elementary schools in Graz were assessed for eligibility and contacted as part of the recruitment process. Parents/legal representatives of the children in the participating schools received information about the study and were asked to sign the respective consent form. With the parents' consent form in place, the children were also informed about the study's purpose in an age-appropriate manner and were asked to give their consent to participate (see supplementary material: Participant Information for Children). Children were also given the possibility to withdraw from a particular measurement at site if they felt uncomfortable with it.

Inclusion criteria: primary school children between the ages of 6 to 11 years.

Exclusion criteria: none

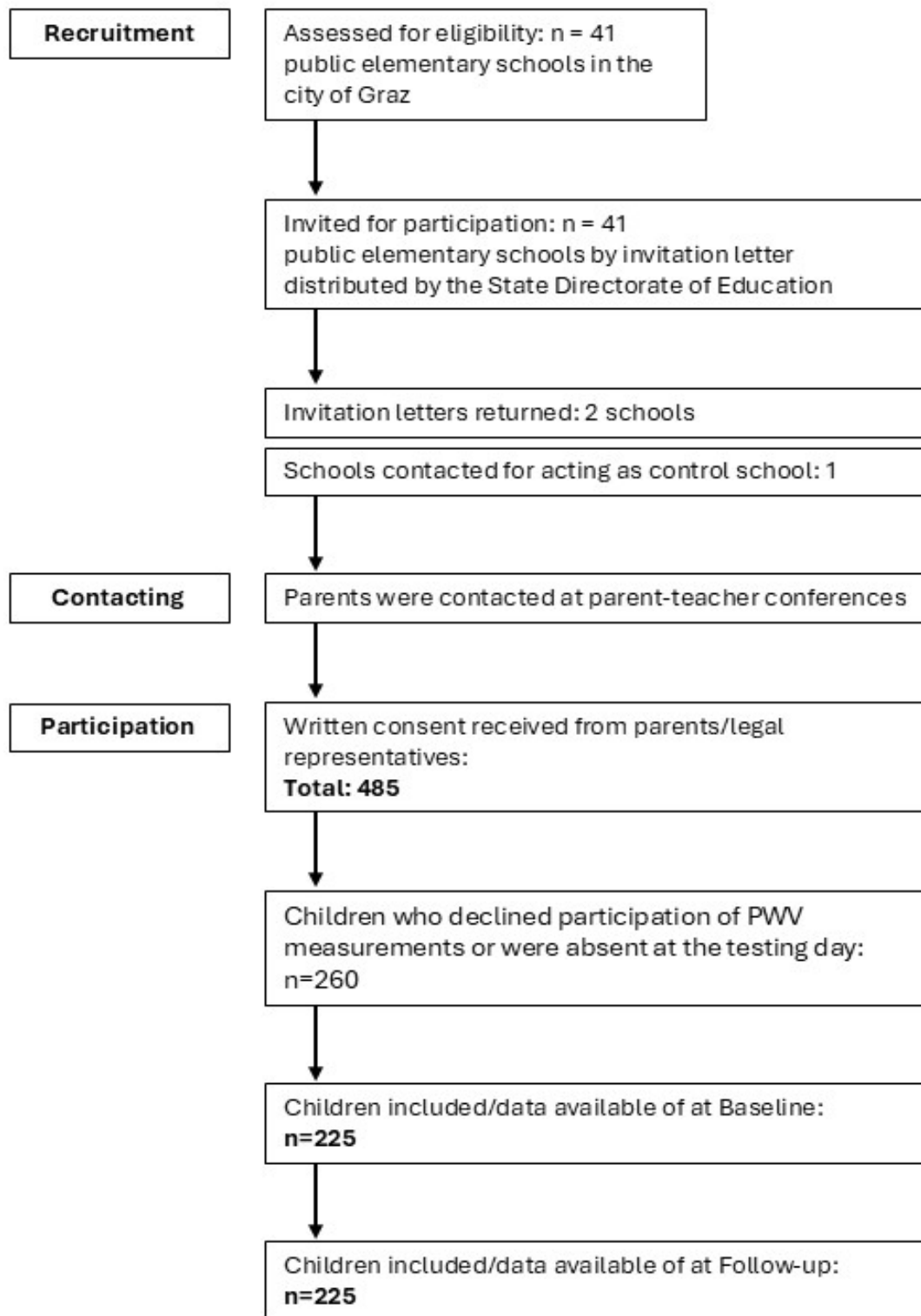


Figure 7: Recruitment process of the study participants. n = number of children.

### **3.4 Intervention**

The PA-intervention was carried out in the school setting, during the regular school hours. Based on the materials from the HOPP study (57), school-grade-appropriate materials for 'active learning' were developed at the PPH Graz and made available to the two intervention schools. Following appropriate training of the teachers at the two intervention schools through professional development at the PPH Graz, the physical activity intervention began after baseline measurements were completed. In this intervention, 45 minutes of learning time were to be conducted through movement each day, with the teacher having the discretion to decide which content would be taught through movement and when. In the event of another COVID-19 'lockdown,' alternative movement programs for 'distance learning' or 'home-schooling' were prepared.

The daily 45-minute movement intervention was conducted in addition to the regular physical education classes prescribed by the curriculum. This intervention involved pupils engaging in moderate to intense physical activity while practicing or working on a lesson.

#### Example 1:

The teacher distributes or hides laminated numbers around the sports field. The pupils had to run from a starting point to find these as quickly as possible to solve equations and complete a puzzle. This exercise can also be done with letters that form a solution word.

#### Example 2:

Students form a group on the sports field or in the gym. Large circles are spread out on the ground. The teacher gives the students a number representing the number of equally sized groups they need to form. If there are 24 students and the teacher calls out the number 4, each student must run to one of the circles so that each group has six students.

#### Example 3:

Students run around the sports field and collect as many twigs or stones as possible, which they then use to form letters for a word.

The movement intervention was documented weekly by the teachers (see supplementary material: Teacher's Movement Log) and evaluated for feasibility and effectiveness. Additionally, in the first year of implementing active learning, the PPH closely monitored and supported the process. During a feedback event, adjustments or changes to the learning materials were made to ensure quality.

The movement intervention was carried out daily throughout the entire school year and with all children at the two intervention schools. If a class teacher was unable to integrate daily movement into learning for medical or other reasons, the school provided another teacher to implement the daily movement intervention in the class.

The extent and intensity of additional physical activity during subject lessons were recorded by both the teachers and the children. The teachers received a weekly plan for documentation (see supplementary material: Movement Log for Teachers), where they could note the daily lesson unit, the activity (duration and intensity), as well as the current academic workload.

The students were encouraged by their teacher to also document their additional physical activity and received a specially designed movement clock for this purpose (see supplementary material: Movement Clock). The movement clock served to playfully motivate the children and could also be used as feedback for the teacher on how the children perceived the new forms of movement and exercises. This clock could be crafted by the children themselves during class (for example, out of cardboard). However, the exact design of the clock was left to the creative freedom of the teachers and children. To assess the children's current mood regarding their workload, a self-constructed Likert scale with smileys (see supplementary material) was used.

All children of the intervention schools took part in the active learning program, however only children with signed consent form were measured for study purposes.

### **3.5 Measurements**

At two of the three primary schools, a daily 45-minute physical activity program was integrated into the "active learning" approach. In contrast, at the control school, children underwent the same testing and assessments but did not participate in the active learning or movement-based intervention throughout the school year.

All examinations were conducted by trained personnel from the fields of medicine, psychology, and education, adhering to legal hygiene regulations and COVID-19 safety measures, within the schools themselves.

Data collection took place in small groups of 4-6 children, utilizing stations set up in changing rooms, the school library and gyms. At all times during the testing process, children were accompanied, ensuring no child was ever alone with an investigator. Efforts were also made to match each child with an investigator of the same sex or ensure the presence of at least one same-sex investigator in the room. Baseline measurements were taken prior to the start of the intervention in September 2021. Follow-up measurements were completed at the conclusion of the school year in June 2022. Two more follow ups (2023, 2024) were conducted as part of the Happy Children study.

The necessary equipment was transported to the schools for a period of about one week up to ten days, and the measurements were carried out on-site by a team.

The measurements were taken at the end of the school year, in the respective school's facilities. Baseline measurements were performed before the start of the intervention, at the beginning of the 2021/2022 school year. Arterial stiffness measurements were performed indirectly via pulse wave velocity. The measurements were taken in a calm environment, in a separate room, between 8 am and 1 pm. Unfortunately, standardization of the room's temperature was not possible. Measurements were performed in a supine position using the Vicorder® device (SMT, Germany). A cuff is placed around the neck so that the sensor is positioned over the carotid artery, while a second cuff is mounted as high as possible on the right thigh. Before inflating the cuffs, the distance between the suprasternal notch and the center of the thigh cuff is measured. Before the measurement, a resting period of 10 minutes took place.

The students' names were anonymized per school using consecutive case numbers, with the expectation that all students would participate in the physical activity intervention and the associated assessments. The group allocation of the schools was determined in advance based on the comparability of the schools. One of the intervention schools was comparable to one of the control schools in terms of catchment area, size, and composition of children (regarding migration background). The collection and storage of personal data for identification purposes, as well as the measurements, were conducted at the Department of

Physiology and Pathophysiology of the Medical University of Graz. Upon completion of the study, this personal data was deleted, while the data associated with case numbers will remain at the Department of Physiology.

### **3.6 Statistical analysis**

All data were checked for their distribution and potential outliers ( $\pm 3SD$ ). Group comparisons (between the schools) were performed by repeated measures ANOVA including school as the dependent variable and baseline/follow-up (pre-/post intervention) as the repeated measures factor. For frequency comparisons,  $\chi^2$  procedures were used. All data were analyzed by IBM SPSS (Statistics for Windows, Version 29.0. Armonk, NY: IBM Corp), using a significance level of at least  $p < 0.05$ .

## 4 Results

### 4.1 Baseline Characteristics

In total, 485 children aged 6 to 11 years of the three schools were included in the measurements for study purposes. Table 2 shows the total number of children in the different schools.

*Table 2: Number of female (F) and male (M) children in the different schools. IV-1 = Intervention School 1; IV-2 = Intervention School 2; CS = Control School; n = number of children.*

School	F	M	N
IV-1	52	49	101
IV-2	88	103	191
CS	88	105	193
Total	228	257	485

Table 3 gives an overview of the number of children in each school grade, across all three schools. Sex was equally distributed in each grade.

*Table 3: Combined total number of female (F) and male (M) children in each grade, pooled over schools.*

Grade	F	M	n
1	58	61	119
2	63	59	122
3	48	65	113
4	59	72	131
Total	228	257	485

No significant difference between girls' and boys' mean age ( $t_{(483)} = -1.194$ ,  $p = 0.233$ ) was observed (see Table 4).

*Table 4: Mean age of female (f) and male (m) children across all schools. f = female; m = male; n = number of children.*

	Sex	n	Mean	SD	SEM
Age in years	F	228	7.78	1.309	0.087
	M	257	7.92	1.297	0.081

Of the 485 children who consented to participating in the study, PWV was measured twice (baseline and follow-up) in 225 participants. Missing data were either due to absence on

the testing day or their decision to decline participation in PWV measurement at site. In particular, inflating of the neck-cuff caused discomfort and led children to withdraw of the measurement or refusal before even starting the measure. Table 5 gives the number of children in each school where PWV measurements were conducted. No significant difference was observed in the number of girls and boys across the schools ( $\chi_{(2)}^2 = 1.71$ ,  $p = 0.425$ ). The mean age of children for whom PWV was measured was 8.02 years, with a standard deviation of 1.29 years. The minimum age of participants was 6 years, while the maximum age was 11 years.

*Table 5: Number of female (f) and male (m) children of whom PWV was obtained. IV-1 = Intervention School 1; IV-2 = Intervention School 2; CS = Control School.*

School	F	M	Total
IV-1	47	55	122
IV-2	39	52	91
CS	18	14	32
Total	104	121	225

Table 6 shows the correlation between PWV, MAP, SBP and DBP at baseline. PWV significantly correlated with SBP ( $r = 0.136$ ,  $p = 0.006$ ) and DBP ( $r = 0.188$ ,  $p < 0.001$ ) at baseline.

*Table 6: Correlation between PWV (m/s), SBP (mmHg), DBP (mmHg) and MAP (mmHg) at baseline. \*\* = correlation is significant at the 0.01 level (2-tailed).*

		PWV	SBP	DBP	MAP
PWV	r	1	0.180**	0.232**	0.241**
	p		0.008	0.001	0.000
	n	225	215	215	215
SBP	r	0.180**	1	0.528**	0.796**
	p	0.008		0.000	0.000
	n	215	215	215	215
DBP	r	0.232**	0.528**	1	0.934**
	p	0.001	0.000		0.000
	n	215	215	215	215
MAP	r	0.241**	0.796**	0.934**	1
	p	0.000	0.000	0.000	
	n	215	215	215	215

Note: n is smaller for correlations with BP since some children refused to have their BP measured.

Furthermore, PWV was found to be correlated to age, height and weight (see Table 7).

Table 7: Correlation between PWV (m/s), Age (years), Height (m), Weight (kg), BMI (kg/m<sup>2</sup>) and waist-to-height ratio (WHtR); \*\* = correlation is significant at the 0.01 level (2-tailed).

		PWV	Age (years)	Height (m)	Weight (kg)	BMI	WHtR
PWV	r	1	0.241**	0.298**	0.229**	0.117	0.030
	p		0.000	0.000	0.001	0.080	0.653
	n	225	225	224	224	224	223
Age	r	0.241**	1	0.783**	0.561**	0.257**	-0.050
	p	0.000		0.000	0.000	0.000	0.455
	n	225	225	224	224	224	223
Height	r	0.298**	0.783**	1	0.765**	0.394**	0.000
	p	0.000	0.000		0.000	0.000	0.996
	n	224	224	224	224	224	223
Weight	r	0.229**	0.561**	0.765**	1	0.885**	0.559**
	p	0.001	0.000	0.000		0.000	0.000
	n	224	224	224	224	224	223
BMI	r	0.117	0.257**	0.394**	0.885**	1	0.828**
	p	0.080	0.000	0.000	0.000		0.000
	n	224	224	224	224	224	223
WHtR	r	0.030	-0.050	0.000	0.559**	0.828**	1
	p	0.653	0.455	0.996	0.000	0.000	
	n	223	223	223	223	223	223

Significant differences in baseline PWV were found between the four school grades ( $F_{(3,221)} = 3.436$ ,  $p = 0.018$ ), indicating an increase of PWV over the grades or with age (see Table 8).

Table 8: Mean PWV values (in m/s), standard deviation and number of children in each grade at baseline.

Grade	Mean	SD	N
1	5.14	0.52	42
2	5.38	0.57	58
3	5.41	0.50	53
4	5.47	0.56	72
Total	5.37	0.55	225

Furthermore, baseline PWV differed significantly between the three schools ( $F_{(2,222)} = 8.776$ ,  $p < 0.001$ ), with IV1 & CS having higher PWV as compared to the IV2 ( $p = 0.019$  between IV-1 & IV-2 and  $p < 0.001$  between CS & IV-2), while no significant difference was observed between the IV1 & CS.

*Table 9: Mean baseline PWV values (in m/s) for each school.*

School	Mean	SD	N
IV-1	5.43	0.56	102
IV-2	5.22	0.50	91
CS	5.65	0.52	32
Total	5.37	0.55	225

The results in Table 9 might originate in the slightly, but significantly older age of the children in the control school than in IV-2 ( $F_{(2,222)} = 3.689$ ,  $p = 0.027$ ) (see Table 10), but could also be driven by the higher mean BMI in the control school as compared to the one of the IV-2 ( $F_{(2,222)} = 10.40$ ,  $p < 0.001$ ) (see Table 11).

*Table 10: Mean age in years, in the three schools.*

School	Mean	SD	N
IV-1	8.07	1.34	102
IV-2	7.80	1.14	91
CS	8.50	1.41	32
Total	8.02	1.29	225

*Table 11: Mean BMI (kg/m<sup>2</sup>) of children whose PWV values were included.*

School	Mean	SD	N
IV-1	18.52	3.80	101
IV-2	16.47	2.07	91
CS	18.42	4.16	32
Total	17.67	3.41	224

Overweight and obesity were not equally distributed between the schools. Significantly more children of the CS and IV-1 met the WHO child criteria for overweight and obesity ( $\chi^2_{(4)} = 16.58$ ,  $p = 0.02$ , see Table 12). Notably, in both schools more than 30% of the children were overweight or obese.

*Table 12: Number of children classified with normal weight (NW), overweight (OW) and obesity (OB).*

School	NW	OW	OB	Total
IV-1	65	17	19	101
IV-2	81	4	6	91
CS	22	4	6	32
Total	168	25	31	224

SBP ( $F_{(2,211)} = 3.077$ ,  $p = 0.048$ ), DBP ( $F_{(2,211)} = 8.537$ ,  $p < 0.001$ ) and MAP ( $F_{(2,211)} = 7.982$ ,  $p < 0.001$ ) were significantly higher in children with overweight and obesity (see Table 13), but there was no significant difference between children with overweight, obesity and normal weight considering PWV ( $F_{(2,221)} = 0.02$ ,  $p = 0.998$ ) (see Table 14).

*Table 13: Blood pressure values (in mmHg) in children with normal weight (NW), overweight (OW) and obesity (OB).*

	SBP		DBP		MAP		N
	Mean	SD	Mean	SD	Mean	SD	
NW	102.88	9.82	70.77	8.42	81.47	7.85	161
OW	106.39	10.75	74.98	8.87	85.45	7.99	25
OB	107.18	10.89	77.09	7.45	87.12	7.59	28
Total							214

*Table 14: Mean PWV values (m/s) of children with normal weight (NW), overweight (OW) and obesity (OB).*

	Mean	SD	N
NW	5.367	0.54	168
OW	5.372	0.50	25
OB	5.371	0.63	31
Total			224

A comparison of PWV between girls (mean PWV = 5.29, +/- 0.52) and boys (5.44 +/- 0.057) revealed no significant difference ( $F_{(1,217)} = 3.176$ ,  $p = 0.076$ ), independent of the school grade (see: supplementary material).

## 4.2 Effect of the Intervention

To test the effect of the intervention on arterial stiffness as measured by PWV, a repeated measures ANOVA was performed comparing PWV before and after the intervention, and therewith between the schools. A significant main effect for PWV ( $F_{(1,222)} = 169.41$ ,  $p = 0.001$ ), school ( $F_{(2,22)} = 8.648$ ,  $p < 0.001$ ), as well as the interaction between PWV and school ( $F_{(2,222)} = 3.032$ ,  $p = 0.05$ ) was observed. PWV increased in all children, but contrary to what was expected, the increase was largest in the IV- 1, followed by the IV-2 and smallest in the CS (see Table 15, Figures 8 and 9).

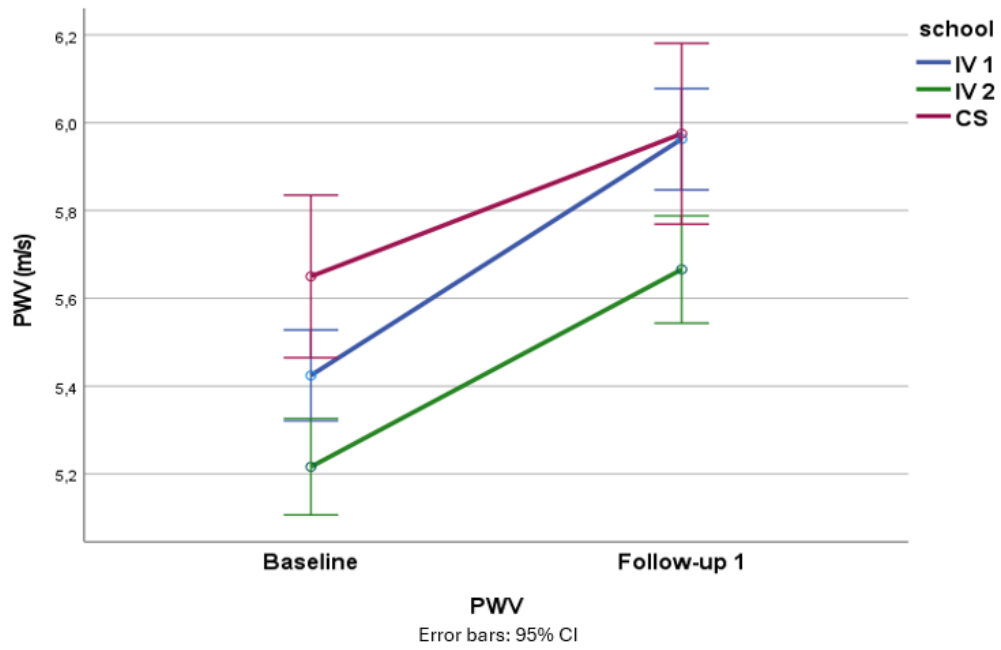


Figure 8: PWV at baseline and follow-up in the three schools.

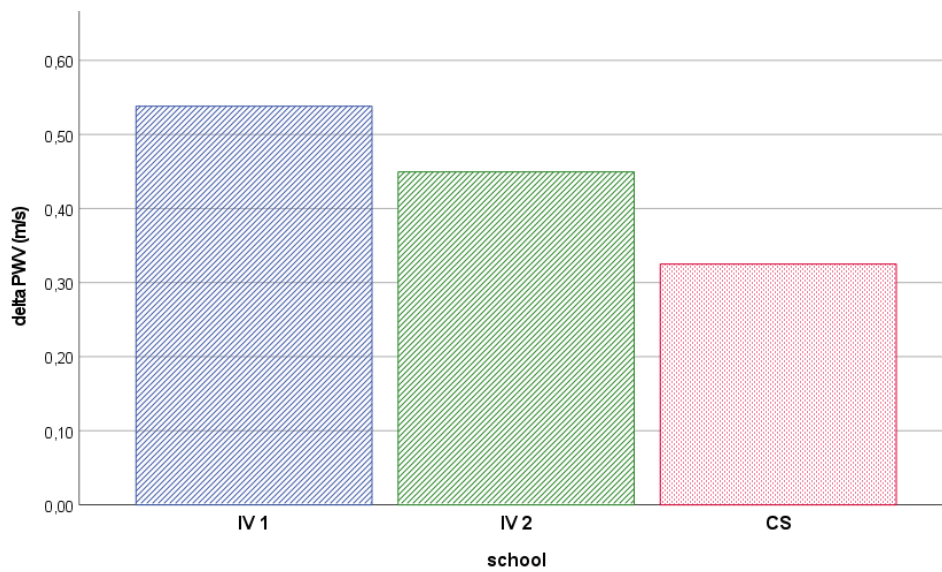


Figure 9: Changes in PWV from baseline to follow-up (absolute differences).

Table 15: PWV values (m/s) of the different schools at baseline and follow-up.

School	Baseline		Follow-up		N
	Mean	SD	Mean	SD	
IV-1	5.43	0.56	5.96	0.61	102
IV-2	5.22	0.50	5.67	0.59	91
CS	5.65	0.52	5.98	0.54	32
Total	5.37	0.55	5.84	0.61	225

### 4.3 Body height

Body height increased significantly in all children ( $F_{(1, 221)} = 1282.62$ ;  $p < 0.001$ ), though children from IV-1 were generally taller ( $F_{(2, 221)} = 7.629$ ;  $p < 0.001$ ) than children from the two other schools.

*Table 16: Height (m) differences in the different schools at baseline and follow-up.*

School	Baseline		Follow-up		N
	Mean	SD	Mean	SD	
IV-1	1.36	0.11	1.41	0.11	101
IV-2	1.31	0.08	1.35	0.08	91
CS	1.35	0.10	1.39	0.10	32
Total	1.34	0.10	1.38	0.10	224

In each of the three schools a significant increase in PWV was recorded after one school year. However, the increase of the first intervention school was larger, as compared to the control school.

Since body height showed the highest correlation with baseline PWV, a further ANCOVA was conducted including the change in body height (from baseline to follow-up) as a covariate in the model. The analysis revealed a significant interaction for PWV \* School \* Change in body height ( $F_{(3, 220)} = 3.315$ ,  $p = 0.021$ ) indicating that the increase in PWV was not independent from the increase in height and school. Children of the IV-1 were generally larger ( $F_{(2, 221)} = 7.629$ ;  $p < 0.001$ ) than children from the two other schools, showed a larger increase of height and increase of PWV ( $F_{(2, 220)} = 3.834$ ,  $p = 0.023$ ).

### 4.4 Sex

Including sex as a further factor in a 3-way ANOVA indicated a significant difference in PWV between girls and boys (sex:  $F_{(1, 219)} = 6.62$ ,  $p = 0.011$ ) but no interaction ( $F_{(1, 219)} = 1.42$ ,  $p = 0.235$ ). Hence, independent of school or intervention, higher PWV was recorded in boys as compared to girls (see Figures 10 and 11). The intervention did not differentially affect boys and girls.

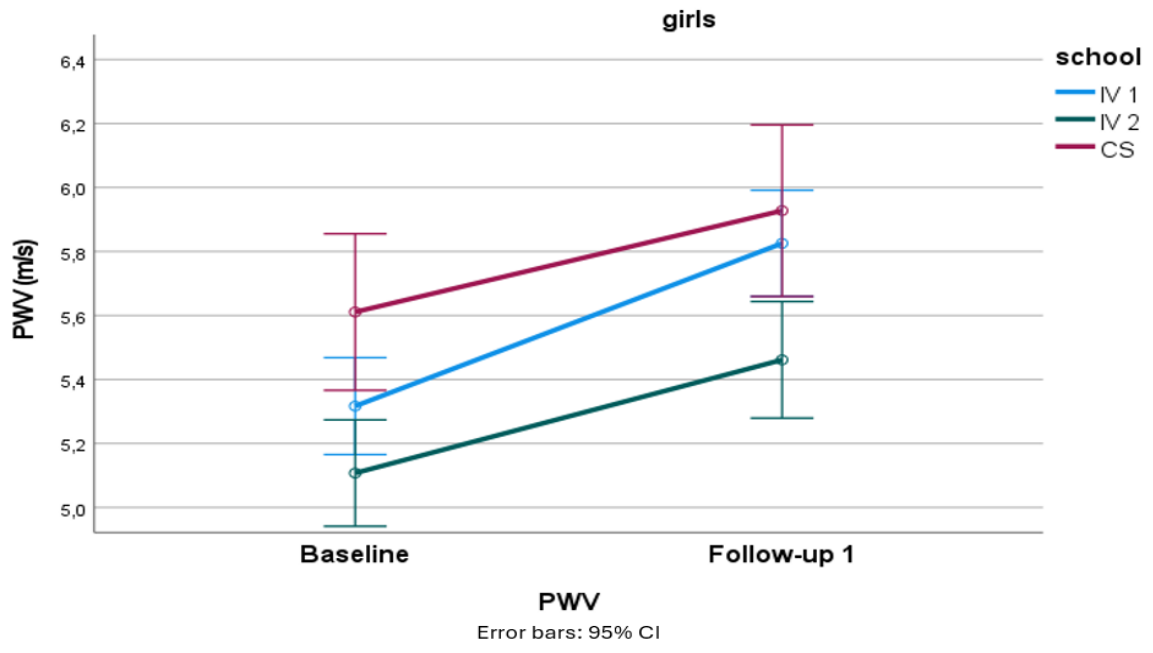


Figure 10: PWV values at baseline and at follow-up for female children.

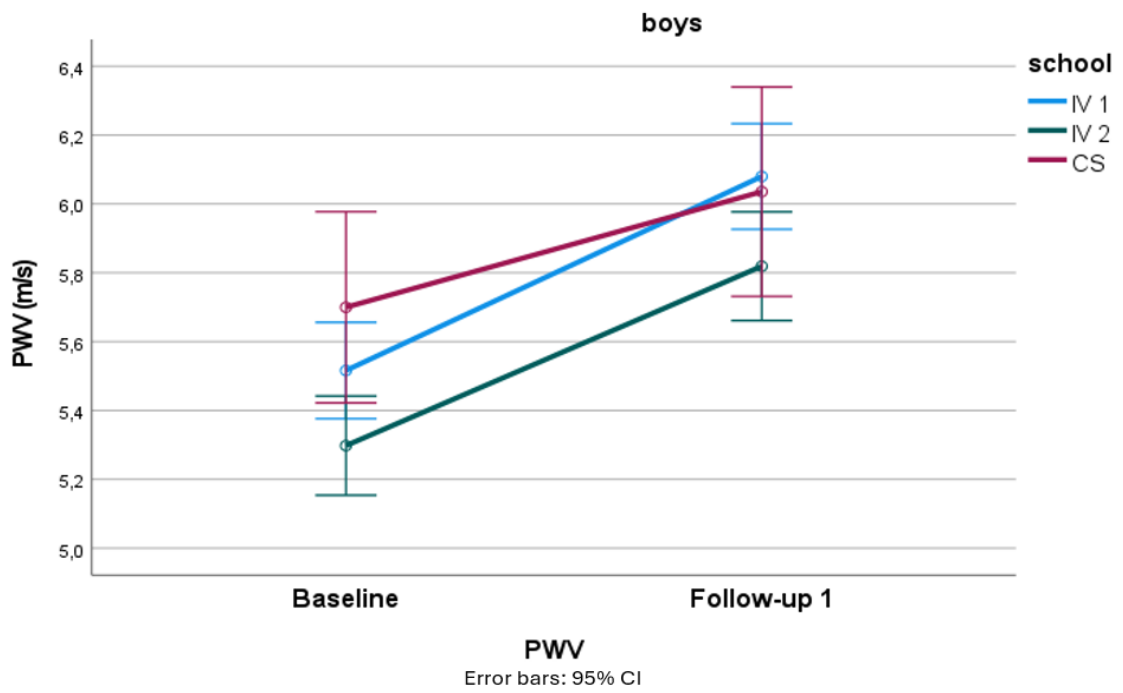


Figure 11: PWV values at baseline and at follow-up for male children.

## 5 Discussion

This study aimed to examine whether a school-based physical activity intervention has an impact on changes in PWV in primary school children. PWV measurements were obtained from a total of 225 children aged 6 to 11 years at the start of the study and again after one school year to evaluate the program's effects.

Baseline PWV was higher than expected and significantly correlated to age, height and weight as well as to blood pressure. We observed a significant increase of PWV over the school grades, and thus with higher age, which corresponds to the current literature. While PWV increases with age, the PWV values of the children in this study are noticeably higher than what has been described in the literature (see Table 1 and Figure 6) (55).

Corresponding to the significant difference in age between the three schools, we also observed a higher PWV in children who were older. In the two schools with high migration background (IV-1, CS) BMI was higher and also the number of children with overweight/obesity was higher. Compared to the baseline measures, PWV significantly increased in all children after one school year. However, the PA intervention had no clear effect on the increase/change of PWV. As to be expected from the literature (55), an increase of PWV was found in all children, though the increase was larger in both intervention schools as compared to the control school.

However, PWV measurements of two time-points were performed in only 32 children in the CS, compared to 122 in the IV-1, and 91 in the IV-2. Furthermore, children of the CS had already a higher PWV at the beginning of the study (at baseline), which might have limited a further developmental physiological increase.

The children of the three schools differed largely in their socio-economic backgrounds, with the IV-1 and the CS showing similar, but lower socio-economic backgrounds, with a higher number of children having a migration-background, as compared to IV-2 (71).

The significant correlation between PWV and SBP as well as the significant difference between the three schools and the school grades in PWV might be explained by the slightly older age of the children in the CS compared to the children in the IV-2.

Furthermore, differences in the mean BMI values of children may have contributed to the differences in the schools. The IV-1 had the highest mean BMI with 18.52 kg/m<sup>2</sup>, which

was comparable to the CS, where the mean BMI was 18.42 kg/m<sup>2</sup> while the mean BMI for children in the IV-2 was lower with 16.47 kg/m<sup>2</sup>. Overweight and obesity were observed in over 30% of the children in the IV-1 and CS, compared to 89% of children having normal weight in the IV2.

Overweight and obesity are associated with a higher PWV in children, as well as SBP and DBP (72, 73). Blood pressure values (SBP, DBP and MAP) were significantly higher in children with overweight and obesity, however, no significant difference between children with overweight, obesity and normal weight were observed considering PWV. Furthermore, at baseline as well as at follow-up, PWV was higher in boys than in girls. One explanation could be the age of the participants (see Table 10) as well as the known sex differences, with higher PWV values having been described in male children, which start appearing at the age of 9 years (55).

Comparing the follow-up to the baseline measures, PWV increased in all three schools. However, the control school showed a smaller delta change than the two intervention-schools. At baseline, the mean PWV for the children of the IV-1 was 5.43 m/s and increased to 5.96 m/s at follow-up. The difference of 0.53 m/s is comparable to the difference in the IV-2, which was 0.45 m/s, with a mean PWV of 5.22 m/s at baseline, and 5.67 m/s at follow-up. In the CS, a mean PWV of 5.65 m/s was measured at baseline, and 5.98 m/s at follow-up. The difference, of 0.33 m/s is surprising, since the CS did not partake in any school-based PA program during the study period. While the PWV values for the two intervention-schools evolved in a similar manner, though at different starting points, the PWV values for the CS were higher at baseline and did not show the same increase as the two intervention schools.

This is a rather unexpected result, since the existing literature suggests that a school-based PA-program would lead to a smaller increase in PWV, compared to a control school where such an intervention was not carried out. Kelhut et. al. described a decrease in PWV after a 9-month school-based PA intervention in 8-year-old children. However, limited data on the effects of school-based PA interventions exists. Similarly to the results of this study, Meucci et. al. (59) could not show significant aPWV changes in children after an 8-week game-based movement intervention.

Davis et. al. investigated the effects of an 8-month after-school aerobic exercise program, where children with overweight and obesity, between the ages of 8 to 11 years, who did not partake in regular PA ( $\geq 1$  h/week), were randomized to participate in daily aerobic activities, which were led by an instructor, for a duration of 40 minutes. They found that arterial stiffness did not improve solely due to the exercise intervention, however, its improvement was linked to reductions in blood pressure, BMI, and insulin resistance (63).

With a majority of children and adolescents not meeting the WHO recommendations for MVPA (28), which, for children between 5 and 17 years should consist of 60 minutes of aerobic MVPA daily in addition to muscle and bone strengthening activities on at least three days per week, as well as the incorporation of vigorous intensity aerobic activities (32), increasing PA in children can lead to significant benefits later in life, since both, PA levels, as well as obesity, persist into adulthood (29,30,34). Different studies have shown the positive effects of PA on PWV (27, 58). Furthermore, the positive influence of cardiorespiratory fitness on PWV, and PA on PWV in children with overweight, have been described in the literature (23,33). However, the hypothesis of this study was not a reduction in PWV but rather a smaller increase due to the PA intervention, considering the physiological and growth-related changes that naturally affect PWV.

An increasing prevalence of obesity, a key element in the development of arterial stiffness, was observed in children over the past decades (20,27,28). The finding that overweight and obesity as well as SBP were correlated with a higher PWV is in accordance with the literature (20, 23, 27, 28). With 31.3% of children in the CS and 35.6% of children in the IV-1 having overweight and obesity, the SBP, DBP and MAP were significantly higher. PWV correlated with BMI at follow-up, however, at baseline, only a weak non-significant correlation between BMI and PWV was observed. The finding is rather unexpected because of what the literature would suggest.

Köchli et al. investigated the relation or association between PWV, obesity and PA in children, which was assessed using the validated 20-meter shuttle run test, as well as a 20-meter sprint test. Furthermore, data on physical activity and screen time were gathered through parent-completed questionnaires. The results showed a correlation between increased PWV and higher BMI and BP, while PA correlated with a lower PWV (27).

However, this study did not hypothesize a reduction in PWV but rather a slower increase as a result of the PA intervention, considering the physiological and growth-related changes that naturally affect PWV.

As part of the “Happy children” study, the physical fitness of children was assessed and an improvement in physical fitness was observed (71). With those findings in mind and according to the existing literature, an improvement in PWV could have been expected as well, which was not the case in this study.

## **5.1 Methodological Considerations**

Possible explanations for the results could be the influence of the physiological changes occurring in the children’s development and the challenges in measuring PWV. Furthermore, the differences in SES and the high percentage of children with a migration background in the IV-1 and CS could be relevant factors influencing the data. The PWV values for children in all three schools, at both measuring points, were higher than the reference values described in the literature (55, 64). The PWV values of the children in the CS in particular were significantly higher at baseline, compared to the other schools. The higher starting point could be a reason for the smaller increase in PWV. While the PWV of the children in the IV-2 was generally lower than in the IV-1, the PWV evolved in a similar manner, what might be a result of the intervention.

With the existing literature showing effects of school-based PA programs, and the fact that the PWV values in all three schools were higher than what the literature would suggest, a reduction in PWV after one school year could have been expected.

The discrepancy of the PWV values in this study and the existing literature as well as the unexpected PWV changes of the CS, could be attributed to different factors. One reason could be different lifestyles and behaviors outside the school environment. Lona et. al. investigated the association of parental SES and PA with arterial stiffness in children and found that higher maternal PA levels positively influence arterial stiffness in their children (65).

Another reason could be the PA-program and the type of exercise itself. Comparing different exercise modalities, Sequi-Dominguez et.al. found that aerobic exercise and high intensity interval training (HIIT) were the most effective strategies for reducing arterial

stiffness in children. However, recommendations for the optimal duration, frequency, volume and intensity were difficult to make, due to the high heterogeneity of the studies (66). The results of Davis et. al., which show an improvement in PWV as a result of multiple factors (63), suggests that extended periods of PA need to be sustained in order to see vascular adaptations and improvements in arterial stiffness, and that the time period between measurements was too short to show significant improvements in PWV, which might also hold true for our results.

Dobbins et. al. analyzed 26 studies and found some evidence for school-based PA interventions positively influencing different health metrics in children and adolescents. However, they also stated that one needs to be careful when interpreting the results, since they show, at least, a moderate risk of bias (67).

The participation of the children in the exercise program can be seen as paramount to the success of the intervention. With teachers being the primary initiators of active learning and PA in this intervention, their role in motivating children to participate cannot be ignored. Errisuriz et. al. found that the engagement behavior of teachers is linked to the activity of the children during the lesson, as well as their PA intensity (68).

## **5.2 Challenges of measuring Pulse Wave Velocity**

While aPWV is regarded as the gold standard for assessing arterial stiffness and recommendation concerning the standardization of the measurements exist (56), differences in the estimation of the arterial length exist in different studies (17, 60, 61). Different measuring techniques for estimating the arterial length have been described in the literature and the use of various methods to estimate arterial length has made it challenging to compare aortic PWV results across different studies (60). Sugawara et al report, in their paper from 2010, that: “There have been no studies that comprehensively assessed the impact of different body surface measurement on absolute PWV values“ (60). In a more recent study from 2021, Stone et al. have stated that different methods of measuring carotid-femoral-PWV exist but that “regardless of the approach, applanation or imaging of the carotid artery is required”, which can be challenging in people with obesity, for example (61). The interobserver variability of PWV measurements could be an important factor contributing to results not being comparable, even in our study.

Furthermore, the physiological and pubertal changes occurring in children need to be kept in mind when discussing the vascular structure (20,23). This can be illustrated by the development of ISH which is a consequence of arterial stiffening and typically affects elderly patients (22), it can also be observed in young males (21). With the clinical significance being somewhat unclear, Scott et al. suggest that for young males the CV risk depends on the modifiable risk factors and that there is no increased CV risk for young males without risk factors such as obesity (21).

Significant body height increases were found in all three schools. However, children from the IV-1 were, with a mean height of 1.36m at baseline and 1.41m at follow-up, generally taller and have also grown more than children of the other two schools. Height in the IV-2 increased from 1.31m at baseline to 1.35m at follow-up and from 1.35m to 1.39m in the CS.

Lastly, the differences in the devices used and their use in a pediatric population, and the fact that they might be developed and validated on adult participants, need to be kept in mind (69, 70). By comparing three different devices for measuring PWV in children, Kis et al. found that the Vicorder device underestimated PWV compared to two applanation tonometry devices. However, after adjusting the path length, the results became comparable. Furthermore, they state that standards need to be established, in order to achieve comparable results when using different devices (70).

### **5.3 Strengths and limitations**

This study had several strengths, but also some limitations. One in particular being it's longitudinal design which allowed changes in PWV to be observed over time. The fact that the intervention was implemented in a school setting ensured that children could consistently carry out the daily PA recommendations in a controlled environment, independent of their leisure time activities. In an attempt to ensure that any observed differences in PWV could be attributed to the intervention rather than external factors, a CS was included. Furthermore, PWV has been described as a reliable marker for the assessment of arterial stiffness, which has been proven to be a marker of vascular health. In an attempt to reduce bias and ensure consistency, an effort was made to standardize the measurement conditions. Furthermore, to support the intervention schools and ensure implementation of the program, a designated contact person, who regularly visited the

intervention schools, was provided. Additionally, teachers from the intervention schools were required to keep a log, received appropriate training before the start of the project and were provided with materials for implementing the intervention in the classroom.

Despite these strengths, the study had some limitations. The presence of uncontrolled external factors, such as diet, sleep patterns, stress levels, and daily activity outside of school were difficult to account for. Additionally, potential measurement variabilities, due to inconsistencies between assessors, which were tried to be avoided, but, unfortunately, could not be fully eliminated, need to be taken into account. With changes in the vascular structure sometimes taking time to develop and adaptation processes of the vasculature being influenced by long-term adaptations to lifestyle and health behaviors, the duration of the study might be a limiting factor, as well as the fact that the optimal dose of MVPA for inducing vascular changes in children is difficult to define. The possibility of any improvement in PWV, as a result of increased PA, was offset by physiological age-related changes, persists. Moreover, age-related physiological changes occurring as part of the children's development are an integral part influencing the observed results.

## **5.4 Conclusion**

This study examined the effects of a school-based PA intervention on arterial stiffness, measured by PWV, in primary school children. Measurements were obtained before the intervention, at baseline, and at a follow-up, after one school year (9 months). Despite the implementation of a structured PA program, in order to achieve 45 minutes of MVPA per day, no significant reduction in PWV was observed in the intervention schools. These findings may be explained by several findings, including the duration of the study, different lifestyle habits and the possibility that the intensity and volume of PA were insufficient to induce significant vascular adaptations.

Nevertheless, with the growing rate of childhood overweight and obesity, the school setting offers an environment where PA can be incorporated in a structured way, creating habits for healthy lifestyle choices which could potentially reap huge benefits by and counteract potential future health problems at an early age. More research is needed to define the optimal duration, frequency and intensity of PA interventions. Furthermore, longitudinal studies could reveal long term adaptations and the role of early PA interventions as a preventative measure against noncommunicable diseases. From a public

health perspective, these findings emphasize the need for long-term strategies for combating the growing prevalence of childhood overweight and obesity.

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## Supplementary material

Table 17: Sex differences in PWV by school grade.

Dependent Variable: PWV (m/s)				
Grade	Sex	Mean	SD	N
1	F	5.01	0.48	20
	M	5.12	0.55	22
	Total	5.10	0.52	42
2	F	5.28	0.48	31
	M	5.49	0.65	27
	Total	5.38	0.57	58
3	F	5.45	0.51	22
	M	5.38	0.50	31
	Total	5.41	0.50	53
4	F	5.31	0.55	31
	M	5.60	0.53	41
	Total	5.47	0.56	72
Total	F	5.29	0.52	104
	M	5.44	0.57	121
	Total	5.37	0.55	225

Table 18: Correlation between PWV, age, height, weight, BMI and WHtR at baseline; \*\* = correlation is significant at the 0.01 level (2-tailed).

		PWV	Age (y)	Height (m)	Weight (kg)	BMI	WHtR
PWV	r	1	0.241**	0.298**	0.229**	0.117	0.030
	p		0.000	0.000	0.001	0.080	0.653
	n	225	225	224	224	224	223
Age (y)	r	0.241**	1	0.783**	0.561**	0.257**	-0.050
	p	0.000		0.000	0.000	0.000	0.455
	n	225	225	224	224	224	223
Height (m)	r	0.298**	0.783**	1	0.765**	0.394**	0.000
	p	0.000	0.000		0.000	0.000	0.996
	n	224	224	224	224	224	223
Weight (kg)	r	0.229**	0.561**	0.765**	1	0.885**	0.559**
	p	0.001	0.000	0.000		0.000	0.000
	n	224	224	224	224	224	223
BMI	r	0.117	0.257**	0.394**	0.885**	1	0.828**
	p	0.080	0.000	0.000	0.000		0.000
	n	224	224	224	224	224	223
WHtR	r	0.030	-0.050	0.000	0.559**	0.828**	1
	p	0.653	0.455	0.996	0.000	0.000	
	n	223	223	223	223	223	223

# Teacher's movement log

HAPHC/Happy children

Bewegungsprotokoll Lehrer\_V1\_12.05.2021

## Bewegungsprotokoll

Für die Woche von ..... bis ..... 2021

Schule/Klasse: .....

Tag	Fach	Aktivität	Intensität*	Dauer (min)	Anmerkung	Kürzel LP
Mo						
Di						
Mi						
Do						
Fr						

\* bitte geben Sie die Intensität der Aktivität in folgenden Abstufungen an:

- Gering: (Erklärung)
- Moderat: (Erklärung)
- Hoch: (Erklärung)

Info: es sollte moderat bis hoch sein, wenn aber nicht möglich, bitte in der Anmerkung eintragen!

Raum für weitere Anmerkungen:

- Wetter/äußere und innere Rahmenbedingungen? Hitze/Kälteperioden, Ausfall Klimaanlage...
- Befinden/Klassenklima/Stresslevel? Z.B. Leistungsdruck durch Tests usw. ...
- Besondere Ereignisse? Feierlichkeiten, besondere Events, Krisen (Verletzungen, Bullying, etc.)

## Gesamteinschätzung

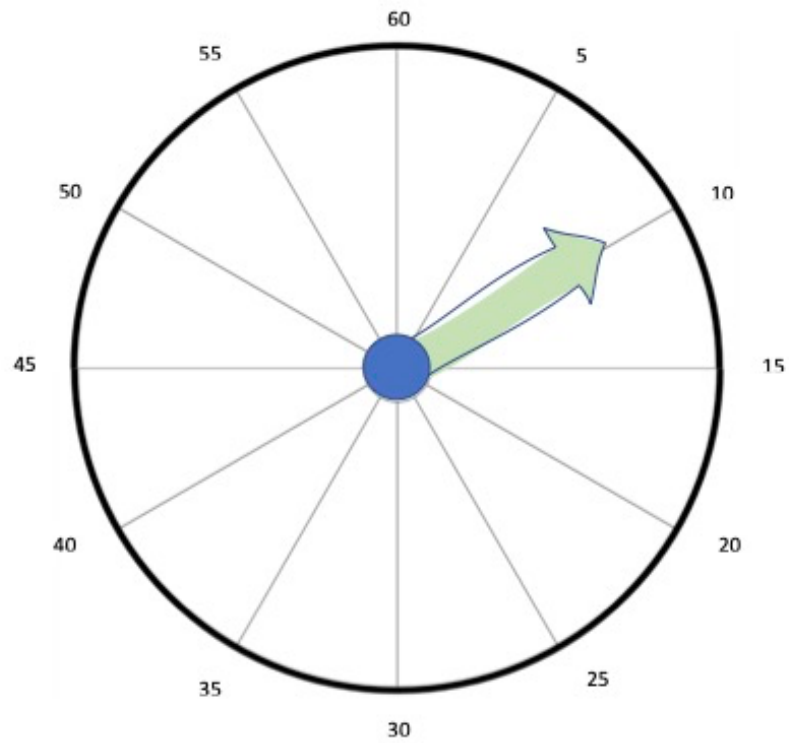
Wie anspruchsvoll war die Woche für die Kinder insgesamt? (Likert-Skala)

Gar nicht belastend	Eher nicht belastend	Weder/noch	Eher belastend	Sehr belastend
1	2	3	4	5

## Movement Clock with Likert scale

### Meine Bewegungsuhr

Wie viele Minuten hast du heute geschafft?



So bleibe ich gesund!

Ich fand die Bewegung im Unterricht heute:



# Parental Consent Form

## Elterninformation und Zustimmungserklärung zur Teilnahme ihres Kindes an der klinischen Studie

### **„Optimierung der kardiometabolischen Gesundheit, der kognitiven und schulischen Leistungsfähigkeit bei glücklichen Kindern durch körperliche Aktivität in der Schule“**

(Kurztitel: „Happy children“)

Originaltitel: Optimizing cardiometabolic Health, Cognition and Academic Performance with Happy Children (HAPHC) using school-based physical activity“

(Kurztitel: Happy children)

### **Eine Studie zur Wirkung einer schulbasierten Bewegungsintervention auf die körperliche Gesundheit, akademische Leistungsfähigkeit und das Wohlbefinden bei Kindern**

Sehr geehrte Eltern!

Die Volksschule Ihres Kindes/Ihrer Kinder wird ab dem kommenden Schuljahr (2021/2022) mehr Bewegung in den Unterricht bringen. Wie sich bereits in einigen Studien gezeigt hat, kann regelmäßige Bewegung nicht nur zu einer Verbesserung der körperlichen Gesundheit und des Wohlbefindens, sondern auch der geistigen Leistungsfähigkeit beitragen.

Viele Volksschulkinder machen zu wenig Bewegung, ernähren sich ungesund und leiden oft schon in frühen Jugendjahren an daraus resultierenden Erkrankungen. Um dieser Entwicklung entgegenzuwirken, wird mehr Bewegung in das Lernen gebracht und Bewegung wird Teil des Lernens.

Um den allgemeinen Gesundheitszustand steirischer Volksschulkinder und die Veränderungen gesundheits- und leistungsrelevanter Parameter als Reaktion auf die kontinuierliche Bewegungsintervention zu erfassen, möchte die Medizinische Universität Graz und die Kirchliche Pädagogische Hochschule in Graz die Kinder der teilnehmenden Schulen begleitend dazu untersuchen.

Das Bewegungsprogramm findet als ‚aktives Lernen‘ im Unterricht statt. Das bedeutet, dass nicht immer im Sitzen gelernt und geübt wird, sondern dass das Lernen in Bewegung stattfindet, indem z. B. bei Mathematik das Addieren beim Hüpfen auf Zahlen am Boden erlernt wird. Davon unabhängig, möchten wir Sie und Ihr Kind mit diesem Schreiben einladen auch an der oben genannten klinischen Studie, die begleitend stattfindet, teilzunehmen.

**Die Teilnahme Ihres Kindes an dieser klinischen Studie erfolgt freiwillig. Ihr Kind kann jederzeit ohne Angabe von Gründen aus der Studie ausscheiden. Die Ablehnung der Teilnahme an dieser Studie hat keine nachteiligen Folgen für die schulische Betreuung Ihres Kindes. Ebenso haben Sie die Möglichkeit, jederzeit und ohne Angabe von Gründen, die Verwendung der Daten Ihres Kindes zu widerrufen. Die in den Unterricht integrierte Bewegung ist eine Lehrmethode und findet auch statt, wenn Ihr Kind nicht an der Studie teilnimmt. Ihr Kind wird ebenfalls befragt, ob es an der Studie teilnehmen möchte.**

Klinische Studien sind notwendig, um verlässliche neue medizinische Forschungsergebnisse zu gewinnen. Unverzichtbare Voraussetzung für die Durchführung einer klinischen Studie ist jedoch, dass Sie Ihre Zustimmung zur Teilnahme Ihres Kindes an dieser klinischen Studie schriftlich erteilen. Bitte lesen Sie den folgenden Text sorgfältig durch und zögern Sie nicht, Fragen zu stellen.

Bitte unterschreiben Sie die Zustimmungserklärung nur

- wenn Sie Art und Ablauf der klinischen Studie vollständig verstanden haben,
- wenn Sie bereit sind, der Teilnahme Ihres Kindes zuzustimmen und
- wenn Sie sich über die Rechte Ihres Kindes bei Teilnahme an der Studie im Klaren sind.

Zu dieser klinischen Studie sowie zur Elterninformation und Zustimmungserklärung wurde von der zuständigen Ethikkommission eine befürwortende Stellungnahme abgegeben.

### **1. Was ist der Zweck der klinischen Studie?**

Kinder und Jugendliche bewegen sich immer weniger. In Kombination mit ungesunder Ernährung hat dies weltweit zu einer starken Zunahme an Übergewicht und Fettleibigkeit bei Kindern geführt. Sehr häufig kommt es bereits in Jugendjahren zu körperlichen Erkrankungen, die unmittelbar auf das Übergewicht und die Fettleibigkeit zurückgeführt werden können. Um Kinder rechtzeitig vor diesen Folgen zu schützen, wird in das Lernen eine tägliche Bewegungseinheit von 45 Minuten eingebaut. Diese Bewegung wird zusätzlich zum Sportunterricht im Rahmen des Schulalltags Ihres Kindes stattfinden und von einem Lehrer oder einer Lehrerin durchgeführt. Die Medizinische Universität Graz und die Kirchliche Pädagogische Hochschule werden die Kinder der teilnehmenden Schulen hinsichtlich gesundheitsrelevanter Merkmale untersuchen.

### **2. Wie läuft die klinische Studie ab?**

Zu Beginn des kommenden Schuljahres (September 2021) wird Ihr Kind von einem Team der Medizinischen Universität Graz und der Kirchlichen Pädagogischen Hochschule im Hinblick auf seine körperliche und seelische Gesundheit untersucht. Diese klinische Studie findet an insgesamt drei Volksschulen mit rund 750 Schülern/innen statt und wird direkt in der Schule durchgeführt. Die aus Studiengründen durchgeführten Messungen und Tests werden an zwei Tagen innerhalb einer Woche am Vormittag in der Schule durchgeführt und jeweils etwa 60 Minuten pro Tag bzw. pro Kind dauern. Nach einer ersten Erhebung im September 2021, erfolgt ein Mal jährlich eine Erhebung im Juni des darauffolgenden Schuljahres um zu prüfen, für wen bzw. unter welchen Bedingungen die Bewegungsintervention effektiv war. Je nach Schulstufe werden wir Ihr Kind daher ein bis zwei Mal pro Schuljahr untersuchen.

#### Folgende Maßnahmen werden ausschließlich aus Studiengründen durchgeführt:

Zu Beginn der Studie wird ihr Kind in Hinblick auf verschiedenen Gesundheitsparameter untersucht und vermessen. Dazu werden Größe, Gewicht, Taillen- und Hüftumfang und der subkutane Fettanteil gemessen. Der Blutdruck und die Pulswellengeschwindigkeit sowie ein Foto des Augenhintergrunds geben Auskunft über die Gesundheit des Herz-

Seite 2 von 7

Klinische Studien sind notwendig, um verlässliche neue medizinische Forschungsergebnisse zu gewinnen. Unverzichtbare Voraussetzung für die Durchführung einer klinischen Studie ist jedoch, dass Sie Ihre Zustimmung zur Teilnahme Ihres Kindes an dieser klinischen Studie schriftlich erteilen. Bitte lesen Sie den folgenden Text sorgfältig durch und zögern Sie nicht, Fragen zu stellen.

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# Participant Information for Children

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## Schüler/innen-Information

### **„Optimierung der kardiometabolischen Gesundheit, der kognitiven und schulischen Leistungsfähigkeit bei glücklichen Kindern durch körperliche Aktivität in der Schule“**

(Kurztitel: „Happy children“)

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Bei Erstklässler/innen entfallen die Fragebögen und der Text ist vorzulesen!

### **Liebe Schülerin! Lieber Schüler!**

Viele Kinder bewegen sich viel zu wenig und essen sehr ungesund!

Das kann später zu einigen Krankheiten führen. Damit es nicht dazu kommt, wird in deiner Schule beim Lernen mehr Bewegung gemacht.

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