Compliance with clustered lifestyle intervention targets and their contribution to obesity in the IDEFICS study

Doctoral (PhD) Dissertation

Dr. Eva Kovacs [1, 2]

[1]Department of Paediatrics, Medical Faculty, Clinical Centre, University of Pécs, Hungary
[2]Institute for Medical Information Processing, Biometrics and Epidemiology and
German Centre for Vertigo and Balance Disorders,
Ludwig Maximilian University, Munich, Germany

Programme leader: Prof. Dr. Dénes Molnár, director

Department of Paediatrics, Medical Faculty, Clinical Centre, University of Pécs, Hungary

Clinical Medical Sciences Doctoral Schools of the University of Pécs
Leader of doctoral school: Prof. Dr. Gábor Kovács L.

University of Pécs, Medical Faculty
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Aims of the study

The aim of this work is to describe the adherence to the most important intervention messages of childhood obesity, and to evaluate how compliance with these recommendations contributes to a reduction in overweight (including obesity) prevalence with respect to each individual message and to the composite compliance score of these pro-health set of behaviour.

Introduction: the epidemiology and importance of childhood obesity

Definition of obesity

Obesity is defined by the World Health Organization (WHO) as accumulation of excessive body fat content which may have adverse effects on health[1]. This definition assumes that we should be able to differentiate between increased total body weight due to fat content or due to increased fat-free mass. Body mass index (BMI; body weight in kilograms divided by the height in meters squared) categorisation, the most frequently used single indicator for assessing obesity status, is not capable for this, referring only on weight for height but not fat content. The direct measurement methods of body composition (densitometry, whole body magnetic resonance imaging or dual energy x-ray absorptiometry) which can provide the most accurate insight into fat content, are not proper for field studies of large samples, so have limited epidemiological value, serving only as reference methods. Thus, in the assessment of obesity we have to rely on approximating non-invasive methods. This assessment can be done by several anthropometric methods, most frequently describing central obesity (waist circumference, waist/hip ratio, waist/height ratio, conicity index) with respect to its pathological importance in indicating metabolic disorders; or estimating body composition (calculation of fat content based on equations of skinfold thickness measurement or bioelectrical impedance). The problem of anthropometric methods (beyond the technical questions of reliability) lies in the comparison to reference values. The references are specific to certain populations having different anthropometric characteristics; besides sensitive to cohort effect: taking into account the increasing prevalence of childhood obesity in the previous decades, i.e. the considerably fast shifting of the mean towards higher values, the date when the reference values were created is also crucial. In spite of these difficulties and considerable restrictions of evaluating the results, thanks to its simplicity in field studies and for screening purposes still the BMI is the most widely accepted approach. The WHO[1] draw the line for underweight at <18.5 kg/m^2, the overweight between 25 - <30 kg/m^2, the obesity >30 kg/m^2 and the serious obesity >35 kg/m^2.

Regarding childhood obesity, in the literature the use of three international BMI reference standards are the most widespread, established by the International Obesity Task Force (IOTF, now World Obesity / Policy & Prevention)[2, 3], which was upgraded and extended in 2012[4], the WHO[5] and the Centers for Disease Control and Prevention (CDC)[6]. They are based on different principles: the IOTF cut-offs correspond with the adult thresholds of the 18.5, 25, 30 and 35 kg/m^2, adjusted to age and gender, while the WHO applies the ±1 and ±2 standard deviation score and the CDC draws the line by the 5th, 85th and 95th centile values. The IOTF and WHO data were derived from various international populations, the latter restricted to those children whose development and circumstances could be considered as optimal; while the CDC, though the use of it is widespread, is restricted to national population. Several countries also established their national standards, which further contribute to the diversity. According to the position paper of the European Childhood Obesity Group[7], for epidemiological purposes, in favour of international and cohort comparability, the use of both IOTF and WHO standards is recommended. For clinical purposes the use of national standards may be more beneficial. In both cases, the additional anthropometric assessment may refine the picture.

Epidemiology of childhood obesity

In the last decades a rapid growth of the prevalence of obesity was experienced worldwide[8], making it a public health crisis the importance of which can be best illustrated with the forecast that this phenomenon could reverse the increase in life expectancy having been observed in the past decades[9]. Between 1980 and 2013 the global prevalence of overweight and obesity combined rose by 27.5% for adults and 47.1% for children[10]. In 2013, in developed countries, the prevalence of childhood and adolescent overweight, including obesity, was slightly greater in boys (23.8%) compared to girls (22.6%). This is a significant increase when compared to 1980 data where 16.9% boys and 16.2% girls were overweight[10]. The greatest incidence of obesity worldwide was experienced between 1992 and 2002, afterwards a slowing has been observed in developed countries[10]. Weight gain seems to have been diminishing since 2006, and there is some evidence that recent birth cohorts are gaining excess weight more slowly than previous generations[10].

In the last years several studies reported an unexpected yet welcomed plateauing of obesity epidemic[11],[12] almost exclusively in the developed countries. Explanation is not consensual: the saturation hypothesis, i.e. that the obesogenic environment influencing both the energy intake[13] and the energy expenditure[14] has already affected all the susceptible individuals, is equally plausible as the beneficial results of cumulated intervention and policy efforts[11]. Unfortunately, the stabilization of obesity prevalence is not a general phenomenon: it affects more but far not all countries among the developed economies, and even within Europe[15] it covers only some segments of population while children with low socioeconomic status[16] are more vulnerable even in this aspect. Participation rate in such convenience surveys may also cause bias, besides, the BMI has several limitations assessing obesity, and according to some recent investigations, the obesity assessed by waist circumferences doesn't correspond with the seemingly favourable trend of BMI change[17]. Moreover, there are examples that previous stable phases have been followed by further increases in the prevalence of obesity[12] so the present trend can`t be regarded as guarantee for a long-term favourable change as long as the environmental systematic contributors[18] remain unchanged on a global level.

Even if long-term observation will reinforce this favourable trend of plateauing, the prevalence of childhood overweight remains unacceptably high, putting a serious burden[19] on individual health, health care systems and economies, thus obesity will still remain a major public health concern for the next decades[20].

Consequences of childhood obesity

If we want to summarize as briefly as possible the consequences, we can best rely on the statement of Abrams[21]: „Obese children suffer from many disease processes once thought to affect only adults". Evaluating this finding on its merit, we need to have a look on long-term consequences of adult obesity.

The repeated waves of the large-scaled NHANES (National Health and Nutrition Examination Survey) study mirrored the progression of the obesity epidemic, providing possibility to estimate the relative risks of mortality associated with body weight status[22]. Their findings reinforced the "U-shaped" correlation of body weight and mortality: compared to normal weight category, a slightly increased risk was observable in the underweight group, and the more severe the obesity was, the increased the risk. The minimum of the risk graph was observable around the 25 kg/m^2 BMI value; thus the overweight category hasn't revealed excess risk for mortality. More refined analysis regarding the cause-specific excess deaths[22] assessed that the body weight categories have different correlates: underweight increased risk for overall mortality, deriving from non-cancer and non-cardiovascular causes. Obesity was associated with significantly increased cardiovascular mortality and with some type of cancers; while combined overweight-obesity increased the risk for mortality from diabetes and kidney disease. Even the result of a systematic review[23], combining data of 97 studies covering a pool of 2.88 million individuals and more than 270,000 death, reinforced the findings of the NHANES, quantifying the hazard ratio as 0.94 (95% CI, 0.91-0.96) for overweight and 1.18 (95% CI, 1.12-1.25) for obesity all grades combined, and 1.29 (95% CI, 1.18-1.41) for grades 2 and 3 obesity.

Considering the pathophysiological characteristics of non-communicable diseases, a similar conclusion can hardly be driven within the timeframe of childhood, however, longitudinal studies could reinforce the long-term impact of childhood obesity as increased risk or morbidity and premature mortality in adulthood[24]. Though the number of the eligible studies was limited, they confirmed sufficiently an increased risk for morbidity of diabetes, hypertension, ischaemic heart disease, and stroke in adult life (OR 1.1-5.1), while associations with cancer morbidity were inconsistent. Early onset of cardiovascular risk could be proved even directly, by carotid intima-media thickness as indicator of impairment in vascular structure[25], which showed the highest correlation with waist circumference among anthropometric parameters assessing obesity.

Population-based data suggest that the epidemic of adult obesity is being followed by an epidemic of type 2 diabetes mellitus (T2DM). In recent years, type 2 diabetes has increasingly been reported among overweight and obese adolescents[26] and children. Currently, children with T2DM are usually diagnosed over the age of 10 years during middle to late puberty. An additional risk factor for childhood T2DM may be the gestational diabetes. As the childhood population becomes increasingly overweight, the occurrence of T2DM may be expected to shift to younger, prepubertal children. Based on gathered data, Daniels[27] estimated a maximum prevalence of 15/100,000 in the total paediatric population. Similar estimations rated the prevalence of high blood pressure 2-4%, the non-alcoholic fatty liver disease 3-8% overall and 50% in obese, the obstructive sleep apnoea 1-5% overall, and ~25% in obese, the dyslipidaemia 5-10%, the atherosclerosis 50% (fatty streaks) and 8% (fibrous plaques). On a sample of 260,000 overweight and obese children[28] at least one cardiovascular or metabolic risk factor was present in 52%.

Traditional cardiovascular risk factors associated with obesity are frequently detected in children and especially in adolescents. Hypertension in paediatric age was usually secondary, dominantly due to nephrologic disease[29], nowadays appears increasingly connected to obesity, achieving a prevalence of 1-5% [28],[30]. Several metabolic complications[31] complete this picture, including unfavourable blood lipid profile, elevated LDL-cholesterol, decreased HDL-cholesterol or elevated triglyceride level, hyperinsulinaemia/insulin resistance.

Childhood obesity carries several other, short-term burdens as well. Hormonal and pubertal developmental alterations may be the most distressing problems: pseudogynecomastia and pseudohypogenitalism for obese boys; hirsutism and increased acne formation in obese girls, which can be aggravated by early menarche, irregular cycles or polycystic ovary syndrome[32]. Orthopaedic complications, musculoskeletal complications[28] in up to 74% of overweight children, pseudotumor cerebri, skin alterations and impaired micronutrient[33] or antioxidant status [34] are also observable in obese children.

Perceived stress contributes to obesity by several means[35] including hormonal pathways or facilitating simply behavioural effects like stress-induced eating as false coping strategy. Family dysfunction or familial stress, adverse parenting style may also play a role in the onset and maintenance of the child's obesity. Unfavourable psychosocial consequences, as a result of altered physical appearance and physical handicap, further aggravated by the presence of metabolic syndrome[36], are also common. Children may be labelled negatively, suffer rejection, have poorer interpersonal relationship and become socially isolated, or acquire a distorted body image[37], elevated depression, anxiety, behaviour problems, attention deficit hyperactivity disorder up to 58% of overweight children[28] and disordered eating[38]. These psychosocial and psychological problems can persist into adulthood[39], [40].

The social burden of obesity also affects educational attainment: lower intelligence quotient[41] and learning difficulties[42, 43] due to night hypoventilation or sleep apnoea and malnutrition due to energy-dense, nutrient-poor foods may lead to completing fewer years of schooling and decreased socio-economic status in adulthood. The correlation of academic performance and obesity can be reinforced even from reverse direction: successful interventions targeting obesity may increase the school achievements[44].

Metabolic syndrome and metabolically healthy obese phenotype

The history[45] of the metabolic syndrome goes back to the Italian physician and anatomist, Morgagni[46], who described an association between visceral obesity, hypertension, atherosclerosis, high levels of uric acid in the blood, and episodes of obstructed breathing during sleep. In 1947, the French physician Jean Vague was the first to identify that upper body adiposity (as he called, 'android obesity') is frequently accompanied by an increased risk for the atherosclerosis, diabetes, kidney stones and gout. The term "metabolic syndrome" was introduced by Herman Haller in 1977 describing the co-existence of obesity, diabetes mellitus, high blood lipids, a high uric acid level and fatty liver disease. In 1988, Ruderman and Reaven stated that insulin resistance might be the underlying common factor linking the elements of this "syndrome X". The concept proved to be useful for identifying the patients being at risk for cardiovascular disease.

A decade later, experiencing the epidemic of obesity in childhood and the consequent „tsunami of chronic diseases"[47], the metabolic syndrome was extended to the paediatric population; though it was difficult to apply the adult, well-established cut-offs to children. The concept went through on different refinement and dispute[47], but proved to be a useful tool for identifying patients and monitoring progress of status in spite that we still lack consensus regarding the exact definition.

Overweight and obesity in youth plays a central role in the development of the metabolic syndrome[48, 49] (MetS), defined as clustering of the above listed risk factors. This was repeatedly reinforced by further investigations[50], comparing the prevalence of MetS among overweight and obese children in five European countries according to the four most accepted definitions (Ferranti et al., the World Health Organisation, the National Cholesterol Education Program and the International Diabetes Federation). The prevalence of MetS was 35.7%, 31.4%, 20.3%, and 16.4%, respectively; while 12.2% of children had MetS and 55.8% were free from MetS according to all four definitions. A recent review[51] estimated the prevalence of MetS in Europe using a greater pool of data, but resulting in a very similar conclusion, finding the median prevalence of metabolic syndrome in whole populations 3.3% (range

0%-19.2%), in overweight children 11.9% (range 2.8%-29.3%), and in obese populations 29.2% (range 10%-66%). The lack of consensus regarding the definition of MetS in childhood can result even a tenfold difference in the prevalence[52] (0.9-11.4%) according to the applied different cut-offs and components. Without proper threshold values for paediatric population it is difficult to establish exact prevalence data or make recommendations regarding screening[49].

This established cluster of metabolic disturbances is closely related to central obesity, however, accumulating evidences suggests that not all obese subjects are at increased cardiometabolic risk, i.e. such as "metabolically healthy obese" (MHO) phenotype exists[53]; and in reverse, even lean subjects can be “metabolically obese”[54]. Similarly to the lack of consensus of MetS, the reverse of this, i.e. the MHO is also ill-defined: a review[55] collected more than a dozen definitions of metabolically healthy obesity. Exact estimation of the prevalence of MHO is difficult: a five-fold difference can occur depending on the applied definitions (6.8% to 36.6% of the obese population)[56].

Several hypotheses have evolved, trying to explain the phenomenon of MHO. Considering the well-known benefits of physical activity, it is evident that several studies assumed to find the difference between MHO and at-risk population in the level of physical activity or fitness[57] and found it a powerful modulator of metabolic risk, regardless of determining obesity either by BMI or by body composition. Quantifying this effect, if MHO was indicated by low insulin resistance, better physical activity meant almost twofold chance for avoiding metabolic risk (OR 1.87, 95% CI 1.19-2.92, $p = 0.006$)[56]. From the other direction, an intervention program aiming at physical activity[58] could reverse the metabolic complications in 40% of the metabolically unhealthy obese population, though still obese, and even a dose-response grade was observable: the higher the energy expenditure and change in fitness, the more likely the metabolic improvement. Interestingly, some other studies do not support this[59]. Explanations regarding muscle quality and muscle metabolism[60] or independent assessment of the muscle strength[61] apart of the fitness level may solve this contradiction.

Several lifestyle factors[56] were also presumed as explanation for MHO. Higher dietary quality were positively associated with metabolic health in obese (OR 1.45-1.53)[56]. Other authors also blame the “typical Western diet”[54], underpinning among these factors the fructose load. Some micronutrients were identified to contribute, e.g. vitamin D deficinecy[62] was observed in the metabolically unhealthy obese population compared to MHO, and the same was true for magnesium[63] or antioxidant[64] level. Other observations also supported the concept that avoiding nutrient-poor diet and high carbohydrate intake[65] may be beneficial for metabolic health.

Research on the role of higher sleep duration is scarce, but a study reported it as a contributor to MHO[66]. Referring to the importance of sleep duration in childhood obesity, this association can`t be fully neglected.

Even the role of environmental pollution[67] is hypothesized, the circulation organic pollutant contributing to disrupted glucose metabolism.

Findings regarding stress level are limited and controvesal[68], but considering the association of psychosocial stress with increased level of inflammatory markers, and the association of low-grade chronic inflammation with obesity, inflammatory processes may mediate between these states[69]. This leads towards the inflammation theory, which is the most plausible underlying hypothesis of MHO[70], being observable already in childhood[71]. Investigating a wide range of inflammatory markers, MHO patients demonstrated better results (OR 1.7-4.0) than the metabolically affected obese subjects[72]. Unfavourable inflammatory status seems to be more helpful in distinguishing between the at risk population and the MHO phenotype, though it is still unclear what triggers the immune response in the unhealthy population.

Based on the above finding, recently an extended definition of MHO is proposed[73], relying not only on the insulin resistance, but emphasizing the major role of the subclinical inflammation in the pathogenesis, including inflammatory markers as well as features of non-alcoholic fatty liver disease to distinguish between healthy and unhealthy obese phenotype.

Longitudinal studies have found that MHO may not be a stable condition[74]. The prospective Pizarra study[75] found MHO a “dynamic concept”, changing with body weight and over time[70]. This observation was reinforced by systematic reviews. A meta-analysis of prospective cohort studies[76] revealed that metabolically healthy obese adults show a substantially increased relative risk 4.03 (95% CI 2.66-6.09) of developing type 2 diabetes as compared to metabolically healthy normal-weight adults, which postulates that though MHO phenotype means a lower, almost halved level of risk compared to the majority of obese subject, it can't be regarded as a harmless condition.

Increasing body of evidence supports the statement that the benefit on MHO phenotype is merely relative. All-cause mortality and cardiovascular events as outcome showed for MHO subjects a relative risk 1.24 (95% CI, 1.02-1.55) compared with metabolically healthy normal-weight individuals, demonstrating that in respect of long-term outcome no healthy pattern of increased weight exists[77].

Thus, we can conclude that metabolically healthy obesity should be regarded as merely a delay, and in spite of having better risk profile that the unhealthy obese or even than the „metabolically obese" normal weight population, this subgroup should be handled as potentially risky population. However, this time window in the dynamically changing metabolic status can be used for intervention, improving body weight and other modifiable lifestyle factors, in favour of preserving the lower risk level. Though, a recent review warns, that this intervention can`t be generalized: the benefit from weight management is not equal for all patients because obesity doesn't equally adversely affect everybody; thus, weight loss is not the only mean of improving the risk status[78].

Evidence-based means of intervention

The intervention of obesity was put in focus even on policy level first in 1974 when the Lalonde-report[79] introduced the health field concept, stating that "there is little doubt that obesity, smoking, stress, lack of exercise and high-fat diets, make a dominant contribution to circulatory diseases". The report calls these behaviours „destructive lifestyle habits" the consequences of which are „self-imposed risks" of increased morbidity and mortality. It targeted explicitly „over-eating, leading to obesity and its consequences; high-fat intake; possibly contributing to atherosclerosis and coronary-artery disease; lack of exercise, aggravating coronary-artery disease, leading to obesity, and malnutrition: leading to numerous health problems", for which "the individual must accept some responsibility and for which he should seek correction". Since that, several health promotion initiatives targeted these behaviours with the aim of either primary or secondary prevention.

The Cochrane Collaboration, providing a cornerstone of evidence-based medicine, has summarized the current findings about intervention for preventing childhood obesity twice: in 2005[80] and in 2011[81]. The first review concluded that in spite of the heterogeneity of the studies, nearly all intervention targeting energy intake or expenditure achieved at least a limited result, but mainly not in terms of body weight reduction but rather in improving dietary or physical activity habits. Six years later the accumulated evidence and the in-depth analysis of further research questions regarding the characteristics of the programs and the target group revealed strong evidence for BMI reduction specially in the age group 5-12 years; and some features contributing to this success, e.g. healthy eating and increased sessions of physical activity being embedded in the school curricula, improvements in school food supply, environmental and cultural approaches which include paternal support for home-based activities. This conclusion goes beyond the traditional targets of energy-balance-related behaviours and the individual responsibility in behavioural choices, and points toward the broader context of the environmental influence of the obesity epidemic.

The ANGELO (analysis grid for environments linked to obesity) framework[82] as a widely accepted structure for considering environmental effects categorizes them according to four aspects: physical, economic, political and sociocultural types, and to two magnitudes: micro-environmental setting and sectorial level. Intervention programs most frequently target the micro-environmental level, considering mainly the group or neighbourhood effects. This setting approach has several advantages, reaching relatively homogenous target groups while building on pre-existing organisational structures or channels. A limitation of these can be detected in that fact that even the best-targeted local messages and empowerment strategies can't counteract fully the influence of the macro-societal level. Thus, the moderate results of those community-based interventions[83] are far not surprising. The similar is true for the home-based setting[84]: some moderate effects in improvement of dietary habits, physical activity level were detectable, but with no singnificant improvement in BMI as outcome. School-based setting[181] proved to be the most succesful, speacily wwhen physical activity interventions were completed with a family and/or community component which reinforced the message.

The potent effect of environmental factors highlights the responsibility of decision-makers who are in the position of forming these influencing factors. Successful and sustainable management of obesity epidemic requires coherent and evidence-based health policies and health-promoting institutional systems[85].

The IDEFICS study

The results of this thesis were based on the data of the IDEFICS (**I**dentification and prevention of **D**ietary-and lifestyle-induced health **EF**fects **I**n **C**hildren and infant**S**) study. The IDEFICS study (2006-2012) is the largest multicentre European cohort study of children 2-9 years old in 2007, aiming to identify risk profiles of children susceptible to obesity or related metabolic disorders. The project contributed to in-depth epidemiological investigation of the childhood overweight/obesity considering genetic and non-genetic factors, psychosocial factors and social settings. The study provided one of the largest European data sets, conducting a longitudinal survey in 8 countries and comprising 25 research centres and SMEs across Europe. A cohort of 16 228 children aged 2 to 9 years was examined in a population-based baseline survey in eight European countries ranging from North to South and from East to West (Estonia, Sweden, Germany, Belgium, Hungary, Italy, Spain, Cyprus) from autumn 2007 to spring 2008. The study was not designed to provide a representative sample for each country. Rather, this baseline survey (T_0) was the starting point of a prospective study with the largest European children's cohort established to date[86].

The most important findings of the study included the combined prevalence of overweight/obesity which ranged from more than 40% in southern Europe to less than 10% in northern Europe. Overall, the prevalence was higher in girls (21.1%) as compared with boys (18.6%). The prevalence of overweight/obesity showed a negative gradient with social position[87]. Low socioeconomic status[88] and low parental educational level[89] worsened diet patterns, and increased the consumption of more processed and sweetened foods. TV viewing was an important mediator[90] for obesity, not only being sedentary behaviour, but shaping preferences and redirecting attention of children to higher-fat and particularly higher-sugar diets. High levels of screen time decreased also well-being[91]. The effect of skipping the breakfasts[92] shouldn't be underestimated: it contributes even to cardiovascular risk status; just like the unsatisfactory level of physical activity[93]. The study also focused on frequently neglected aspects of prevention as the role of early developmental factors[94, 95] including feeding practices[96] or mental burdens[97].

Paediatricians often face the problem that reference values for routine clinical parameters are not available or are of questionable value for the assessment of children's health status, especially if the child is young. Many physiological parameters undergo important changes as children grow up and the range of normal values changes accordingly. One of the most important result of the IDEFICS study was the development of European standards in this field, e.g. for anthropometric measures and indices[98], glucose[99] and lipid[100] metabolism or blood pressure[101].

Based on the above percentiles, a new definition of metabolic syndrome (MetS) was suggested[102]. The prevalence of the monitoring level (i.e. the z-score standardisation of values of at least three of the MetS components exceeding the 90th percentile) of metabolic syndrome was 5.5%, while the action level (exceeding the 95th percentile), requiring paediatric intervention, was 1.8%. This 2-stage assessment of metabolic status may guide paediatricians and support decisions about close monitoring or intervening, while draws the attention of the serious consequences of childhood obesity.

The IDEFICS study investigated the aetiology of childhood obesity, by assessing the contributing role of potential risk factors, i.e. the effects of diet, lifestyle, psychosocial and genetic factors[103], thus providing a solid scientific basis for intervention activities. The IDEFICS study also launched an intervention programme[103] which was developed according to the intervention mapping protocol[104], a methodological framework for the elaboration of public health promotion programmes and community interventions. This IDEFICS intervention programme was based upon an intervention mapping protocol[104], i.e. a methodological framework for the elaboration of public health promotion programmes and community interventions. It targeted behaviours and their determinants in three major areas: diet, physical activity and stress – the three most important risk factors for childhood obesity according to prior research. The IDEFICS intervention addressed each of these areas with two key messages for a total of six key messages: (1) diet (a) enhancing daily consumption of water and (b) daily consumption of fruit and vegetables; (2) physical activity (a) reducing TV-viewing, (b) increasing daily physical activity; (3) ability to cope with stress (a) spending more time together, (b) ensuring adequate sleep duration. The intervention was introduced in three settings[105]: on community level, at schools and for parents, promoting the above key messages in various forms and channels.

Subjects and methods

Study subjects

For the descriptive statistics of key message adherence, the baseline cohort[86] of 16 228 children aged 2 to 9 years during the baseline examination (T0) in the 2007/08 academic year, and additional 2 517 children aged 2 to 10.9 years who were newly recruited during a second survey (T_1) two years later comprise the study sample of the first part of the present analysis, the adherence to the behavioural targets.

Exactly the same survey modules were deployed at baseline (T_0) and at follow-up (T_1). All children in the defined age group who resided in the defined regions and who attended the selected primary schools (grades 1 and 2), pre-schools or kindergartens were eligible for participation. Children were enrolled via schools and kindergartens to facilitate equal enrolment of all social groups. The actual age of school enrolment varied in the survey countries, so the school-aged subgroup was defined according to the most frequent date, i.e. being 6-year or older. All survey centres obtained ethical approval according to their national regulations. In addition to the signed informed consent given by parents, each child was asked to give verbal assent immediately before examination. The examinations followed detailed standard operation procedures (SOPs) being the same in both waves of the follow-up survey, documented in a manual and augmented with practical skills acquired during central trainings, ensuring uniform techniques over all survey centres. All examination modules were offered to each participant, except accelerometry where the number of available devices limited the participation. Parents and children were free to opt out of any element of the survey protocol in accordance with standard ethical agreements. Therefore, according to their decision, the number of the available data on key messages differs.

Though children newly recruited in T1 were not explicitly the subject of the intervention program, due to the school and community modules and media channels of the intervention they still might have been contaminated with these messages. Therefore, for the analysis of the contribution of the selected key lifestyle factors to obesity, only the T0 sample was included, a total of 16,228 children from the same eight centres, aged 2 to 9 years at the baseline survey.

Body mass index assessment

Weight was measured using an electronic scale (Tanita BC 420 SMA, Tanita Europe GmbH, Sindelfingen, Germany) to the nearest 0.1 kg, with the children wearing only underwear. Height was measured barefooted, using a telescopic height measuring instrument (Seca 225 stadiometer, Birmingham, UK) to the nearest 0.1 cm. BMI was calculated as the body weight in kilograms divided by the height in meters squared. BMI was then categorized according to IOTF cut-offs[4]. In contrast to the normal weight children, the overweight and obese children were considered together as ‘overweight`.

Physical activity

Physical activity was objectively assessed by a uni-axial accelerometer (ActiGraph® or ActiTrainer® [n] ActiGraph, Pensacola, FL, USA) worn on the child’s hip over three consecutive days, including one weekend day[106]. A minimum duration of six hours monitoring time per day was required to achieve proper reliability[106]. Data were analysed using a 15 second epoch[106]. The duration of moderate to vigorous physical activity (MVPA) was determined according to the cut-offs established by Evenson[107, 108].

Questionnaires

Questionnaires providing information for the indicator variables for five of the six key messages were proxy-reported by parents who completed

(1) a core questionnaire assessing demographic and socio-economic background, gestational, and behavioural factors, and attitudes;

(2) a ‘Children’s eating habits questionnaire’[109] (CEHQ) including a 43 item food frequency questionnaire referring to the dietary habits of the previous four weeks as well as questions regarding home nutritional behaviour and

(3) a ‘Self-Administered Children and Infant Nutrition Assessment’ (SACINA), a computer-based 24-hour dietary recall, referring to the food consumed at the home, under parental notice. SACINA besides included an interview, where, among other questions, parents reported what time their child went to bed the previous day and what time he/she got up in the morning, from which the nocturnal sleep duration

was calculated for the previous day as the difference between the child's bedtime and get-up time.

Indicators for diet-related key messages, i.e. the frequency of water consumption and fruit and vegetable consumption were obtained from CEQH because SACINA proved to be less reliable on individual level[110]. For the descriptive statistics of key message adherence, proxy-reported water consumption was chosen, assessed as times per day. Parents reported their child's fruit and vegetable consumption on the CEHQ as 'never / less than once a week' to '4 or more times per day' in the food categories 'Fresh fruits (also freshly squeezed smoothies, but excluding juices) with or without added sugar', and 'Cooked vegetables, potatoes and beans (also in mixed recipes)', 'Legumes' and 'Raw vegetables (mixed salad, carrot, fennel, cucumber, lettuce, tomato etc.)'. The total fruit and/or vegetable consumption was derived by summarising the daily consumption of the above categories.

For the analysis of the contribution of the selected key lifestyle factors to obesity the diet-related key message indicators were modified. In the IDEFICS intervention, the message was to consume water while in exchange reducing the intake of sugar-sweetened beverages. Taking into both the direct and indirect part of the key message, water and plain milk were counted as the healthy beverage options, while sweetened drinks, juices and sweetened milk were categorised as the unhealthy options for the assessment of complying with this key message. Regarding the child's fruit and vegetable consumption, the same CEHQ food categories were considered, i.e. 'Fresh fruits (also freshly squeezed) with or without added sugar', and 'Cooked vegetables, potatoes and beans (also in mixed recipes)', 'Legumes' and 'Raw vegetables (mixed salad, carrot, fennel, cucumber, lettuce, tomato etc.)'; but the calculation was different, in favour of getting a more holistic picture of the child' diet, extrapolating the parental proxy-reported intake to the global diet. The total daily intake frequency was calculated as the sum of the assigned frequencies to fruits without added sugar, the half of the intake frequency of fresh fruits with added sugar (in order to indicate that sugar intake along with fruit is not the best way to eat fruit but still accounting for the fruit intake), and the assigned frequencies to vegetables, averaged for one day. The intake reported by the parents only included meals eaten at home. Therefore it had to be adjusted to the whole diet, assuming that children have similar consumption habits when eating outside the home environment. The number of those meals was assessed by the question “How often does your child usually eat at kindergarten, pre-school or school meals?”. Thus, the parental report referring to home meals was extrapolated for the total number of the meals, dividing the reported home consumption by the ratio of home meals and all meals, resulting in the estimated total consumption.

Parental proxy-completed core questionnaires on behavioural factors were the source for proxy-reported daily screen-time of the child, assessed with the help of the questions: ’How long does your child usually watch TV/video/DVD per day?’ and ’How long does your child usually sit at a computer/game console per day?’ These questions were separately reported for weekdays and weekend days. The “time spent with audio-visual media” was calculated as daily average of the total weekly exposure to the above screen-based activities.

To measure stress-related aspects, the parental core questionnaire included questions from the KINDL® (Questionnaire for Measuring Health-Related Quality of Life in Children and Adolescents)[111] questionnaire designed to assess health-related quality of life in children and adolescents independently of the current health status[111]. Since it was assumed that high quality of life indicates more balanced family life, a health-related quality of life score was used as an indicator of the key message referring to improved quality of family life, though the score itself covers a broader range of information than the family life. This health-related quality of life score comprised four of the six original KINDL® dimensions[112]: emotional self-being, self-esteem, family relations and social contacts. These aspects were evaluated by the parent on a four-point scale (1-4). The results were summed to create a total score that ranged from 12-48, the greater the value the greater the reported well-being[113]. This value served as an indicator for the stress-related intervention message of the ability to cope with stressors and spending more time together.

Compliance score

A total compliance score was calculated as the sum of those key messages where the internationally recommended target values were met.

Since water consumption is subject to relevant seasonal and climate influences, further, the differences in physical activity, and water content of the diet can also contribute to hydration; we have not considered the international recommendation[114] for this key message but used the highest category of intake frequency in CEHQ, i.e. 4 or more times per day as the target to be met. In case of further analysis, taking into account the above aspects of water consumption requirements; besides, the lack of consensual agreement on an acceptable limitation for sugar-sweetened soft drink consumption, the first key message was indicated by consuming only water or plain milk and no sweetened beverages of any sort.

As a standard for daily consumption of fruit and vegetables, the World Health Organization's CINDI (Countrywide Integrated Non-communicable Diseases Intervention) nutritional guidelines[115] were applied, i.e. a daily intake of five or more portions of fruits and/or vegetable.

Among the various recommendations for sleep duration we considered 11 hours or more for pre-school children and 10 hours or more for school children[116] as target values of optimal duration.

The most generally accepted recommendation for screen time restricts the viewing time to one hour per day for pre-school children and two hours per day for school age children[117] .

KINDL® questionnaire was validated[113] on a German representative national sample, but hhaving applied only four modules of KINDL® questionnaire, we couldn't rely on those data, so the 85th percentile of this scale range (i.e. 44 points) was used as threshold of optimal reported quality of life.

As regards physical activity, the most widely accepted recommendation for children is to accumulate 60 minutes of moderate to vigorous physical activity each day[118], hence this value was applied in our analysis.

Based on the thresholds described above, a compliance score[119] was calculated by summing the number of key messages for which compliance was met. Hence, the compliance score ranges from zero (no compliance with key messages) to six (full compliance with all six key messages). In case of the descriptive analysis, achieving at least five points was considered as good compliance. In the further analysis, taking into account the very limited number of children fulfilling the above criterion of good compliance, the applied limit was more permissive, i.e. complying with more than the half of the key messages (achieving a score of four points or more) was regarded as good compliance.

Statistical analysis

Based on the above described variables and pre-defined cut-off points we assessed country-specific means and standard deviations and prevalences of compliance with each of the six key messages as well as country-specific distributions regarding the compliance score, stratified by pre-school/school and sex. All analyses were performed using SAS 9.2 (SAS Institute Inc.). To determine whether compliance with the key messages modify the risk of being overweight/obese (outcome variable) we used multilevel logistic regression models (Proc Glimmix, SAS 9.3, Cary, North Carolina, USA) to derive age- and sex-adjusted odds ratios (ORs) with corresponding 95%-confidence intervals (95% CIs), with country modelled as a random intercept.

Smoothed age- and gender-specific percentile graphs were created by LMSchartmaker ProVersion 2.54.[120] software, a program to fit smooth centile curves to reference data using the LMS method, i.e. fitting the median (M), the coefficient of variation (S) and the skewness (L), the latter expressed as a Box-Cox power, using penalised likelihood. Graphs were created by the automated model fitting with the Loop from L, M and S equivalent degrees of freedom (edf) having start values of 2 to end values of 5, where 2 edf corresponds to a straight line, 3 edf gives a simple curve like a quadratic and 4 or more edf indicates progressively more complex curve shapes. Optimal fitting was determined by detrended Q-Q plot and Q tests of the same software.

Quality management

All survey elements followed detailed standard operation procedures (SOPs) that were laid down in the general survey manual and finalised after the pre-test of all survey modules.

To check and improve the quality of data, the reliability of questionnaires was checked by re-administering the CEHQ and selected questions of the parental questionnaire in a convenience sample of study participants[109] confirming an acceptable reproducibility even by more than 4 months between the first and second administration, without any systematic differences in reproducibility by sex and age. Food consumption assessed by the CEHQ was validated against selected nutrients measured in blood and urine[121] which revealed a significant positive correlation between reported intake and excretion. A methodological study was carried out to compare uni-axial and tri-axial accelerometers in children and to validate them using doubly labelled water as the gold standard[122].

Results

Descriptive statics of intervention key messages

The study population was described in detail by Ahrens et al.[123]. The data were obtained from 8 302 (physical activity) to 17 212 (screen-time) children, according to the varying proportions of participation in the various modules. Information on all six behaviours was available for 5 140 children (Figure 1).

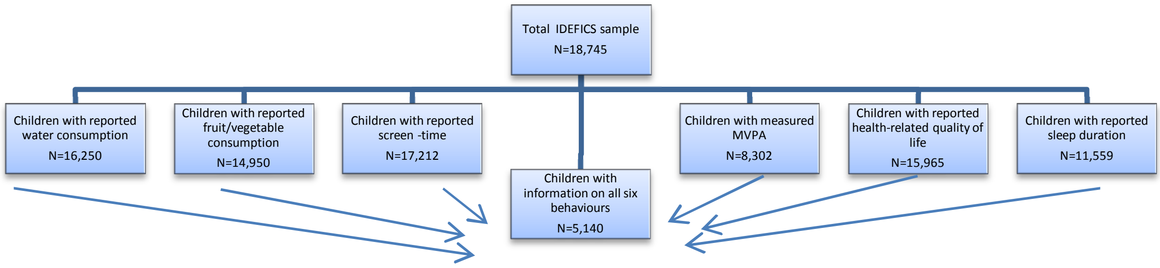


Figure 1. Flow chart for subpopulations having information on certain key messages

No noteworthy differences were found regarding the socio-demographic characteristics between the total sample and the various sub-populations according to the availability of data on the various key messages (Table 1).

Table 1. Socio-demographic profile of the total sample and of the various analysis groups

Children providing information on…	**N**	**Girls (%)**	**ISCED-Level[1)] Low/High (%)**	**Age Mean (SD)**	**BMI z-score Mean (SD)**
Water consumption	16,250	49.6	9.8 / 38.7	6.14 (1.88)	0.31 (1.19)
Fruit/vegetable con-sumption	14,950	49.8	9.6 / 39.2	6.13 (1.88)	0.31 (1.19)
Screen-time	17,212	49.6	9.9 / 38.7	6.15 (1.88)	0.32 (1.19)
MVPA	8,302	49.8	9.9 / 36.8	6.40 (1.85)	0.35 (1.17)
Health-related quality of life	15,965	49.6	9.9 / 38.2	6.17 (1.88)	0.32 (1.19)
Sleep duration	11,559	49.7	11.4 / 35.2	6.18 (1.98)	0.35 (1.18)
All six key messages	5,140	50.1	8.4 / 37.0	6.33 (1.90)	0.31 (1.16)
Total sample	**18,745**	**49.6**	**10.4 / 38.2**	**6.16 (1.88)**	**0.33 (1.20)**

[1)] Educational level of parents, according to the International Standard Classification of Education
Low: (Pre-) Primary and lower secondary education (ISCED-level categories 0/1/2)
High: Tertiary education (ISCED-level categories 5/6).
Percentages are calculated related to the number of children with non-missing values for the variable ISCED-level.

Characterization of the key behaviours

We characterized the observed behaviours by mean (SD) stratified by country and age group.

The higher amount of water consumption (Table 2) in the south countries was most probably a climate effect, while age didn't play a role.

Table 2. Water consumption (times per day) by country and age group (means and standard deviations)

	Pre-school children			School children			All		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Estonia	932	2.72	1.45	1,042	2.57	1.46	1,974	2.64	1.46
Sweden	881	2.55	1.37	861	2.40	1.42	1,742	2.47	1.39
Germany	836	2.70	1.66	1,160	2.57	1.70	1,996	2.62	1.68
Belgium	986	2.31	1.44	1,034	2.30	1.48	2,020	2.31	1.46
Hungary	1,160	2.97	1.55	1,882	2.93	1.58	3,042	2.94	1.57
Italy	899	3.96	0.90	1,235	3.90	0.98	2,134	3.92	0.95
Spain	676	3.99	0.80	781	3.97	0.82	1,457	3.98	0.81
Cyprus	804	3.92	0.84	1,081	3.81	0.97	1,885	3.86	0.92
All	**7,174**	**3.09**	**1.46**	**9,076**	**3.05**	**1.51**	**16,250**	**3.07**	**1.49**

Fruit and vegetable intake was below the recommended level in all countries, but despite the geographical/agricultural possibilities, some Northern countries achieved better results in consumption than the Southern counties (Table 3).

Table 3. Fruit/vegetable consumption (times per day) by country and age group (means and standard deviations)

	Pre-school children			School children			All		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Estonia	822	2.80	1.68	941	2.81	1.78	1,763	2.80	1.73
Sweden	830	3.09	1.64	809	3.18	1.69	1,639	3.13	1.66
Germany	763	3.13	1.80	1,010	2.89	1.70	1,773	2.99	1.75
Belgium	924	2.19	1.13	1,008	2.25	1.07	1,932	2.22	1.10
Hungary	1,069	2.40	1.53	1,725	2.16	1.42	2,794	2.25	1.47
Italy	842	2.13	1.56	1,156	2.13	1.57	1,998	2.13	1.57
Spain	638	2.40	1.51	719	2.58	1.65	1,357	2.50	1.59
Cyprus	713	3.11	2.05	981	2.81	2.03	1,694	2.94	2.04
All	**6,601**	**2.63**	**1.66**	**8,349**	**2.54**	**1.65**	**14,950**	**2.58**	**1.66**

An increasing trend with age can be observed for total screen-time in the sense that older children spent more time in front of the TV or computer (Table 4). In all countries total screen-time was higher for boys than girls (in pre-school age: 1.53 vs. 1.36 hours/day; in school age 2.06 vs. 1.76 hours/day).

Table 4. Total screen-time (hours per day) by country and age group (means and standard deviations)

	Pre-school children			School children			All		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Estonia	957	1.63	0.95	1,092	2.49	1.18	2,049	2.09	1.16
Sweden	887	1.35	0.69	863	1.92	0.85	1,750	1.63	0.82
Germany	852	1.22	0.91	1,191	1.72	1.03	2,043	1.51	1.01
Belgium	1,057	1.37	0.92	1,148	1.85	1.05	2,205	1.62	1.02
Hungary	1,186	1.51	1.02	1,923	1.75	1.01	3,109	1.66	1.02
Italy	995	1.59	1.12	1,346	2.03	1.20	2,341	1.84	1.19
Spain	677	1.16	0.76	782	1.61	0.91	1,459	1.40	0.87
Cyprus	938	1.64	1.03	1,318	1.90	0.99	2,256	1.79	1.01
All	**7,549**	**1.45**	**0.96**	**9,663**	**1.90**	**1.07**	**17,212**	**1.71**	**1.05**

The mean daily duration of MVPA (Table 5) was higher for boys than for girls (in pre-school age: 38.2 vs. 30.6 minutes; in school age 47.9 vs. 36.2 minutes).

Table 5. Moderate-to-vigorous physical activity (minutes per day) by country and age group (means and standard deviations)

	Pre-school children			School children			All		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Estonia	690	33.87	16.46	751	46.1	22.07	1,441	40.24	20.51
Sweden	210	39.77	20.55	343	50.00	22.54	553	46.11	22.35
Germany	411	37.86	20.88	754	47.29	23.44	1,165	43.97	23.01
Belgium	213	32.55	17.72	445	43.30	18.42	658	39.82	18.87
Hungary	574	31.37	17.82	1,213	39.70	19.73	1,787	37.03	19.52
Italy	261	32.38	18.55	649	28.35	18.36	910	29.51	18.50
Spain	619	36.55	20.18	656	46.40	22.00	1,275	41.62	21.69
Cyprus	197	32.76	18.54	316	35.36	18.13	513	34.36	18.31
All	**3,175**	**34.57**	**18.89**	**5,127**	**41.91**	**21.75**	**8,302**	**39.10**	**21.01**

Health-related quality of life score (Table 6) demonstrated a negative trend with age in all countries.

Table 6. Health-related quality of life score (points) by country and age group (means and standard deviations)

	Pre-school children			School children			All		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Estonia	919	41.89	4.26	1,045	39.84	4.76	1,964	40.80	4.64
Sweden	861	42.41	3.69	848	41.75	4.31	1,709	42.08	4.02
Germany	765	40.61	4.29	1,103	40.07	4.86	1,868	40.29	4.64
Belgium	1,002	41.50	4.32	1,101	40.24	4.95	2,103	40.84	4.71
Hungary	1,142	38.21	3.92	1,878	37.38	4.12	3,020	37.69	4.07
Italy	951	39.97	4.47	1,302	38.75	4.93	2,253	39.27	4.78
Spain	644	40.49	3.94	760	39.95	4.25	1,404	40.20	4.12
Cyprus	618	38.08	4.91	1,026	37.87	4.77	1,644	37.95	4.82
All	**6,902**	**40.41**	**4.47**	**9,063**	**39.22**	**4.81**	**15,965**	**39.73**	**4.70**

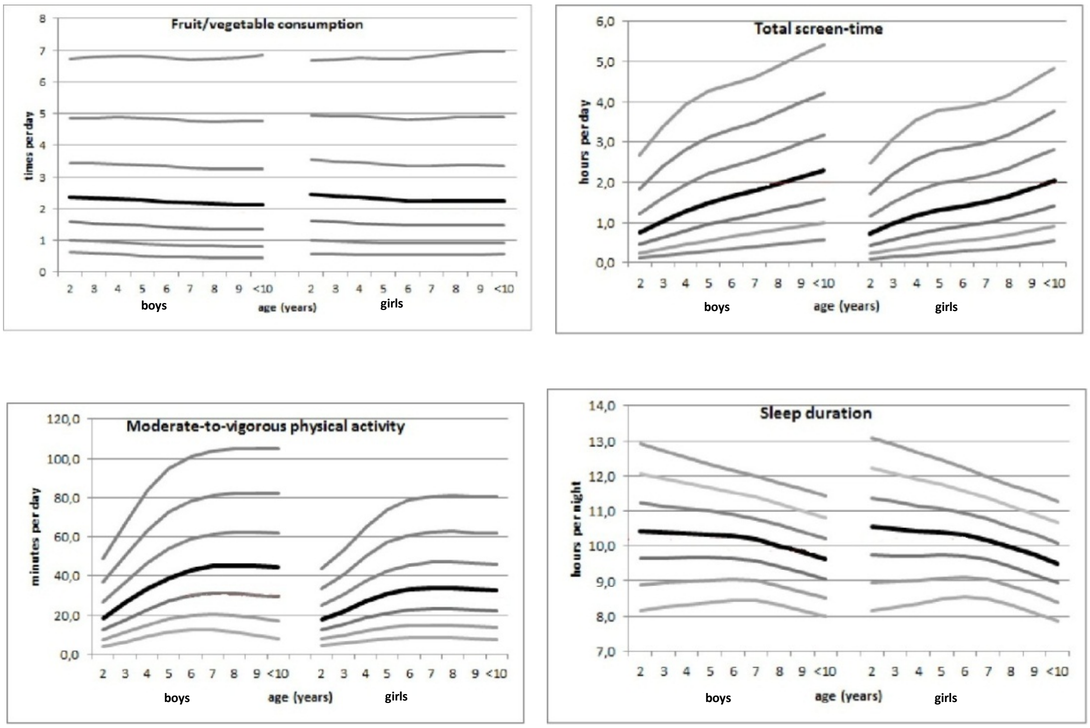
Nocturnal sleep duration demonstrated a negative trend with age. The shorter duration in southern countries may reflect the influence of climate (Table 7).

Table 7. Sleep duration (hours per night) by country and age group (means and standard deviations)

	Pre-school children			School children			All		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Estonia	932	9.58	0.77	1,005	9.38	0.72	1,937	9.48	0.75
Sweden	688	11.00	0.82	697	10.50	0.66	1,385	10.75	0.78
Germany	790	11.29	0.85	1,134	10.79	0.72	1,924	11.00	0.81
Belgium	388	11.28	0.62	504	10.84	0.51	892	11.03	0.60
Hungary	552	10.05	0.55	990	10.00	0.61	1,542	10.01	0.59
Italy	793	9.85	0.88	1,153	9.53	0.71	1,946	9.66	0.80
Spain	469	10.37	0.57	452	10.02	0.40	921	10.20	0.52
Cyprus	350	10.19	0.52	662	10.12	0.53	1,012	10.14	0.53
All	**4,962**	**10.39**	**0.99**	**6,597**	**10.09**	**0.83**	**11,559**	**10.22**	**0.92**

Percentile charts (Figure 2) of those behaviours for which international standars are available depict an at-a-glance overview (with details in the next section) where the distribution and age-related trend of these behaviours can be observed. Fruit and vegetable consumption doesn't demonstrate characteristic differences by age or gender, though it is remarkable that only the 90th percentile reaches the recommended level of consumption. Total screen time, being higher in boys, increased rapidly by age, where roughly the 50th percentile corresponds with the resommendations. Regarding physical activity, by school age the 75th percentile in boys and the 90th percentiles in girls equals with the recommended treshold. Sleep duration decrases by age, which is physiological, but this speeds up by the age of school enrolment. In both sexes, roughly the 75th percentile fulfils the recommendations.

Figure 2. Percentile (3rd, 10th, 25th, 50th, 75th, 90th and 97th) distribution of certain life-style factors



Compliance with recommended thresholds

In the following, we investigated the compliance with each of the key messages.

Overall, 52.5% of the children were in the highest category of water intake, which represented the recommended level of consumption (Table 8), without any characteristic age-related difference. The water intake in southern countries was much higher than in central and northern European countries.

Table 8. Country- and age-specific proportions of children complying with water consumption ≥4 times/day

	Pre-school children		School children		All children	
	Boys (%)	**Girls (%)**	**Boys (%)**	**Girls (%)**	**Boys (%)**	**Girls (%)**
Estonia	38.0	36.9	30.5	34.1	34.3	35.3
Sweden	28.0	31.0	24.5	28.7	26.3	29.8
Germany	44.9	44.6	42.7	42.3	43.6	43.3
Belgium	26.0	23.6	26.3	26.5	26.1	25.2
Hungary	50.4	51.1	49.2	50.5	49.7	50.7
Italy	83.3	84.8	81.8	83.7	82.5	84.1
Spain	87.5	80.9	81.6	84.5	84.5	83.0
Cyprus	82.0	76.7	76.2	73.8	78.6	75.1
All	**53.4**	**51.9**	**51.9**	**52.8**	**52.6**	**52.4**

Fruit and vegetable consumption (Table 9) was far below the recommended target value in all countries and age groups: the proportion of children who achieved the "5 a day" recommendation was only 8.8%. Fruit and vegetable consumption were above average in Nordic countries and Cyprus. None of the diet-related key behaviours showed major differences by sex or age.

Table 9. Country- and age-specific proportions of children complying with fruit/vegetable consumption ≥"five a day"

	Pre-school children		School children		All children	
	Boys (%)	**Girls (%)**	**Boys (%)**	**Girls (%)**	**Boys (%)**	**Girls (%)**
Estonia	9.7	13.2	9.8	12.8	9.8	13.0
Sweden	12.2	15.0	13.5	17.6	12.8	16.3
Germany	17.4	14.8	11.3	10.9	14.0	12.5
Belgium	2.7	2.3	1.2	3.9	1.9	3.2
Hungary	6.6	6.1	5.1	4.7	5.6	5.3
Italy	5.0	6.0	5.7	6.7	5.4	6.4
Spain	7.8	4.8	7.8	6.1	7.8	5.5
Cyprus	16.2	13.5	13.7	11.9	14.8	12.6
All	**9.3**	**9.3**	**8.1**	**8.8**	**8.6**	**9.0**

Total screen-based activities (Table 10) were below the recommended maximum threshold in 51.5% of all children with no major regional differences, girls having better compliance than boys (56.4% vs. 46.6%).

Table10. Country- and age-specific proportions of children complying with total screen-time <1 hour in pre-school and <2 hours in school children

	Pre-school children		School children		All children	
	Boys (%)	**Girls (%)**	**Boys (%)**	**Girls (%)**	**Boys (%)**	**Girls (%)**
Estonia	31.2	30.9	29.9	45.4	30.5	39.0
Sweden	33.0	39.9	48.6	71.0	40.5	55.6
Germany	50.1	58.8	65.7	70.1	59.1	65.5
Belgium	35.8	50.4	58.3	67.6	47.2	59.6
Hungary	36.2	41.6	58.6	68.1	50.1	57.9
Italy	31.5	40.0	48.9	67.5	41.1	56.5
Spain	50.7	59.8	68.0	74.3	59.4	68.0
Cyprus	29.8	34.4	58.1	65.2	46.3	52.4
All	**36.6**	**43.6**	**54.8**	**65.8**	**46.6**	**56.4**

The recommended target value of MVPA (Table 11) was achieved in only 15.2% of the children, with threefold difference in the prevalence between countries (8.8% in Cyprus vs. 25.7% in Sweden). The same order of magnitude in difference was observed according to sex: the proportion of children achieving the recommended target value of MVPA was higher among boys than among girls (in pre-school children 15.0% vs. 4.5%; in school children 26.8% vs. 10.5 %).

Table 11. Country- and age-specific proportions of children complying with moderate-to-vigorous physical activity >60 min

	Pre-school children		School children		All children	
	Boys (%)	**Girls (%)**	**Boys (%)**	**Girls (%)**	**Boys (%)**	**Girls (%)**
Estonia	11.5	2.4	33.4	13.9	22.3	8.7
Sweden	21.5	12.4	43.1	17.8	34.2	15.9
Germany	19.6	4.8	42.5	15.0	33.5	11.8
Belgium	12.2	1.7	30.7	10.0	24.9	7.2
Hungary	11.2	5.1	18.0	9.3	15.9	7.9
Italy	14.0	5.6	8.4	1.9	10.0	3.0
Spain	18.3	4.4	33	11.6	25.4	8.4
Cyprus	12.1	4.1	15.2	3.2	14.0	3.5
All	**15.0**	**4.5**	**26.8**	**10.5**	**22.1**	**8.3**

Key messages promoting lifestyle changes to cope with stress indicate far better results in the northern region than in the southern region, especially among girls (Table 12). In addition, we observed a negative trend with age for the health-related quality of life score.

Table12. Country- and age-specific proportions of children having health-related quality of life score ≥44 points

	Pre-school children		School children		All children	
	Boys (%)	**Girls (%)**	**Boys (%)**	**Girls (%)**	**Boys (%)**	**Girls (%)**
Estonia	38.3	45.7	21.5	24.7	29.9	33.9
Sweden	41.8	48.2	38.7	42.0	40.3	45.0
Germany	25.1	29.4	25.3	27.9	25.2	28.5
Belgium	36.2	39.4	28.5	29.7	32.3	34.2
Hungary	5.5	7.8	4.1	4.7	4.6	5.8
Italy	17.7	27.2	16.3	18.6	16.9	22.0
Spain	22.3	24.5	15.6	23.7	18.8	24.0
Cyprus	10.5	14.8	11.3	11.5	11.0	12.7
All	**24.9**	**29.5**	**18.4**	**20.8**	**21.3**	**24.4**

The recommendation on sleep duration (Table 13) was fulfilled in 37.9% of our study sample. In both age groups and in all countries except Estonia, the prevalence of adherence to recommendation was better in girls.

Table13. Country- and age-specific proportions of children complying with Sleep duration ≥11 hours in pre-school and ≥10 hours in school children

	Pre-school children		School children		All children	
	Boys (%)	Girls (%)	Boys (%)	Girls (%)	Boys (%)	Girls (%)
Estonia	3.3	3.3	13.1	10.1	8.1	7.0
Sweden	36.0	44.5	74.6	76.0	55.0	60.7
Germany	53.8	63.9	85.2	86.1	72.0	77.2
Belgium	60.7	73.1	93.9	94.6	78.8	85.7
Hungary	1.2	2.0	40.4	42.6	27.1	27.4
Italy	5.3	7.0	14.9	18.5	10.8	14.1
Spain	5.7	10.2	45.6	50.2	23.6	31.6
Cyprus	4.5	4.1	48.0	54.8	32.3	37.9
All	**20.8**	**25.1**	**48.8**	**49.7**	**36.3**	**39.6**

Regarding the compliance score the two extremes of the scale showed a sharp contrast in prevalence: 0 and 1 point, i.e. poor compliance, were observed for 37.6% in our study sample, while a good compliance with this set of lifestyle recommendations was observed in only 1.1% of the children. Figures 3 and 4 depict the distribution of the compliance score according to age, sex and country. The score showed a similar pattern as most of the key messages, i.e. a better adherence of children to the six key messages in the northern countries and among younger age groups.

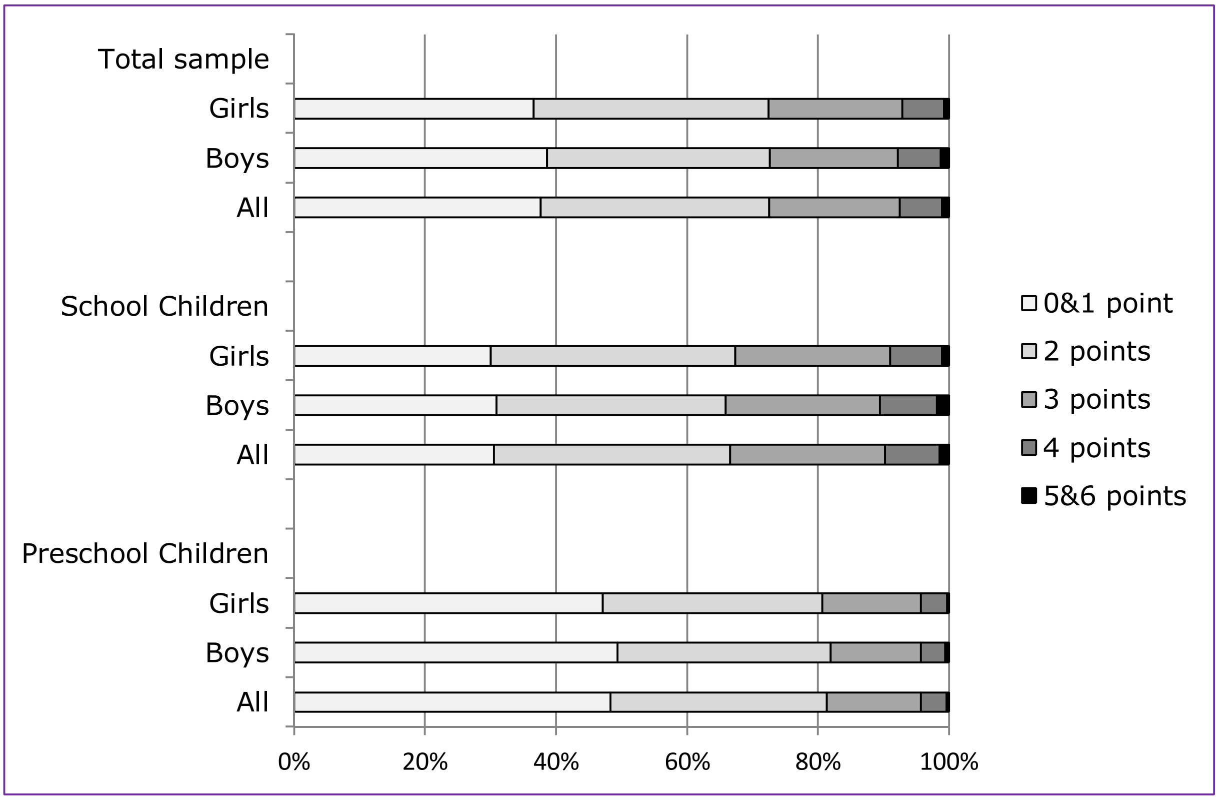


Figure 3. Distribution of compliance score by sex and age group

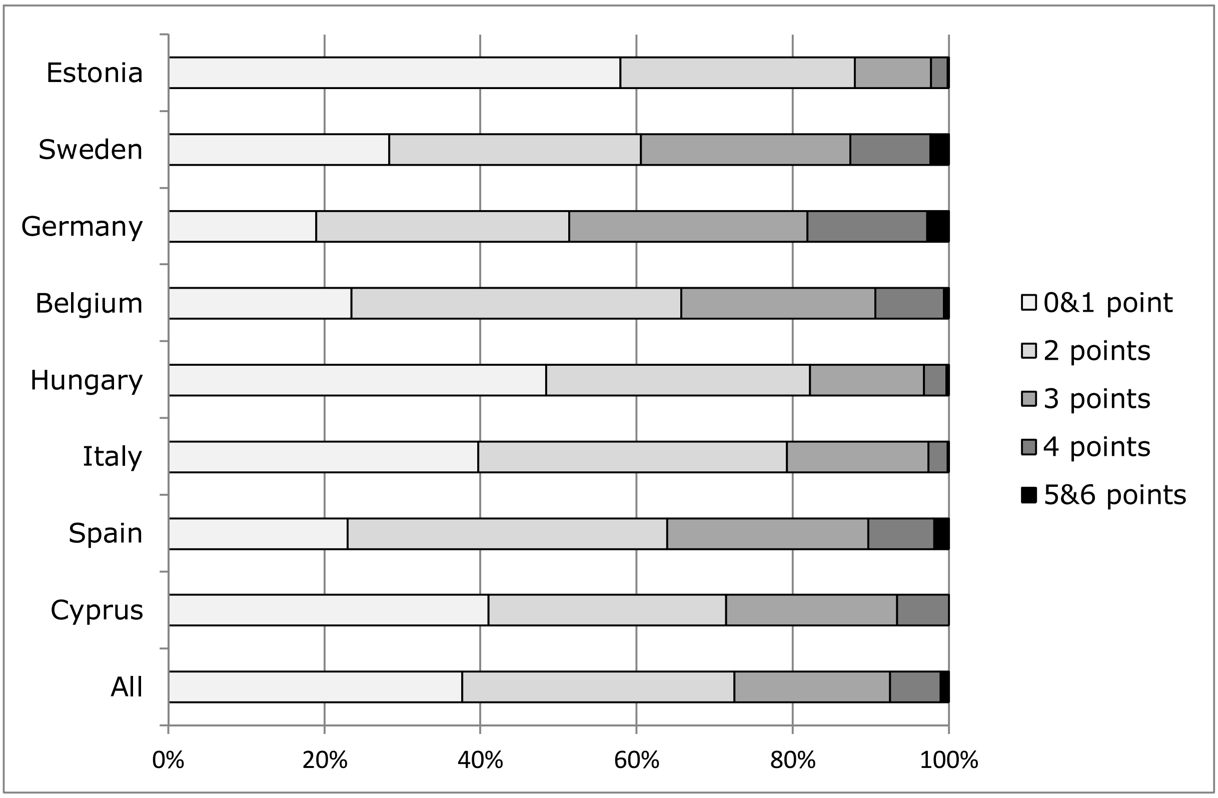


Figure 4. Distribution of compliance score by country

Contribution of adherence to certain lifestyle factors to obesity

Regarding the analysis about the contribution to obesity, the data were somewhat different from the data of descriptive statistics, in respect of the population restricted to the baseline study (T0), unaffected by the intervention; and of the modified diet-related key messages. From the 16,228 children participating in the IDEFICS study, data on key messages ranged from n=7,444 (objectively measured physical activity) to n=15,084 (reported screen time). 4,340 children had all six elements available for calculation of a total compliance score (Figure 5).

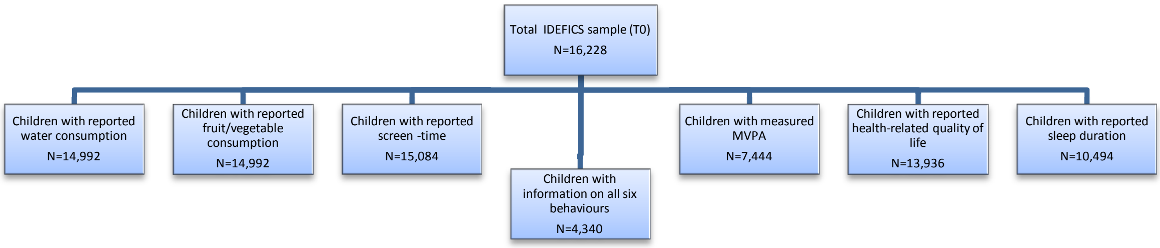


Figure 5. Flow chart for subpopulations having information on certain key messages

Similarly to the previous, extended cohort of T0 and T1 new recruitment children, there was almost no difference between the proportion of boys and girls (Table 14) and no relevant differences when considering mean age, BMI z-score and parental educational level as an indicator for socioeconomic background between subgroups according to reported key message indicators even in this T0 cohort.

Table 14. Socio-demographic profile of the total sample and of the various analysis groups

Children providing information on...	N	Girls (%)	ISCED-Level[1)] Low / High (%)	Age Mean (SD)	BMI z-score Mean (SD)
Water consumption	14,992	49.2	10.7 / 38.5	5.99 (1.80)	0.32 (1.19)
Fruit/vegetable consumption	14,992	49.2	10.7 / 38.5	5.99 (1.80)	0.32 (1.19)
Screen-time	15,084	49.2	10.2 / 38.2	5.99 (1.79)	0.32 (1.19)
MVPA	7,444	49.5	10.0 / 37.1	6.22 (1.76)	0.36 (1.18)
Health-related quality of life	13,936	49.3	10.2 / 38.7	6.01 (1.80)	0.33 (1.18)
Sleep duration	10,494	49.5	11.7 / 35.9	6.04 (1.83)	0.35 (1.18)
All six key messages	4,340	49.4	9.8 / 35.6	6.25 (1.77)	0.38 (1.17)
Total sample	16,228	49.1	10.7 / 38.7	6.01 (1.79)	0.33 (1.19)

[1)] International Standard Classification of Education
Low: (Pre-) Primary and lower secondary education (ISCED-level categories 0/1/2)
High: Tertiary education (ISCED-level categories 5/6).
Percentages are calculated related to the number of children with non-missing values for the variable ISCED-level.

Table 15 shows the proportion of children complying with the individual key messages. There was no significant correlation between diet-related messages and overweight (OR 0.99, 95% CI 0.90-1.10 and OR 1.07, 95% CI 0.95-1.21, respectively) and compliance with both key messages decreased with age. Compliance with recommended screen time was 1.5 times higher in school age children than in the pre-school age children (61.6% vs. 40.4%). Yet, for interpretation, the different thresholds of one hour and two hours, respectively for these age groups should be considered. Screen-time proved to be the best accepted message among respondents with 51.9%; showing an odds ratio 0.77 (95% CI 0.70 - 0.83) for obesity. Performing at least 60 minutes MVPA decreased the chance of obesity (OR 0.70, 95% CI 0.58-0.84), though the adherence to this message was poor (15.0% in the total population). Compliance with MVPA guidelines improved with age among the normal weight children, doubling from kindergarten to school age (9.7% vs. 20.8%), while no change was observed by age in the overweight children (10.2% vs. 11.7%). Health-related quality of life, our marker for stressors, showed a characteristic decrease from pre-school to school age in both normal weight and overweight children (from 28.2% to 21.9% and from 25.7% to 17.45%, respectively); overall only 24.0% of the respondents achieved full compliance and for those no association with overweight was found OR 0.94 (95% CI 0.84-1.05). Children with optimal sleep duration had a decreased risk of overweight (OR 0.85; 95% CI 0.74-0.96). Normal weight children followed sleep guidelines ~1.5 times more frequently than overweight children in both age groups; however a twofold better compliance was observed among school age children.

Table 15. Number and proportion of children complying with key messages according to BMI category and age group

	Preschool Children						School Children						All					
	Normal		Overweight *		All		Normal		Overweight *		All		Normal		Overweight *		All	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
No reported sweet-ened drink con-sumption	1659	27.7	237	26.0	1896	27.5	1330	21.8	441	22.1	1771	21.9	2989	24.7	678	23.3	3667	24.5
Fruit/vegetable consumption ≥"five a day"	1263	21.1	164	18.0	1427	20.7	1019	16.7	288	14.4	1307	16.1	2282	18.9	452	15.5	2734	18.2
Total screen-time <1 hour in pre-school and <2 hours in school children	2488	41.5	306	33.3	2794	40.4	3903	63.3	1132	56.5	5035	61.6	6391	52.6	1438	49.2	7829	51.9
Moderate-to-vigorous physical activity >60 min	253	9.6	40	10.2	293	9.7	692	20.8	130	11.7	822	18.6	945	15.9	170	11.3	1115	15.0
Health-related quality of life score ≥44 points	1541	28.2	214	25.7	1755	27.9	1261	21.9	328	17.4	1589	20.8	2802	25.0	542	19.9	3344	24.0
Sleep duration ≥11 hours in pre-school and ≥10 hours in school children	1013	24.9	108	16.8	1121	23.8	2360	54.2	545	37.9	2905	50.2	3373	40.1	653	31.4	4026	38.4

* including also obese

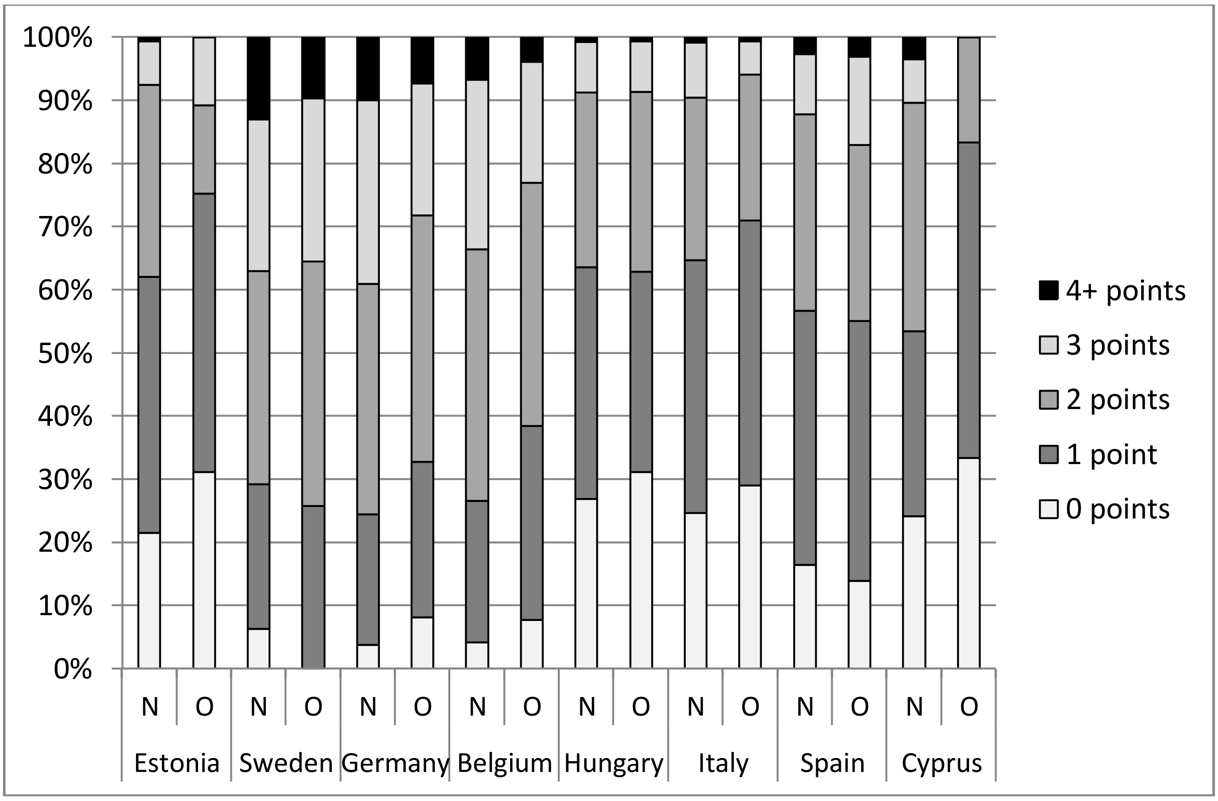
Results for meeting overall compliance are shown in Table 16. Only a minor proportion of the overall sample demonstrated adherence to at least four key messages (3.8%), and among this small group an almost twofold better results was observed among normal weight children compared to overweight children (4.3% vs. 2.2%). Overall, compliance improved with age in both weight groups (1.7% vs. 5.3% for preschool age vs. schoolchildren, respectively). On the other side of the spectrum, the non-compliance (score 0-1) also reinforced the observed lifestyle differences, being more prevalent in overweight children than in normal weight children (60.7%: vs. the 48.8%). The proportion of non-complying children declined by age, being 61.7.5% vs. 44.4% for kindergarten and school children, respectively).

Table 16. Distribution of compliance score value according to age and weight group

	Preschool Children				School Children				All			
	Normal		Overweight*		Normal		Overweight *		Normal		Overweight *	
	N	%	N	%	N	%	N	%	N	%	N	%
0 point	346	23.0	72	34.1	211	10.8	133	19.8	557	16.1	205	23.2
1 point	551	36.7	88	41.7	580	29.7	242	36.1	1131	32.7	330	37.4
2 points	420	28.0	41	19.4	682	34.9	194	28.9	1102	31.9	235	26.6
3 points	156	10.4	10	4.7	364	18.6	83	12.4	520	15.0	93	10.5
4+ points	29	1.9	0	0.0	119	6.1	19	2.8	148	4.3	19	2.2
All	1502	100.0	211	100.0	1956	100.0	671	100.0	3458	100.0	882	100.0

* including also obese

Figure 5 shows the distribution of compliance score by survey centre country and weight status (normal vs. overweight). It reveals significant inter-country differences with a characteristic North-South contrast, with the exception of Estonia. Overall, the northern European countries reported better compliance with the key messages, while also having lower obesity prevalences[123]. In most countries the normal weight children demonstrated better compliance with key messages than the obese children with the exceptions of equally low compliance in Hungary and Italy and a reversed direction in Spain.



N: normal weight; O: overweight and obese

Figure 5. Distribution of compliance score value according to country and weight group

Children were categorized according to complying more than the half of the key messages (Table 17.) of IDEFICS intervention. This highlighted the improvement by age (from 1.7% in kindergarten children to 5.3% in schoolchildren) and the regional differences of compliance, ranging from 0.6% in Estonia to 12.7% in Sweden, with respect to the whole population. None of the overweight kindergarten children complied with at least half of the key messages; and even in the group of best achievement, i.e. the normal weight schoolchildren only 6.6% was this proportion.

Table 17. Number and proportion of children having good compliance (with ≥4 key messages) according to country, age and weight group

	Preschool Children						School Children						All					
	Normal		Overweight *		All		Normal		Overweight *		All		Normal		Overweight *		All	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Estonia	0	0.0	0	0.0	0	0.0	4	1.3	0	0.0	4	1.1	4	0.7	0	0.0	4	0.6
Sweden	7	6.0	0	0.0	7	5.7	30	17.9	3	12.5	33	17.2	37	13.0	3	9.7	40	12.7
Germany	12	5.5	0	0.0	12	4.9	48	12.5	8	9.3	56	11.9	60	9.9	8	7.3	68	9.5
Belgium	8	5.4	0	0.0	8	5.2	16	7.6	1	5.6	17	7.5	24	6.7	1	3.8	25	6.5
Hungary	0	0.0	0	0.0	0	0.0	5	1.2	1	0.8	6	1.1	5	0.7	1	0.7	6	0.7
Italy	2	1.5	0	0.0	2	1.0	1	0.4	2	0.8	3	0.6	3	0.8	2	0.6	5	0.7
Spain	0	0.0	0	0.0	0	0.0	13	6.0	4	4.7	17	5.6	13	2.6	4	3.1	17	2.7
Cyprus	0	0.0	0	0.0	0	0.0	2	6.7	0	0.0	2	5.0	2	3.4	0	0.0	2	2.6
All	29	1.9	0	0.0	29	1.7	119	6.1	19	2.8	138	5.3	148	4.3	19	2.2	167	3.8

* including also obese

Table18. demonstrates the effect of compliance with the recommended set of behaviours on obesity: increasing score decreased clearly and consequently the chance of obesity. Compliance with merely one of the key messages had a significant effect (OR 0.798, 95% CI 0.641 - 0.994) on the risk for obesity. With improved compliance score a gradual decreasing risk of obesity is observable, and within the good compliance category the risk of obesity is almost halved (OR 0.464, 95% CI 0.272 - 0.792).

Table 18. Contribution of compliance score to the odds of obesity

Score value	Odds Ratio	95% Confidence Interval
0 point	reference	
1 point	0.798	0.641 - 0.994
2 points	0.633	0.501 - 0.801
3 points	0.583	0.430 - 0.790
4 + points	0.464	0.272 - 0.792

Discussion

The present paper investigated the adherence of European children to selected[105,124,125] health behaviours known to be associated with childhood obesity and being essential for children´s optimal and healthy development. The results demonstrate that surprisingly low proportions of these children meet the recommended target values of the investigated health behaviours (8.8-52.5%). Compliance with the six key messages in IDEFICS showed a significant correlation with overweight. However, the respective contribution of the individual six elements of this score was different.

Enhancing daily consumption of water

The first key message of IDEFICS intervention targeted the enhancement of water consumption, in favour of formulating the recommendation in a positive way, i.e. promoting pro-health behaviour instead of discouraging risk behaviour[104], thus with the indirect content of decreasing the sugar-sweetened beverage intake in exchange. The consumption of sugar-sweetened beverages is an important contributor to childhood obesity[126, 127] confirmed even by longitudinal studies[128]. In spite of this, there is no special recommendation regarding soft drink consumption. The WHO CINDI guideline[115] simply proposes the limitation of sugary drinks. A recent guideline[129] reinforced the message that sugar-sweetened beverages should be consumed only occasionally if at all. The review of Libuda[126] also underlined that the most reasonable preventive measure is replacing soft drinks by non-caloric beverages e.g. tap water and mineral water. International recommendations[127] stress the importance of limiting soft drink intake, which increasingly replaces non-caloric drinks or those having beneficial nutritional value[126]. Even longitudinal studies[130] confirmed that soft drink consumption is not only an important contributor to childhood obesity but even demonstrated a direct dose-response relationship to long-term weight gain. In our study, half of the children showed a satisfactory water intake reflected by the highest category of intake frequency reported in the CEHQ. However, this also implies that almost half of the children do not drink enough water.

While we found no significant association between the dietary messages and overweight, discouraging sweetened drink consumption is still a widely accepted and valid message[131]; so the lack of correlation in our data might be explained by reporting bias[109, 132]. A recent meta-analysis[130] of cohort studies found that higher soft drink intake among children was associated with 55% (95% CI 32-82%) higher risk of being overweight or obese compared with those with lower intake. Long-term observation[133] revealed that the replacement of not more than one serving of sugar-sweetened beverage with water pro day may limit weight gain, thus supporting the first key message of IDEFICS intervention. In our study a clear majority, 75.5% of the families reported that the child consumed sugar-sweetened beverages, with a range from 61% in Cyprus to 84% in Hungary or Spain. The currently available national guidelines don't provide a clear, quantified message for the parents to what extent they should reduce their children's sweetened drink consumption which also may contribute to the low compliance of this message.

Enhancing daily consumption of fruits and vegetables

According to the a report on existing guidelines[134] the national recommended target values in the eight survey centres proved to be so diverse, that regarding the recommended intake, we had to rely on the WHO CINDI recommendation[115]. A level of fruit and vegetable consumption lower than this threshold among children is consistently reported. The position paper of the American Dietetic Association on Dietary Guidance for Healthy Children Ages 2 to 11 Years[135] reported that 63% and 78% of children 2 to 9 years do not consume the recommended number of servings of fruits and vegetables. They found an average daily intake of two servings of fruits and 2.2 of vegetables. A recent review[136] confirmed this observation, demonstrating low intakes of fruits and vegetables in most American, European, and Australian studies, between 2 and 3 portions per day which are well below the recommended five portions. This target value of five portions, when converted from consumption frequency to amount of intake, should consider the age of the child, i.e. the appropriate amount of fruits and vegetables depends on the energy needs, where e.g. a young child should eat more than 200 g per day[115]. In the Netherlands more children complied with the World Health Organisation recommendation of 400 g fruit and vegetables per day (17.0%) in 2009 than in 2003 (11.8%, $p = 0.004$) [137]. However, even the 2009 figures were lower than expected. Two German studies[138] reported a fruit intake of 110 and 114 g in boys and girls, respectively, and a vegetable intake of 104 and 115 grams; in total 2.6-2.8 portion according to the WHO CINDI conversion. A British study[139] revealed that the daily consumption of at least one portion of fruit and of vegetables in 9-10-year-old children was 56.8% and 49.9%, respectively. The data gained from the IDEFICS survey correspond to the results demonstrated by the studies discussed above. Fruit and vegetable consumption is very low in the participating European children, not even approaching the widely accepted internationally recommended target value of 5 times per day, where the proportion of adherers ranged from 2.5% in Belgium to 14.5% in Sweden; while in total 91.2% of the children have an intake lower than optimal. Fruit/vegetable intake does not differ substantially between age groups. It is worth mentioning that fruit/vegetable intake is relatively low even in the Mediterranean countries. Based on these data, we can state that plant food consumption should be highly promoted among European children. When extrapolated the home diet to the whole of the intake, the fruit and vegetable consumption corresponding to WHO standards remains still very low in the participating countries, ranging from 4.1% in Belgium to 39.4% in Sweden. It didn't demonstrate a significant correlation with the body weight, which is in concordance with the literature. A recent metaanalysis[140] revealed increased fruit and vegetable consumption was not or minimally associated with reduced body weight if the increase was not accompanied by a reduction in total calories, though the low energy density and the satiating effect of high fibre content still may be beneficial to a certain extent. Regarding the amount of fruit and vegetable intake, the PRO GREENS multicentre European study[141], using a similar method as the IDEFICS study of FFQ, found that only 23.5% of the total sample met the recommended 400 grams/day (which equals five portions). While being unacceptably low, this result was still higher than our average value of only 18.2%. Only British data[142] showed, within the same age group, a more unfavourable situation, with only 3% of the study subjects meeting the 5-a-day fruit and vegetable recommendation. As no association between dietary intake and obesity in either sex could be detected, it can be concluded that satisfactory fruit and vegetable intake should be recommended not directly with respect to weight management. Nevertheless, high fruit and vegetable consumption contributes to a well-balanced nutrient containing diet, and benefits deriving from nutrient-density and dietary phytochemicals content should be highlighted, which can contribute to long term reduction of the risk of the development of chronic diseases as cancer[143] or cardiovascular diseases[144, 145].

Reducing TV-viewing

Reviews concerning the relationship between TV time, sedentary time and obesity are equivocal[146], however, the majority of them confirm a positive association. Possible explanations are multifold[147], involving direct and indirect mechanisms contributing to the childhood obesity epidemic. Time spent on TV viewing potentially decreases the time spent in physical activity. Food proved to be the most frequently advertised product category on children's TV, the majority of these products being energy-dense and nutrient-poor[147]. This facilitates adverse dietary patterns: energy-dense snack consumption, fast-food consumption, energy-dense drink intake, higher total energy intake, and higher percentage energy from fat[148, 149]. Watching TV redirects attention from conscious eating and provides opportunity for unnoticed and unrestricted snacking[150]. These arguments support the American Academy of Pediatrics Policy Statement suggesting that daily screen-time should be restricted to 1-2 hours, the lower limit applying for younger children[117] which has a wide consensus in the literature.. In the IDEFICS study we have observed a positive trend with age for total screen-time, but due to the duplication of permitted screen-time in school age, this does not appear as an increase in non-compliance with the guidelines. The majority of studies reported a significant relationship between television viewing time and adverse dietary outcomes with as little as 1 hour of daily television exposure[151]. According to the present data the recommendation of < 1 hour of total screen-time per day for pre-school children and < 2 hours per day for school children – not exclusively TV viewing – seems to be reasonable. These thresholds were reached by 51.5% of the IDEFICS population which was the second best compliance in the present study after compliance to water consumption. Our finding that screen time is associated with overweight is not surprising. The systematic review of Tremblay[152], including 232 studies and nearly one million participants also confirmed that in the 5-17 year old population the TV viewing of more than 2 hours/day is connected with several adverse effects, e.g. unfavourable body composition and other metabolic risks, including metabolic syndrome. Their aggregated result for successful screen time reduction revealed a significant decrease in body weight (OR: -0.81; 95% CI -1.44 to -0.17). A Dutch study confirmed findings similar to the IDEFICS results, detecting an odds ratio of being overweight 1.70 (95% confidence interval: 1.07-2.72) for viewing TV >1.5 hour among 4- to 8-year-old children[153] even when adjusted for family characteristics and nutrition habits. The OR 0.77 (95% CI 0.70 - 0.83) for obesity in the IDFICS cohort of children complying with the above screen time limitations corresponds with these findings; but in this regard we should keep in mind that the lower levels of recreational screen time, even below than the permitted threshold of 1-2 hours, are more beneficial in terms of health.

Enhancing daily physical activity

Physical activity and sedentary behaviour are also considered important aetiological factors[154] in childhood obesity. The beneficial effect of physical activity exceeds the simple prevention of overweight. It improves metabolic and mental health[155], besides, it is also positively associated with academic performance[156]. The recommended target value of MVPA for children ranges from 15-20 minutes in the Mediterranean countries, e.g. Cyprus and Italy, to 90 minutes in Canada[157]. Unsatisfactory compliance with most widely accepted recommendation of 60 minutes of MVPA is not exceptional. A similar study[142] found that only 7% of children meet this threshold.

A positive trend with age for compliance to physical activity recommendations was observable in the IDEFICS population, but even school children's physical activity levels were far below the recommended target value. The prevalence of spending more than one hour per day in MVPA was overall very low, ranging from 6.8% in Italy to 25.7% in Sweden. Boys were more physically active than girls, which confirms previous findings[158, 159] where it is repeatedly stressed from an overall European perspective that girls are less likely to be sufficiently physically active than boys. In accordance with our results, higher physical activity was associated with a lower risk for obesity (OR 0.20, 95% CI 0.04 to 0.88) in boys. In the European Youth Heart Study [160], low MVPA meant an OR 2.48 (95% CI 1.36- 4.53) for obesity in boys.

Improving the quality of family life

There is a growing interest how different aspects of family life affect children's health. Although we did not explicitly measure, for instance, the stress level of the family, but various other indicators of the quality of family life instead, it is interesting to note that the stress level of the family can be an important contributor to childhood obesity[161-163], and the other way round, obesity may increase the stress level[164-168]. Our cross-sectional study cannot identify causal relationships, though literature suggests that impaired mother-child relationship, reduced social support and parenting care may play a role in establishing adverse diet patterns. This puts in focus the relationships within the family confirming the results of our intervention mapping approach, which addressed stress management as one of the intervention targets for the IDEFICS study. The strengthening of a supportive family environment may have beneficial effects on stress coping and consequently on obesity. A negative trend with age was observed for the health-related quality of life score in the IDEFICS population, with lower values in the southern countries at all ages. Our results regarding health related quality of life and overweight are in line with prior studies. A recent review[169] about quality of life in overweight and obese children and adolescents confirmed that more than 90% of the analysed studies revealed psychological and social burdens among obese youth which involved several aspects of life. According to this review, the parent-reported KINDL® results indicated significantly lower quality of life scores in the dimensions of physical functioning, psychological/emotional dimension, self-esteem and family and social relationships in obese children compared to normal-weight children.

Ensuring adequate sleep duration

Sleep duration has shown a decreasing trend in the past century, reflecting changing lifestyles[170]. Parallelly, the recommended sleep duration[171] also followed this trend and was reduced in preschool age (3-5 years) from 15-14 hours in 1897 to 12-10,5 in 2009; and in school age (6-9 years) from 11.9 hours in 1897 to 10,5 in 2009. This clearly reflects profound changes in lifestyle that are not favourable regarding obesity. An increasing body of evidence suggests that shorter sleep duration is independently associated with weight gain, particularly in younger age groups[172].

Even a dose-response relationship between sleep duration and obesity could be revealed: the review of Liu et al.[173] collected studies which quantified the risk of short sleep duration related to obesity. In this review the highest OR reported for obesity was 4.76 for kindergarten children sleeping less than 9 hours, compared to those sleeping 11 hours or more. Similarly, investigation of sleep patterns in the IDEFICS study[174] confirmed the association of sleep duration with obesity: a dose-dependent association between sleep duration and overweight was observed. A clear gradient in sleep duration could also be seen between regions: children from northern Europe sleep longer than children in southern Europe[174]. In our study, the age-specific recommendations were met by 7.5% of Estonian children up to 82.2% of Belgian children. According to the study of Bell and Zimmerman[175] the risk of obesity was 1.8 (0-5 year-old) and 1.2 (6-13 year-old) in children being below the 25th percentile of age-specific sleep time, which corresponds to our result. Children of the IDEFICS cohort with optimal sleep duration had a decreased risk of overweight (OR 0.85; 95% CI 0.74-0.96). Based on these results we can conclude that striving for longer sleep duration among European children would be essential, and this should be promoted especially in the southern countries. (Please note that we only recorded nocturnal sleep duration although sleep during the daytime might be relevant in Mediterranean countries where for instance napping after lunch is common, but this was not recorded in the IDEFICS study.)

Compliance score

Several lifestyle factors are described as behavioural contributors to childhood obesity[125], which are often associated with each other. Regarding intervention targets, the literature typically deals separately with these factors. The advantage of combining the most important lifestyle factors in a compliance score may provide a more holistic view: complying with certain aspects of lifestyle recommendations can vary even within an individual, but these aspects can compensate each other, creating a final common effect on the outcome of obesity. The score can express the fulfilment of a comprehensive set of recommended behavioural factors, such as in the present study the compliance with the six key messages of the IDEFICS intervention. Detecting the co-existence and correlation between healthy behaviours resulted in attempts to cluster them. Our unique combination of key messages does not readily compare to other studies, however, several authors have examined combination and cumulative lifestyle elements that contribute to obesity. For example, TV viewing and computer use seem to be both associated with shorter sleep duration[153] ; improved quality of life has been found to be associated with greater levels of physical activity and reduced screen time[169]; and more sedentary behaviour has been associated with lower self-esteem[152]. A review[151] including children between the ages of 2-6 years found a significant relationship between television viewing time and adverse dietary outcomes, most frequently lower fruit and/or vegetable intake. Another study reported excess television viewing associated with lower psychosocial quality of life in children aged 0-4 year[176]. The MoMo study[177] concluded that higher levels of physical activity were a good predictor for better health-related quality of life in adolescents as measured by KINDL®. Healthier sleeping patterns, including longer sleep duration, also contributed to increased health-related quality of life[178]. The SPEEDY study[179] examined a grouping of behaviours, including physical activity, dietary habits (fruit, vegetable, fat, added sugar intake), self-reported screen time and sleep duration among 9-10 year old children. Findings from SPEEDY indicate that over 80% of children failed to meet guidelines for two or more health behaviours. A similar approach was used in an Australian study[180] where an unhealthy behaviour score was calculated from the risk factors of low physical activity, increased screen time, unfavourable snacking behaviour, soft drink consumption and fruit and vegetable consumption below recommendations, i.e. four of the five factors overlapped with the IDEFICS key messages. The prevalence of unhealthy lifestyle behaviours in this study ranged from zero to five, and similar to our own findings, 4.2% of the Australian sample met zero of the risk factors, 17.1% one, 30.7% two, 30.5% three, 13.9% four, 3.6% met all five, which corresponds to our results. Children with 5 versus 0 unhealthy behaviours had 9.2-units lower quality of life score (p=0.001) five years later, which stresses the long-term consequences. This underpins the importance of the results of the IDFICS study, the prevalence of complying with more than half of the key lifestyle elements being merely 3.8% in the total population, while an almost complete compliance (i.e. five or six messages) with recommendations was exceptional among European youth: the range was 0 (Cyprus) to 2.8% (Germany) with 1.1% prevalence in the total IDEFICS population. The distribution of the compliance score was different between countries and compliance increased with age, while demonstrating a close correlation with obesity as outcome.

Strength and limitations

The strength of the study lies in the large geographical coverage with eight centres, spanning Europe, the carefully planned and performed a standardised and quality controlled data collection, and the huge sample size. IDEFICS did not aim to recruit a nationally representative sample, but because of the size and scope, it can be considered characteristic of European children. One limitation of the present analysis may be that the children participating in the various modules were not a random sample of the overall study population since participation was at the discretion of study subjects. However, there were no apparent differences in the socio-demographic profile between the responders and non-responders to the various modules. Despite this limitation and the varied number of observations for the key behaviours, a sample size with enough statistical power was still achieved. Another potential limitation is the quality of indicators that were based on parental proxy-reported questionnaires which limited reliability specially for the diet-related key messages[109], though for children below eight years parental reporting is an established and accepted solution[181]. The reliance on self-reports with respect to variables where an objective assessment or a direct measurement was not feasible in such a large population-based study. This was for instance the case for questions that were related to family life. Furthermore, the relationship of our key message to improve the quality of family life and the newly developed quality of life score has not been directly shown. But since the quality of life score used in this paper contains a module characterising the quality of family relations (taken from the original KINDL questionnaire), we are quite confident that its use is valid for indicating the key message with respect to an improved quality of family life. A final notable limitation is the cross-sectional study design which does not permit casual interpretation of the results.

Conclusion

The overall compliance of young children to health-behaviour recommendations was very low and should therefore be improved, preferably via those actors who can serve as role model, mediator for the different lifestyle aspects or nutritional gatekeeper for the children. The present work directs the attention to the gap between the present and the required situation.

The compliance score, an indicator of a set of pro-health behaviours, was significantly correlated with body weight, and as the number of pro-health behaviours increased a gradual reduction for the odds of being overweight was observed. This finding supports the selected intervention settings[83, 84, 182] in the IDEFICS study, its target areas and the six key messages. It demonstrates that these messages are potent and relevant in spite of incidental moderate reported success, which, in the mirror of our results, might be attributed rather to implementation barriers. The proven favourable effect of guideline adherence underpins that these guidelines represent an important anchor point and an easy-to-use heuristic for all actors – children, parents, schools – to tackle obesity effectively.

The other important finding was the general low prevalence of pro-health behaviours. Almost none of the children has achieved full compliance with the six key behaviours selected during intervention mapping. Even the compliance of more than half of the key messages, which in contrast could be evaluated as good compliance, was dramatically low. This demonstrates that there is an enormous reserve in the intervention tackling the obesity epidemic, and confirms the potential of obesity intervention. Our results demonstrated that even a slight improvement in lifestyle, i.e. complying with one more pro-health behaviour, demonstrates a meaningful and statistically significant benefit, which is an encouraging message for both the target population and the health promotion professionals.

New findings of the study

This work contributes to the intervention of childhood obesity by

- providing data on spontaneous (before intervention) adherence to the most important behavioural risk factors;
- creating the compliance score as composite measure of adherence to pro-health lifestyle contributing to obesity, an indicator of a set of relevant behaviours;
- proving the potential of the intervention and that even a small increment in the adherence regarding the recommended set of behaviours creates a detectable improvement, an encouraging message in tackling the obesity epidemic.

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I dedicate this work to the memory of my father; and to my mother who transferred me his message.

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