Obesogenic environments; why are they important?

Body mass index (BMI) is an index of weight-for-height that is commonly used to define overweight and obesity in adults for surveillance studies. Overweight is defined by a weight-for-height between 25 kg/m² and 30 kg/m², while obesity is defined by a weight-for-height of 30 kg/m² or more.[5] Current surveillance data indicate that more than half a billion adults worldwide are obese.[6] The prevalence of overweight and obesity has increased dramatically during recent decades, especially in the developed world: during the years between 1980 and 2010, obesity rates have doubled or even tripled.[6] In Europe, more than 50% of the total adult population is now overweight and obesity rates among adults exceed 20% in many EU Member States (see also Figure 1.1.1.1).[7]
1.1 Introduction

Overweight and obesity are major public health problems given their high prevalence and wide range of negative consequences.[1–3] Primary prevention of overweight and obesity is traditionally focused on changing the direct behavioural determinants; reducing energy intake by focusing on dietary behaviours and/or increasing energy expenditure by focusing on physical activity or sedentary behaviours. Sustained change in obesity-related behaviours has, however, turned out to be very challenging. Obesity-related behaviours are determined by a wide range of factors, including personal motivations, preferences, beliefs, abilities and skills. But contextual factors - including the social, economic, political and physical circumstances individuals live in- are also of relevance. These ‘contextual’, ‘upstream’ or ‘environmental’ factors can facilitate or hinder healthy behavioural choices by promoting unhealthy eating or physical inactivity. Consequently, changing the environment could support individuals to make healthier choices. In order to design obesity prevention interventions that take into account these environmental aspects, we need to better understand what environmental factors are associated with and/or affect health behaviours and weight status, as well as how, and under which circumstances. The evidence to date regarding such potential ‘obesogenic’ (obesity-inducing) environments mainly originates from studies conducted in the USA or Australia.[4] The present thesis is largely based on data from across Europe and aims to provide a better insight in the ways in which physical, social, economic and policy environmental factors are associated with obesity-related behaviours and obesity in adults.

This general introduction will provide a global overview of the prevalence, the consequences and the determinants of overweight and obesity in adults. While acknowledging the complex, multifactorial nature of obesity (which has been described extensively elsewhere), this introduction will describe individual and contextual determinants of obesity based on ecological models of health behaviours. Some important shortcomings of previous literature will be highlighted, and an outline of the thesis will be given.

1.1.1 Prevalence and consequences of overweight and obesity

Body mass index (BMI) is an index of weight-for-height that is commonly used to define overweight and obesity in adults for surveillance studies. Overweight is defined by a weight-for-height between 25 kg/m² and 30 kg/m², while obesity is defined by a weight-for-height of 30 kg/m² or more.[5]

Current surveillance data indicate that more than half a billion adults worldwide are obese.[6] The prevalence of overweight and obesity has increased dramatically during recent decades, especially in the developed world: during the years between 1980 and 2010, obesity rates have doubled or even tripled.[6] In Europe, more than 50% of the total adult population is now overweight and obesity rates among adults exceed 20% in many EU Member States (see also Figure 1.1.1.1).[7]
Figure 1.1.1.1 Prevalence of obesity in European adults

Although the data in Figure 1.1.1.1 stem from 2012, data from 2015 (on a limited number of countries) show the same trends, with highest prevalence in the UK and lowest in Italy.[8]

The increase in overweight and obesity goes hand in hand with an increase in obesity-related diseases such as type 2 diabetes, musculoskeletal problems, cardiovascular disease, several types of cancer, musculoskeletal disorders, sleep apnoea and gallbladder disease.[9–11] As a result, obesity now accounts for approximately 400,000 deaths per year, second only to tobacco.[12] Beyond the toll overweight and obesity take on the health of individuals, they impose a considerable economic burden on societies through decreased household wages, earnings and income, increased absence from work, premature retirement, unemployment and higher dependence on welfare.[13] Additionally, Finkelstein et al. estimated that between 5% and 7% of US annual medical expenditures are spent on obesity.[14] However, estimates of health-care costs attributable to obesity vary enormously due to differences in methodology and definitions of health-care costs.[15,16]

1.1.1 Variations in overweight and obesity across Europe
There is considerable variation in prevalence of overweight and obesity within and between European countries. Obesity prevalence is lower in Western/Southern (11%) countries compared to Central/Eastern (12%) and Northern European countries (18%). Prevalence ranges from 7.6% in Italy to more than 20% in Croatia (21.5%) and England (20.1%).[8,17]
Differences in overweight and obesity may be partly due to socio-demographic variations, including variations in age, gender and socioeconomic status.[18,19] Across European countries, overweight and obesity is more prevalent among older people (50-64 years) than in younger people (25-49 years).[8,18,20] A recent study showed that overweight was more common in men than in women, while obesity was more common in women. Exceptions occurred in Ireland and the UK, where obesity was more common in men in some surveys.[20] There is also a strong relationship between obesity and low socioeconomic status (at least in females[21–25]), which can be partly explained by social inequalities in physical activity[26,27] and eating behaviour.[28–30] There is also evidence that weight status differs by ethnicity or race. For example, a systematic review showed that obesity is more common among Turkish and Moroccan migrant groups in Europe than in the Western European population.[31,32] Studies from the US show that overweight and obesity is most prevalent among non-Hispanic Blacks and least prevalent among Asian-Americans than among Whites.[33] However, as the health risks associated with a higher BMI is markedly higher in some groups (Asians) than in others (Caucasians), definitions of overweight should be tailored to ethnic background.[34]

1.1.2 Determinants of overweight and obesity

Already in 1783, Lavoisier and Laplace showed that living organisms obey the first laws of thermodynamics; the amount of energy in a closed system remains constant.[35,36] In terms of a constant human weight status, this means that the amount of energy eaten must equal the amount of energy expended. Any energy that is not expended will be stored, mostly as fat tissue. Physical activity, sedentary behaviours and dietary behaviour are important ‘energy balance-related behaviours’ (EBRBs).[37]

Physical activity can be defined as ‘any bodily movement produced by skeletal muscles that results in energy expenditure’.[38] Physical activity can be done in different settings, such as during work (e.g. walking to a meeting), during household chores (e.g. cleaning, gardening), during transport (e.g. walking or cycling to work) or during leisure time (e.g. walking for leisure or participating in sports activities). As such, physical activity is not only limited to exercise, which is a planned, structured and repetitive physical activity (going to the gym three times a week).[38] Physical activities can be performed at varying intensities, ranging from light-intensity physical activity (e.g. ironing, casual walking), moderate intensity physical activity (doubles tennis, cycling) to vigorous-intensity physical activity (e.g. running, singles tennis). It is recommended that adults should take part in at least 150 minutes of moderate intensity physical activity or 75 minutes of vigorous physical activity each week.[39]

Sedentary behaviours (from the Latin ‘sedere’, which means ‘to sit’, and defined as any waking behaviour in a sitting or reclining position and a low energy expenditure[40]), are behaviours with a lower energy expenditure than physical activities, and include behaviours such as TV viewing, sitting during meals and driving a car.[41] In our current society, individuals are likely to both engage in sufficient physical activity but also spend a large share of their day sedentary. So sedentary behaviour is not just a synonym of lack of moderate to vigorous physical inactivity.[42] People who are sufficiently active can sit too much during the rest of their waking hours, and such extensive sitting has been shown to be associated with all-cause mortality, independent of physical activity behaviour.[43,44]
Dietary behaviour refers to the eating patterns people engage in, and include the nature, quality, variety and quantity of food consumed, how it is prepared as well as aspects related to choice of food products, meal timing and composition. Dietary behaviours can be regarded as more or less healthy (such as consuming sufficient fruit and vegetables) and more or less unhealthy (such as high consumption of sugar-sweetened beverages). Whereas the health benefits of a healthy diet are well documented,[45] what exactly makes up a healthy diet is harder to define. The exact composition of a diverse, balanced and healthy diet depends on individual characteristics (age, gender, lifestyle), but general dietary recommendations include advice to restrict intakes of saturated and trans fats, salt, sugar and red meat and/or meat products, and to eat ample amounts of fruit, vegetables, (other) fibre-rich products and whole-grain products.[45] Regarding weight management, dietary recommendations include restricting portion sizes, snacking and consumption of sugar-sweetened beverages while eating regular meals with a lower energy density.[46]

Neither of these energy balance-related behaviours (also referred to as ‘obesity-related behaviours’) can be designated as a universal causal factor in obesity; instead their co-existence and interaction determine whether or not a positive energy balance, and thus weight gain, is experienced.[47]

Nevertheless, differences in overweight and obesity across regions may be partly explained by variations in obesity-related behaviours. While walking is quite common in Spain, Dutch people are most often sufficiently physically active, probably due to cycling.[48] In the Netherlands, 26% of all trips are made by bicycle, compared to only 2% in the United Kingdom.[49] Regarding dietary behaviours, Mediterranean countries consume relatively high levels of plant foods, while diets in Nordic countries, the Netherlands, Germany and the United Kingdom are often characterised by high levels of potatoes and animal-sourced foods.[50] Regarding sedentary behaviours, the highest amount of sitting per day are reported in Northern European countries, while the lowest amounts of daily sitting are observed in southern and Eastern European countries.[51,52] The high amount of sitting in Northern European countries is probably partly due to a relatively large share of white-collar workers. This is supported by findings that higher levels of sitting were observed in males, younger age groups and those with high education levels.[51,52]

These above described energy balance-related behaviours are influenced by a range of individual psychological and genetic/biological and contextual (environmental) factors. But it has also been suggested that variations in obesity-related behaviours and obesity may be partly due to variations in contextual factors; the physical, social-cultural, economic and political environment. For example, the higher modal share of cycling in the Netherlands may be due to the high-quality cycling infrastructure, including cycling highways and parking at railway stations, in the Netherlands.

1.1.2.1 Individual - Psychological factors

It is still a common prejudice that obese individuals can ameliorate their condition by simply deciding to eat less and exercise more. However, many more psychological factors than willpower alone have an influence on obesity-related behaviours. Several theoretical frameworks, such as the health belief model[53] and the theory of planned behaviour,[54] describe the individual-level factors that determine health behaviours. Such factors include knowledge, self-efficacy, perceived benefits and perceived barriers, intention and attitude. The self-determination theory describes the importance of ‘a sense of autonomy, relatedness and competence’ for having the motivation to behave healthily.[55]
Traditionally, interventions to promote health behaviours focused on changing knowledge, intentions and attitudes towards the targeted behaviour, in accordance with the health belief model.[53] Though some of these interventions have been effective, they demonstrated limited success in promoting long-term maintenance of health behaviours.[56] It seems that these types of interventions often affect individual behaviour initially, but contextual factors may cause the individual to return to previous unhealthy behaviour after the intervention.

### 1.1.2.2 Individual - Genetic and biological factors

The idea that obesity is preventable by just ‘deciding’ to eat healthily and exercise more is also contradicted by scientific evidence suggesting that the propensity to be obese is, to a certain extent, determined by biological and genetic factors.[58] Biological factors include the hormone Leptin, which regulates the energy balance (consumption) through appetite.[59] Both physical activity and eating behaviours have shown to be strongly genetically defined.[60,61] Obesity also has a strong hereditary component (equivalent to that of height, often cited as 40–70%[62]), but large genome-wide association studies seeking to identify single nucleotide polymorphisms (SNPs) associated with BMI have not yet been able to explain more than a small proportion (<2%) of weight variability.[63,64] In conclusion, the role of genetics and biological factors in obesity-related behaviours and obesity is important, but complex and in many cases not modifiable.

### 1.1.2.3 Contextual - Environmental factors

Unlike genetics and biological factors, some environmental factors have changed during the last decades, and these factors may have contributed to the exponential rise in overweight and obesity. Examples of environmental factors that have changed during the last decades and may have contributed to the obesity epidemic include: the relative price inflation of healthy food; modern technologies that allow us to be less physically active for work; the increased easily availability of food; cars and public transport that allow us to travel faster without being physically active; and female emancipation that may have led to a bigger workforce but also to less attention for cooking at home.[65] These processes have had a major impact on physical activity and dietary behaviours at population levels. Some of these processes are likely to be irreversible (such as modernisation of work; we are not likely to go back to heavy labour force), but there are factors that we could influence and which may contribute to a halt in the increasing obesity prevalence. Those things include pricing, subsidizing and taxation to stimulate healthy behaviour (economic), laws and policies to promote healthy behaviour (political), a physical environment that enables and stimulates healthy behaviour (physical) and changing social norms and the way society interacts (social).

The ANalysis Grid for Environments Linked to Obesity (ANGELO) framework has further specified these four environmental types: physical (what is available), economic (costs), socio-cultural (social support, cultural differences) and political (the rules).[66] These types of environment may be set in either a macro or micro environment. Macro environments are those beyond individual control, whereas micro environments are more local, such as the home or neighbourhood. The four environmental types are further delineated below:
1.1.2.3.1 Physical environmental factors

The physical environment encompasses ‘what is available’ in an environment; the variety of food outlets, worksites, community centers, cycle paths, street lighting, public transport etc.[66] The ‘built environment’ refers to environmental features that are ‘man-made’ such as bridges, roads and buildings, and the ‘natural environment’ refers to environmental features such as beaches, dunes and hills. Often studied factors of the physical environment include:

- ‘aesthetics’ (often including indicators such as graffiti, litter, natural features and well-maintained buildings);
- ‘safety’ (safety from crime as well as traffic safety);
- ‘land use mix’ (the range of land uses, including residential, commercial and industrial, that are co-located);
- ‘connectivity’ (how well areas are connected through a network of paths or roads);
- ‘walkability’ (often an index including indicators such as population density, residential density, land use mix, intersection density and connectivity);
- ‘urban sprawl’ (spreading of development out of a city);
- and ‘density’ (of food outlets, recreational facilities, residences, parks, etc.).

Several overview studies on the physical environmental determinants of body weight have been conducted. For example, Booth et al. showed that walkability, land use, sprawl, and level of deprivation were related to overweight prevalence.[67] However, the authors also concluded that the methods used to characterise the environment were often indirect (asking individuals about their environments, instead of objectively measuring the environment), and varied between studies, which made it difficult to draw definite conclusions.[67] Papas et al. conducted a similar study, ending in a similar conclusion: measurements of the built environment were inconsistent between studies.[68]

Additionally, a number of overview studies have been conducted regarding the physical environmental determinants of obesity-related behaviours. For example, Brug and van Lenthe concluded that there were few replicated studies of good quality examining the influence of environmental determinants on dietary behaviours.[69] Similarly, Wendel-Vos et al. showed that there was only evidence for an association between few environmental factors and physical activity in adults, including connectivity of trails and availability of physical activity equipment.[70] Caspi et al. showed that environmental perceptions were associated with dietary behaviours, but there was little evidence for an influence of the objectively measured food environment.[71]

Only around 5-10% of the studies included in the reviews were conducted in Europe, showing a clear lack of evidence from the European region. As European environments and health behaviours differ from North America and Australia, evidence from Europe is needed to examine whether the associations found in North America and Australia also apply there. Evidence from a recent Belgian study showed that adults living in high-walkable neighbourhoods reported more walking for transportation, more cycling for transportation, more recreational walking and less motorised transport than adults living in low-walkable neighbourhoods.[72] Although a more robust methodology was used, the authors acknowledged that the use of cross-sectional data could have led to bias due to residential self-selection. That is, physically active adults tend to choose (self-select) their neighbourhood based on characteristics that facilitate physical activity.[73] The authors of the Belgian

...
study attempted to adjust for this and concluded that, even beyond residential self-selection, 
neighbourhood walkability was consistently associated with physical activity.[72] However, when 
comparing the built environmental correlates of walking and cycling between Belgium, the USA and 
Australia showed that these associations differed between country and between walking and 
cycling.[74] As such, the authors concluded that future studies should include even more countries to 
maximise environmental variability.[74]

1.1.2.3.2 Socio-cultural environmental factors
Socio-ecological models suggest there is a dynamic relation between individuals and their broader 
social environment. The social environment has been broadly defined as ‘the environment that 
influences an individual’s behaviour through promoting a sense of social control through the creation 
of social norms’.[75] Communities’ social and cultural norms (attitudes, beliefs and values) may be 
shaped at the micro level (at home, at work, in a group of friends, etc.) or at the macro level (via the 
media or advertisements).

It has been suggested that the social environment can broadly be categorised into five dimensions: 
socioeconomic status and income inequality; neighbourhood deprivation; social isolation (racial/ethnic 
segregation) and crime; social support and social networks; and social cohesion and social capital.[76] 
Socioeconomic status is commonly conceptualised as the social position or class of an individual or 
group. Deprivation suggests that something is missing, and in the context of socioeconomic 
deprivation, this often encompasses lack of psychosocial or material resources. Social isolation 
describes the process whereby some persons or groups are not in contact with other persons of groups. 
Evidence on the first three dimension is quite consistent. Several systematic reviews linking obesity to 
socioeconomic status have been published,[24,25] showing an inverse association between 
socioeconomic status and obesity. Moreover, an experimental study showed that the opportunity to 
move from a neighbourhood with high level of poverty to a lower level of poverty (by receiving 
housing vouchers) was associated with reductions in obesity and type 2 diabetes.[77] Numerous 
studies assessed the association between neighbourhood deprivation and overweight, suggesting that 
prevalence of overweight and obesity is higher in more deprived neighbourhoods.[78–80] Lastly, 
studies from the US have shown that racial segregation is associated with higher BMI,[81–84] and 
neighbourhood crime and unsafety has been associated with lower levels of physical activity.[85,86] 

Evidence on the association of social support, social network, social cohesion and social capital with 
weight status is not so consistent. It has been suggested that social norms for health-related behaviours 
may vary across neighbourhoods.[87,88] Higher psychosocial stress has been related to an increase in 
BMI among women.[89] Several studies have been conducted examining the association between 
social capital and weight status.[90–93] Yet, no overview study on these social environmental 
determinants of obesity is available yet. Moreover, there seems to be uncertainty about how distinct these different social constructs are.

With regard to other social factors (not included in these five dimensions), such as subjective norms, 
social modelling (including parenting) and descriptive norms, there is debate about whether they are 
individual or environmental constructs. It may be that broader constructs, such as deprivation or social 
networks, affect behaviours via psychosocial stress or social support. For example, evidence suggests 
that eating behaviours are heavily influenced by social modelling, whereby individuals use others’
1.1

Eating behaviours as a guide for what to eat and how much.[94] And a recent field-experiment showed that individuals exposed to healthy descriptive norms resulted in more healthy food choices.[95]

1.1.2.3 Economic environmental factors

Although obesity is very much of economic concern,[96,97] economic factors have been an underexposed focus of research compared to other socioeconomic factors affecting weight status.[24,98,99]

First, economic factors such as food price, cost of healthy diets, personal or household income or the amount of money available to purchase food may be important for dietary quality.[100–106] Studies have shown that constraining food budgets can lower the nutritional adequacy of the diet[107,108] and that economic uncertainty may adversely affect people’s food choices.[109] Dietary costs may therefore be a barrier for the uptake and maintenance of healthy diets[110,111] Research from the US has shown that adherence to a healthy diet (lower energy-density, higher intake of vitamins, potassium and dietary fiber) is more costly than adherence to a less healthy diet (e.g. [105,106,112,113]), and these results have been replicated in the UK.[114,115] Importantly, healthy diets are also perceived to be more expensive than unhealthy diets.[115,116] An intervention examining the effect of price discounts on fruit and vegetables showed higher fruit and vegetable purchases after a 50% price reduction,[117] suggesting that pricing strategies may be part of an effective strategy to promote healthy diets. Research from the US also suggests that area level housing prices are strongly associated with obesity, such that women in the bottom quartile of property values were over 3 times as likely to be obese than women in the top quartile.[118]

Second, not only absolute measures of income (such as personal or household income), but also more relative measures such as relative income, relative position, deprivation and income inequality have been associated with weight status. Income inequality (the gap in income between those with the highest income and those with the lowest income) may thus contribute to the unequal distribution of obesity across and within countries.[119,120] It has been suggested that country- or state-level income inequality influences population health via political mechanisms, for example through associations with the patterns of state spending on social goods such as education and welfare.[121] Alternatively, income inequality at lower levels, for example at the neighbourhood level, may be related to lower levels of community social capital in such neighbourhoods.[119] Erdem et al. showed that structural neighbourhood inequalities were associated with higher levels of psychological distress, and that this association was mediated by the level of neighbourhood social cohesion.[122] In turn, social stress – which may indicate low levels of social capital- has been associated with risk factors for overweight and obesity[37] such as over-eating[123] and preferences for energy-dense foods.[124]

In contrast to food, physical activity does not necessarily have a direct financial cost.[75] However, there are a number of economic factors which can influence the amount of physical activity people engage in, such as municipal budgets for the maintenance of recreational facilities and footpaths, the proportion of national budgets allowed for health promotion, traffic safety or paid parking policies.[75,125]
1.1.2.3.4 Political environmental factors

The policy or political environment describes the rules and regulations at a micro level and macro level that influence obesity. At a micro level, one can think about rules and regulations at home, such as family rules on television watching. At a macro levels, one can think about regulations, laws and town planning policies, such as restricting inner city centres to foot or bicycle traffic.[75] Or with regard to the food environment: nutrition labelling on packaged foods, rules on marketing on unhealthy foods, calorie labelling on restaurant menus and fiscal interventions such as food taxes.[126]

The European Union has a range of options for the regulation of obesity-related risk factors, including:

- disclosure requirements and information schemes (food packages should contain information);
- regulation of marketing (information must be trustworthy and not misleading);
- measures affecting product availability;
- economic instruments (subsidies, e.g. for fruit and vegetables at schools, and fiscal measures such as earmarked taxes);
- fundamental rights (right to health life, clean environment, information, and (nutritious) food);
- performance-based regulation;
- self-regulation;
- and supportive policies (such as education campaigns, research and monitoring).[127]

In a recent Lancet Series, Asaria et al. and Lim et al. showed that the implementation costs of a set of preventive strategies were estimated to range from $1.5 to $4.5 per head.[128,129] This included the most efficient fiscal, regulatory, and health-care measures to tackle the main risk factors for chronic diseases (fiscal measures, worksite interventions, mass media campaigns, physician counselling, food labelling, food advertising regulation and school-based interventions) and excluded any future treatment cost savings resulting from these preventive measures. This suggests that only a very small, almost negligible, price for the value of a human life is needed to avert the deaths or health losses associated with chronic disease.[128,129]

There is now consensus that the most promising policy options for the prevention of obesity are multi-sectorial. After identifying the key targets, a political process is likely to decide whether voluntary measures, legislations, initiatives led by local authorities and so on should be used.[130] These decisions are ideally evidence-based, but it is often difficult to translate the evaluation of specific policy measures from one context to the other. For example, the expansion of bicycle routes combined with education on cycling safety may have larger effects in areas where cycling is less common (such as Greece) than in areas where cycling is business as usual (Denmark). However, by monitoring trends in obesity, describing the context in which policies will be or have been implemented, and sharing good practices, a portfolio of evidence-based priority actions for preventing obesity may be created.[130]
1.1.2.4 Ecological models of health behaviours and obesity

Ecological frameworks of health conceptualise the interrelationships between individual and contextual variables. This has been done in several ways. The ecological model by Dahlgren and Whitehead [131] for instance, describes the individual located in the centre, having a number of fixed characteristics (sex, genetic composition; Figure 1.1.1.2). Surrounding the individual are the factors that influence health, such as lifestyle behaviours, social and community networks and structural factors such as working conditions and access to services and facilities.[131]

Figure 1.1.1.2 The socio-ecological model of health as presented by Dahlgren and Whitehead[131]

Ecological models of obesity-related behaviours and obesity propose that behaviours are influenced by an interaction of intrapersonal, socio-cultural, policy, and physical environmental factors.[132] Ecological models pose that healthy behavioural choices are not only the result of conscious individual decision-making, but can also be a relatively automatic reaction to environmental cues.[133,134] The EnRG framework (Environmental Research framework for weight Gain prevention; Figure 1.1.1.3) describes how energy balance-related behaviours are the result of a simultaneous influence of both individual and environmental factors. This framework integrates theories on behavioural change models and the ANGELO model.[135] The depicted arrows describe that micro-level and macro-level environmental factors (that can be either physical, political, economic or sociocultural) can directly influence EBRBs, but can also influence EBRBs via cognitive mediators, such as attitude. These associations can also be influenced by moderators such as gender or personality. The model specifically distinguishes between the objectively measured environment and the perceived environment.
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![Figure 1.1.1.2](image)

The socio-ecological model of health as presented by Dahlgren and Whitehead [131] Ecological models of obesity-related behaviours and obesity propose that behaviours are influenced by an interaction of intrapersonal, socio-cultural, policy, and physical environmental factors. [132] Ecological models pose that healthy behavioural choices are not only the result of conscious individual decision-making, but can also be a relatively automatic reaction to environmental cues. [133,134] The EnRG framework (Environmental Research framework for weight Gain prevention; Figure 1.1.1.3) describes how energy balance-related behaviours are the result of a simultaneous influence of both individual and environmental factors. This framework integrates theories on behavioural change models and the ANGELO model. [135] The depicted arrows describe that micro-level and macro-level environmental factors (that can be either physical, political, economic or sociocultural) can directly influence EBRBs, but can also influence EBRBs via cognitive mediators, such as attitude. These associations can also be influenced by moderators such as gender or personality. The model specifically distinguishes between the objectively measured environment and the perceived environment.

Recently even more detailed ecological models have been developed. For example, the Foresight report acknowledges that the wide range of proximal and distal causes of obesity interact, and have proposed a ‘complex web of societal and biological factors that have, in recent decades, exposed our inherent weight gain’. [136] Important environmental elements in this web include the activity environment (air pollution, safety); societal influences (media, education) and the food environment (availability of fresh fruit and vegetables). [136]
1.2 The SPOTLIGHT project

The Sustainable Prevention of Overweight Through integrated strategies (SPOTLIGHT) project was launched in the year 2012. The project aimed to “increase and combine knowledge on a wide range of determinants of obesity in a systematic way, and to identify multi-level intervention approaches that are strong in terms of Reach, Efficacy, Adoption, Implementation and Maintenance (RE-AIM)”.[137]

The SPOTLIGHT project had four aims, namely:

i. to identify individual-level, environmental-level and multi-level entry points for approaches aimed at changing obesity-related behaviours and environments;
ii. to assess interventions using the RE-AIM framework
iii. to identify success factors and failure factors for implementation of multi-level intervention approaches;
iv. to provide an evidence-based model for effective multi-level intervention approaches in health promotion practice applicable across the European region, and disseminate findings to stakeholder in European Union (EU) Member states.

For the first aim, three systematic literature reviews were carried out to identify individual-level determinants,[138] physical environmental determinants[139] and social environmental determinants[140] of obesity. Further, a tool to assess dimensions of obesogenic environments using remote imaging was developed[141] and a survey was conducted across five countries in the EU to assess the characteristics of inhabitants of the audited neighbourhoods.[142]

For the second aim, a systematic literature review was carried out to identify the success of evidence-based multi-level obesity prevention interventions in terms of RE-AIM.[143] Additionally, an overview was created of existing multi-level intervention approaches that are currently being implemented across the EU.[144] This has resulted in an interactive web-atlas of multi-level interventions.

For the third aim, a case study approach was used to identify the factors associated with success and failure of multi-level obesity prevention interventions. A combination of quantitative and qualitative methods were used to identify factors that enhance or impede the reach, effectiveness, adoption, implementation and maintenance of multi-level interventions.[137]

For the fourth aim, the new evidence gathered through the SPOTLIGHT project was summarised learning objectives for researchers and policy makers, and findings of the project were disseminated through symposia, conferences, scientific articles, web reports and social media.[137]

The work presented in this thesis is largely based on the first part of the SPOTLIGHT project, which aimed to identify environmental determinants of obesity in adults.
1.2.1 The SPOTLIGHT survey

The SPOTLIGHT survey was conducted in five European countries: Belgium, France, Hungary, the Netherlands and the UK. Large cities in each of these countries were defined as study areas: Ghent and suburbs in Belgium; Paris and suburbs in France; Budapest and suburbs in Hungary; the Randstad (a conurbation including Amsterdam, Rotterdam, the Hague and Utrecht) in the Netherlands; and Greater London in the UK. Within these urban areas, neighbourhoods were sampled based on a combination of residential area density (RAD) and socioeconomic status (SES). Neighbourhood level was defined according to small scale local administrative boundaries as used in each country except for Hungary. Budapest is divided into districts and suburbs that are highly heterogeneous in terms of population and much larger than the equivalent administrative areas in the other study countries. In order to ensure comparability between study areas, we thus defined 1 square km areas to represent neighbourhoods in Budapest and suburbs. Data on RAD were obtained from the Urban Atlas database.[145] This atlas is a geographic information system (GIS) database distributed by the European Environmental Agency, based on a compilation of satellite photographs covering Europe and providing high-resolution land use data.[146] The Urban Atlas includes a land use index that is comparable across European countries. The index is based on density of residential areas, commercial and industrial zones, green urban areas, commercial areas, industrial areas and water areas. RAD is calculated as the percentage of coverage of buildings devoted to residential facilities in a minimum mapping unit (MMU) of 0.5 hectare. Among six existing residential density categories in the Urban Atlas only two classes were used, defined as high and low residential area density (corresponding to >80% and <50% of areas covered by residential buildings, respectively). Neighbourhood SES data were based on income data at neighbourhood level retrieved from national statistical offices and national census databases. Two classes of SES were used (high and low, corresponding to the first and third tertile of the distribution in each country) (Table 1.1.1.1). The combination of the neighbourhood SES and RAD categories allowed the definition of four classes: high SES/high RAD, low SES/high RAD, high SES/low RAD, and low SES/low RAD. Based on this 2x2 grid applied to each study area in the five countries, three neighbourhoods were randomly sampled per neighbourhood category (i.e.12 neighbourhoods per country, 60 neighbourhoods in total). An additional inclusion criterion was that sampled neighbourhoods had to contain at least 800 households.

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1. This paragraph is largely based on the publication by J Lakerveld, M Ben Rebah, JD Mackenbach, et al. 2015: Obesity-related behaviours and BMI in five urban regions across Europe: sampling design and results from the SPOTLIGHT cross-sectional survey.
Adult residents from the selected neighbourhoods were invited to participate in an online survey. In the selected neighbourhoods, a random sample of residential addresses was drawn from postal companies (the Netherlands), Yellow Pages (France), electoral rolls (UK), or public administration services (Belgium, Hungary). As we expected lower response rates from participants in low SES neighbourhoods,[147] we oversampled adults from low SES neighbourhoods (1200 adults per neighbourhood) relative to high SES neighbourhoods (800 adults per neighbourhood). The aim was to recruit at least 100 participants per neighbourhood (6,000 in total), with an anticipated response rate of around 10%. Between February and September 2014, participants were recruited via postal invitation using the Dillman method.[148] In order to increase response rates, a prize (one or more bicycles) was offered for participants in the Netherlands, Belgium and Hungary. Furthermore, we used posters, flyers and local newspaper advertisements to raise awareness about the survey. In the Netherlands and France, in the neighbourhoods with lowest response rates, researchers also randomly visited people at home to encourage study participation. Response rates per country and neighbourhood type are shown in Table 1.1.1.2. A total of 6,037 adults completed the survey.

Table 1.1.1.1. Characteristics of the wider study areas in the five countries of the SPOTLIGHT survey

<table>
<thead>
<tr>
<th>Country</th>
<th>Study area</th>
<th>Neighbourhood characteristics according to each study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Ghent and suburbs have around 400,000 inhabitants and cover 537 km² (i.e. 464 neighbourhoods)&lt;br&gt;Statistical sectors</td>
<td>Name: Statistical sectors&lt;br&gt;Mean population: 946&lt;br&gt;Mean surface (km²): 1.4&lt;br&gt;First tertile of income (in €)<em>: &lt;22034&lt;br&gt;Third tertile of income (in €)</em>: ≥24351</td>
</tr>
<tr>
<td>France</td>
<td>Paris and first suburbs have a population of over 6 million inhabitants and cover 762 km² (i.e. 2749 neighbourhoods)&lt;br&gt;Ilot Regroupé pour l’Information Statistique (IRIS)</td>
<td>Name: Ilot Regroupé pour l’Information Statistique (IRIS)&lt;br&gt;Mean population: 2411&lt;br&gt;Mean surface (km²): 0.3&lt;br&gt;First tertile of income (in €)<em>: &lt;17290&lt;br&gt;Third tertile of income (in €)</em>: ≥25236</td>
</tr>
<tr>
<td>Hungary</td>
<td>Budapest and the 80 settlements surrounding the capital city have more than 2.5 million inhabitants and cover 2,538 km² (i.e. 1689 neighbourhoods)&lt;br&gt;The Randstad (Amsterdam, Rotterdam, The Hague and Utrecht)</td>
<td>Name: 1 square kilometer grid using a GIS**&lt;br&gt;Mean population: 1817&lt;br&gt;Mean surface (km²): 1.0&lt;br&gt;First tertile of income (in €)<em>: ≤3269&lt;br&gt;Third tertile of income (in €)</em>: ≥3955</td>
</tr>
<tr>
<td>Netherlands</td>
<td>have a population of 7.1 million inhabitants and cover 3,790 km² (i.e. 2078 neighbourhoods)&lt;br&gt;The Randstad (Amsterdam, Rotterdam, The Hague and Utrecht)</td>
<td>Name: Buurt&lt;br&gt;Mean population: 2343&lt;br&gt;Mean surface (km²): 1.2&lt;br&gt;First tertile of income (in €)<em>: &lt;29000&lt;br&gt;Third tertile of income (in €)</em>: ≥32000</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Greater London (including the City of London and 32 London boroughs) has a population of 8.1 million and covers 1,572 km² (i.e. 1649 neighbourhoods)&lt;br&gt;The Randstad (Amsterdam, Rotterdam, The Hague and Utrecht)</td>
<td>Name: Medium Super Output Area (MSOA)&lt;br&gt;Mean population: 5607&lt;br&gt;Mean surface (km²): 3.6&lt;br&gt;First tertile of income (in €)<em>: &lt;46888&lt;br&gt;Third tertile of income (in €)</em>: ≥55474</td>
</tr>
</tbody>
</table>

*Income data from Hungary and UK were converted to Euro
GIS: Geographical Information System

Between February and September 2014, participants were recruited via postal invitation using the Dillman method.[148] In order to increase response rates, a prize (one or more bicycles) was offered for participants in the Netherlands, Belgium and Hungary. Furthermore, we used posters, flyers and local newspaper advertisements to raise awareness about the survey. In the Netherlands and France, in the neighbourhoods with lowest response rates, researchers also randomly visited people at home to encourage study participation. Response rates per country and neighbourhood type are shown in Table 1.1.1.2. A total of 6,037 adults completed the survey.

**Table 1.1.1.2.**
Table 1.1.1.2. Invitation and response rates of the SPOTLIGHT survey

<table>
<thead>
<tr>
<th>Country</th>
<th>High SES/</th>
<th>Low SES/</th>
<th>High SES/</th>
<th>Low SES/</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High RAD</td>
<td>Low RAD</td>
<td>High RAD</td>
<td>Low RAD</td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2400</td>
<td>3486</td>
<td>2400</td>
<td>3578</td>
<td>11864</td>
</tr>
<tr>
<td></td>
<td>410 (17.1%)</td>
<td>451 (12.9%)</td>
<td>449 (18.7%)</td>
<td>464 (13.0%)</td>
<td>1849* (15.6%)</td>
</tr>
<tr>
<td>France</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2911</td>
<td>2058</td>
<td>2196</td>
<td>1612</td>
<td>8777</td>
</tr>
<tr>
<td></td>
<td>253 (8.7%)</td>
<td>183 (8.9%)</td>
<td>228 (10.4%)</td>
<td>156 (9.7%)</td>
<td>844* (9.6%)</td>
</tr>
<tr>
<td>Hungary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2690</td>
<td>3490</td>
<td>2304</td>
<td>3359</td>
<td>11843</td>
</tr>
<tr>
<td></td>
<td>163 (6.1%)</td>
<td>264 (7.6%)</td>
<td>188 (8.2%)</td>
<td>260 (7.7%)</td>
<td>875 (7.4%)</td>
</tr>
<tr>
<td>Netherlands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2336</td>
<td>3539</td>
<td>2382</td>
<td>3509</td>
<td>11766</td>
</tr>
<tr>
<td></td>
<td>405 (17.3%)</td>
<td>318 (9.0%)</td>
<td>367 (15.4%)</td>
<td>519 (14.8%)</td>
<td>1609 (13.7%)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2303</td>
<td>3441</td>
<td>2354</td>
<td>3545</td>
<td>11643</td>
</tr>
<tr>
<td></td>
<td>173 (7.5%)</td>
<td>203 (5.9%)</td>
<td>247 (10.5%)</td>
<td>225 (6.3%)</td>
<td>860 (7.4%)</td>
</tr>
<tr>
<td>Total</td>
<td>12640</td>
<td>16014</td>
<td>11636</td>
<td>15603</td>
<td>55893</td>
</tr>
</tbody>
</table>

SES: neighbourhood socioeconomic status; RAD: neighbourhood residential area density
Residents with unknown neighbourhood type: *n = 75,*n = 24,*n = 12

The study protocol was approved by the corresponding local ethics committees of each participating research centre and all survey participants provided informed consent.

Information on individual characteristics was obtained through the online survey. Participants were able to complete a paper-based survey instead of the online version upon request. The questionnaire was translated from English to French, Hungarian, Flemish and Dutch according to published guidelines for the translation of measurement instruments.[149,150] We used forward and backward translations by researchers working in the same or similar field, and native speakers of English and the targeted languages. In each country, two independent experts translated the questionnaire into their language. Together with a third person, the two versions were combined into one. This combined version was translated back into English by two other experts. An expert committee (four translators together with researchers) reviewed all translations and reports and took decisions on discrepancies. After data collection, a standardised in-country data cleaning protocol was followed by each research centre involved.

1.2.2 The SPOTLIGHT neighbourhood audit

First, we performed a systematic literature review on the use of free geospatial services as potential tools to assess physical environmental characteristics related to dietary behaviour and physical activity.[151] Direct observations (‘field audits’) of neighbourhoods require visits to each area to observe and rate characteristics of the physical environment and may take a lot of time. New, freely available remote sensing technologies (such as Google Earth, Google Street view and Bing Maps) offer the potential to assess neighbourhoods from a computer, potentially taking much less time. The systematic review assessed the validity of conducting ‘virtual audits’ compared to ‘field audits’, and concluded that agreement between them was high for objectively verifiable measures (such as the presence of infrastructure), but lower for subjectively assessed items (such as aesthetics or social nuisance).[151]

Based on this literature overview, we developed the SPOTLIGHT-Virtual Audit Tool (S-VAT) to assess the obesogenicity of neighbourhoods.[141] This tool is based on items from validated virtual
Detailed information on the validity and reliability of the S-VAT is described in Part 2, Chapter 1.3. The tool is designed to assess key street-level features of the neighbourhood environment and makes use of the Google Streetview feature in Google Earth: online omnidirectional imagery of simultaneously collected images in multiple directions from a single location, thus producing a panoramic view. It allows the auditor to virtually walk through a neighbourhood to observe characteristics of the physical environment. The S-VAT can be used in different places and at different time points, and allows for cross-country and -city comparison of environmental characteristics. The S-VAT was used to identify and compare environmental characteristics in European neighbourhoods, allowing for standardised and harmonised data collection across European countries.[141] The Standard Operating Procedure (SOP) is published as a supplementary file to the scientific article on the validation of the S-VAT (link: http://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072Z-13-52#MOESM1).

Detailed information on the validity and reliability of the S-VAT is described in Part 2, Chapter 1.2.[141]

### 1.3 Objectives and outline of this thesis

Despite increased interest in the associations between environmental factors and obesity in adults, the current literature still suffers from several shortcomings. First, there is a lack of evidence for such associations in the European context. As European environments and health behaviours differ from the USA and Australia, more European research is needed to examine whether associations found in other countries also apply in Europe. Second, almost all studies have been conducted in one single country, region or city. Given the limited variability in environments and health behaviours within one geographical area, true associations may have been undiscovered and other associations may have been overestimated (due to the specific characteristics of the area under study). Third, given the lack of conclusive evidence on the environmental determinants of obesity based on a large number of publications, more insight is needed in how environmental factors are associated with obesity (through which pathways), under what circumstances, and in which subgroups. Yet, current evidence on mediating pathways and moderating subgroups is limited, and this needs to be better understood in order to identify the most promising targets for environmental interventions.

In this thesis, I aimed to summarise the evidence available for the physical and social environmental determinants of obesity, as well as to report on new findings from the European SPOTLIGHT project, the Fenland cohort and the WILUTE model. The overall purpose of this thesis is to provide better insight in the role of environmental factors for health behaviours and obesity. In other words, the purpose is to identify potential ‘obesogenic environments’, with a special focus on urban environments.

In the different chapters, the aim was to address the following central research questions:

1) Which factors in the physical and social environments of adults have consistently been linked to adult weight status?
2) How can we define, measure and operationalise factors in the physical and social environments that may contribute to obesity risk across different regions?

3) To what extent, via which pathways and for what subgroups are physical, social, economic and political environmental factors associated with obesity-related behaviours and obesity in adults?

Following this general introduction (Part 1), the second part of this thesis will describe the results from original studies conducted to answer the main research questions. Chapter 2.1 describes the rationale for using virtual audit tools to characterise neighbourhood environments, and the validity and reliability of the SPOTLIGHT Virtual Audit Tool. The following chapters are classified according to the four ANGEL0 environmental domains. Chapter 2.2 relates to the role of the physical environment in relation to health behaviours and obesity. This chapter aims to understand what is already known based on previous literature; why lower educated individuals have less favourable neighbourhood perceptions than higher educated individuals; how individual perceived barriers and neighbourhood destinations interact in relation to obesity-related behaviours; how supermarket proximity and educational attainment interact in relation to weight status; and how the presence of fast food outlets may be associated with obesity. Chapter 2.3 describes the relation between social environmental factors, health behaviours and obesity. In this chapter, I aimed to understand what is already known based on previous literature; how different operationalisations of the construct of social capital relate to health behaviours and obesity; what social network characteristics are associated with health behaviours; and how neighbourhood income inequality is associated with body mass index. Chapter 2.4 describes the role of economic factors for health behaviour, with the aim to understand the interaction between dietary costs and socioeconomic position in relation to fruit and vegetable intake; and whether affordability and accessibility of supermarkets matter for adherence to the Dietary Approaches to Stop Hypertension (DASH) diet. Chapter 2.5 describes the political environmental factors associated with health behaviours, with the aim to understand the influence of urban land-use and public transport facilities on active commuting. In Part 3, the general discussion, main results are discussed in a broader perspective and summarised.
References general introduction


1.3


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1.3


PART II – ORIGINAL RESEARCH

Obesogenic environments; what are they and how do we measure them?