



# **Early warning indicators of obesity and physical inactivity trends**

Reviews of Scientific Evidence and Policies on Nutrition and Physical Activity -Objective Area D:  
Early Warning Indicators



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## **Preface**

### **About this project**

Overweight, obesity and their related diseases represent a leading cause of morbidity and mortality, and pose a major challenge for the sustainability of healthcare systems of EU Member States. The growing prevalence of overweight and obesity among all age groups across Europe constitutes a serious concern for policy makers. Tackling this issue requires a comprehensive response that reflects the multifactorial and complex nature of obesity and overweight. One particularly important area of focus has been on the development of preventative strategies which include nutritional and physical activity interventions.

The European Commission Directorate General for Health and Food Safety (DG SANTE) recognises the significant challenges policy makers face in developing effective and efficient policy interventions relating to diet and physical activity. One such challenge includes the complexity and breadth of the evidence base. By providing independent, accurate summaries of recent and relevant information and statistics on determinants of diet and physical activity and their impact on health, this project aims to support policy makers to continue to develop policy instruments which enable people to make healthier lifestyle choices. In particular, this project aims to support the development of healthier behaviours in vulnerable and/or at-risk subpopulations (including children, pregnant and lactating women, and older adults) and low socio-economic status groups (including low income and education).

### **About this series**

This evidence review is one of eight reviews relating to different determinants of diet and physical activity.

Seven of the reviews are of the scientific evidence and policies in the following areas:

- Knowledge, attitudes and behaviours contributing to positive energy balance (objective area A1);
- Dietary and physical activity patterns in Europe (objective area B1);
- Consumption of fruit juices, artificially and sugar-sweetened beverages and its impact on weight status and health (objective area B2);
- Consumption of high-fructose syrup and its impact on weight status and health (objective area B3);
- Relationship between weight status and physical activity with school and work performance outcomes (objective area C);
- Early warning indicators of obesity and physical inactivity trends (objective area D);
- Nutrition and physical activity guidelines for specific population groups (objective area E).

Building on these seven reviews, the final review (objective area A2) examines specifically the evidence for effective and efficient policies and interventions in terms of promoting, supporting and improving nutritional and physical activity behaviours at both individual and population level.

All reviews, and their summaries, are available on the DG SANTE webpage [here](#).

### **Approach and purpose**

The reviews have been designed to provide policymakers with summaries of recent and relevant evidence in these key areas of interest. Given the broad scope of each of the reviews, it should be stressed that they are not intended to be rigorous systematic reviews of all literature published in this field. Rather, they are intended as pragmatic reviews combining a comprehensive search methodology with expert academic input,

facilitated through workshops, to provide a practical and accurate summary of key issues and tackling broad lines of enquiry, with the greater aim of supporting the development and improvement of policies in this area. Each of the project's eight methodologies and analyses was reviewed by DG SANTE and academic experts in these topics.

While the methods to conduct this comprehensive literature review are systematic, it is *not* a systematic review. This review does not systematically analyse literature to identify *all* relevant published data and/or appraise its quality. Methods to conduct the literature review consisted of five steps: (1) refining the research questions, (2) developing a search approach and databases, (3) conducting literature searches, (4) screening articles for inclusion; and (5) abstracting and synthesising relevant data.

To minimise bias, the literature search approach included identification of a priori search parameters (also considered first level inclusion and exclusion criteria), agreed with DG SANTE, to guide searches and inform screening and selection processes for data inclusion. Due to the immense number of literature search results at step 3, the application of quite limiting exclusion criteria at step 4 was deemed necessary. This may however have resulted in not screening all potentially relevant literature. All relevant articles that were found appropriate for inclusion were reviewed for relevance to each objective area, and the scope of the specific research questions. Furthermore, the inclusion of different types of scientific evidence (from systematic reviews and peer-reviewed original articles down to BSc theses) and the presentation of this scientific evidence next to grey literature information presented a challenge in terms of maintaining an understanding of the quality and weight of the evidence. The authors addressed this to some extent by structuring the document in such a way that peer-reviewed and grey literature are clearly identified. The full methodology and steps taken for each review is included in Annex of the full literature review documents.

DG SANTE and the Joint Research Centre (JRC) provided input on all stages of the project and comments on the literature reviews. Expert workshops were organised to discuss findings, highlight additional relevant sources to fill gaps and improve the series of reviews. Experts were carefully selected from academic and policy-making fields, based on expertise of the specific topics addressed.

The methodology used across all eight reviews remained consistent, and within each review a detailed summary of the approach is provided, along with a full bibliography for further reading.

## **Objective D: A comprehensive review of the early warning indicators of obesity and physical (in)activity**

This report presents the findings of a peer-reviewed literature and grey literature review on factors associated with overweight and obesity and provides suggestions for reliable early warning indicators for obesity and overweight in children and adolescents and in adults. Because physical (in)activity is so strongly associated with the development of obesity, factors that influence physical (in)activity that could also serve as early warning indicators are also reviewed and explored.

### **1.1 Scope of this review**

To ensure the most relevant sources were reviewed, we:

- Focused primarily on literature published after 2005, unless otherwise stated.
- Did not focus in detail on particular dietary behaviours e.g. the consumption of sugar sweetened beverages (SSBs), artificially sweetened beverages (ASBs) or high fructose corn syrup, as these are the focus of separate reviews published as part of this series, Objective B2 and Objective B3, respectively. Other influences on diet and more general effect of these behaviours on obesity are discussed.
- Did not look at determinants of obesity and physical (in)activity on a societal/policy level as these are also considered in a separate review, Objective A2, which looks at policies and interventions found to be effective in promoting healthier behaviours.

### **1.2 Methodology**

The review is based primarily on peer reviewed literature (which is prioritised), with grey literature used to supplement any gaps (but treated with caution and the strength of the evidence assessed). A full description of the methodology used for all literature reviews can be found in the original literature review report. The review draws on 53 peer-reviewed and 23 grey literature sources selected as relevant. These findings were presented at an expert workshop, following which seven further peer-reviewed and four grey literature sources were added.

### **1.3 Research questions**

In this review, we focus on the most current literature (peer-reviewed original research and systematic reviews, as well as grey literature) that examines factors associated with overweight, obesity, and physical (in)activity structured according to the levels of influence within the social ecological model. The review considers which factors and measures might work as early warning indicators and potential monitoring systems to keep track of prevalence and trends. The research addressed the following questions specified for the review:

- What factors are associated with overweight, obesity and physical (in)activity?
- What factors could be of use as early warning indicators of overweight and obesity and physical (in)activity prevalence and trends?
- How could a feasible, effective and efficient early warning monitoring mechanism be put in place to keep track of these issues?

## **What factors are associated with overweight, obesity and physical (in)activity?**

Factors that impact or influence overweight, obesity, and physical (in)activity are abundant and complex. These factors range from genetic influences, familial environment, behaviour and conditions, and the external environment and represent the multiple levels of influence illustrated in the social ecological model of health. Factors associated with child and adolescent obesity and adult obesity are discussed separately; and the same for physical activity.

### **Factors associated with overweight and/or obesity in children and adolescents**

#### ***Individual-level factors***

The peer-reviewed and grey literature identified a wide variety of individual-level factors associated with overweight or obesity in children and adolescents. These included an increased risk of obesity among children with particular genetic factors (e.g. certain gene markers) (Liu et al. 2013, Silvertoinen et al., 2011, Choquet and Meyre, 2011), and also for those with high birthweights (Kapral et al. 2017, Weng et al. 2012, Rooney et al., 2011). Dietary behaviour risk factors identified by the peer-reviewed literature as positively associated with overweight and obesity among children were: overall caloric intake; increasing intake of potato chips and potatoes, sugar-sweetened beverages (SSB), and processed and unprocessed red meats (Hruby and Hu, 2015; Papandreou et al., 2013). Review evidence was inconclusive on the protective role of breakfast in preventing overweight or obesity in children, but suggests it does, at least, not lead to an increase (Blondin et al., 2016).

While clear links were identified, explanations for any associations found between both ethnicity (Gurnani et al., 2015; PHE 2016; WHO 2016) and short sleep duration (less than 10 hours a night for children) (Cappuccio et al. 2008; Patel and Hu 2008) with child overweight and obesity appear either complex or difficult to establish. Finally, systematic review evidence confirmed that physical activity is negatively associated with obesity, particularly moderate-vigorous intensity activity. Janssen and Leblanc (2010) found that the odds of being obese was 33% higher in the least active groups compared with the most active ones across 25 different physical activity intervention studies.

#### ***Interpersonal-level factors***

A number of factors in an individual's immediate environment can influence overweight or obesity and obesity-related behaviours, particularly the home environment, parent behaviours and close family/personal relationships. Peer-reviewed review evidence (Brisbois et al. 2012, Baidal et al.2016, Weng et al.2012) and grey literature (Parkes et al.2012) reported that different parental factors (maternal or fraternal) during gestation and infancy can increase the risk of overweight or obesity in children e.g.:

- Maternal pre-pregnancy overweight or obesity
- Excess maternal weight gain in pregnancy
- Maternal smoking or pre-natal tobacco exposure or pre-natal tobacco exposure.

Pan-European studies suggest that parental low socio-economic status and educational attainment is associated with increased risk for overweight or obesity and related health behaviours in their children (Van Stralen et al., 2012) which review evidence indicates is a reverse of historical trends where wealth was positively associated with obesity. Higher education seems to play a protective role in high income and transitioning countries. (Hruby and Hu, 2015).

Other protective factors against overweight and obesity identified included breast feeding (Yan et al., 2014; Weng et al., 2012) authoritative parenting, parental modelling and encouragement of fruit and vegetable consumption (Berge et al., 2009; Van der Horst (2007). A meta-analysis by Yan et al. (2014) found that among children who were

breastfed during the first year of life the risk of childhood obesity was 22% lower than those who were not, that children who were breastfed for seven months or more had a lower risk of obesity than those who were breast fed for a shorter amount of time and that the protective effect gradually decreased as the length of time a child was breastfed decreased. Berge et al. (2009) found that an authoritative parenting style (high levels of demandingness, high levels of responsiveness) was positively associated with the child consumption of fruits, vegetables and dairy products, lower consumption of sugar-sweetened beverages, higher levels of physical activity and negatively associated with BMI. Van der Horst et al.'s 2007 review identified the role of parental modelling around fruit and vegetable consumption in positively influencing children's behaviour, and that their encouragement is an important factor in children's consumption, while Berge (2009) also noted the parents who had regular family meals had children with a lower BMI and healthier dietary intake.

### ***Institutional and organizational level factors***

In contrast to individual and interpersonal factors, our review found limited evidence in the peer reviewed literature relating to associations between different organisational settings and child obesity. In the school setting, physical activity opportunities and healthy foods/beverages may be important for preventing obesity and increasing physical activity. Katz et al. (2008) found that across different international studies school-based nutrition and physical activity interventions resulted in significant reductions in weight, particularly when both physical activity and nutrition interventions were implemented together.

### ***Community level factors***

Community-level factors such as access to stores where healthy foods are available or land mix of neighbourhoods show some evidence of being associated with obesity (either positively or inversely) but findings are inconsistent. A significant positive association between fast food outlet density and obesity was found in an analysis of English data by Cetateanu et al. (2014) and a systematic review by Cobb et al. (2015) also found this association among children from low-income backgrounds. However, the majority of studies they reviewed did not find a significant association between the food environment and obesity overall (Cobb et al. 2015).

## **Factors associated with overweight and/or obesity in adults**

### ***Individual-level factors***

Many of the various individual-level factors associated with obesity in adults identified in the peer-reviewed and grey literature closely resembled those found for children and adolescents (e.g. increased SSB consumption, low socioeconomic status), there were some key differences and some variables which were found to particularly apply to adult obesity. These include strong and consistent increased risks of adult overweight or obesity in the case of rapid weight gain in early childhood, early adiposity rebound and childhood obesity aged less than five years old (Brisbois et al., 2011).

The evidence for links between both high birthweight and short sleep duration with adult obesity were not as conclusive for adults as for children. We found evidence of a positive association between high birthweight and obesity in early adulthood in the peer-reviewed literature, including a systematic review and meta-analysis (Yu et al. 2011) and cohort study (Rooney et al.2011), which found that higher birthweight was a main predictor of obesity in young adulthood (19-20 years) (Rooney et al.2011). However, in their systematic review of early markers of obesity Brisbois et al. (2011), found no clear conclusion for a link between higher birth weight and either higher adult BMI, overweight or obesity. In the literature about sleep duration identified, the associations between short sleep duration (less than 6 hours for adults) and obesity were significant (Cappuccio et al. (2008) but mainly found in lower quality cross-sectional studies and less consistent than studies investigating the link among children (Patel and Hu, 2008).

Socio-economic status was also highlighted as being an important determinant of weight for adults, but potentially affected by gender as well as national socio-economic influences. Several grey literature sources found the association between socioeconomic status and obesity was stronger for women than men, but that national context may affect whether this association is positive or negative. (Aguirre et al., 2016; Health and Social Care Information Centre (HSCIC) 2016; HSCIC 2015; Loring and Robertson 2014; Keenan et al., 2011; Robertson et al., 2007).

### ***Interpersonal-level factors***

The association between some parental influences and obesity is maintained into adulthood. Brisbois et al. (2012) as part of their review of potential early markers of obesity, found that three maternal influences for adults had positive associations with adult obesity: maternal BMI (significantly positively associated with development of adult obesity in their children), maternal weight gain during pregnancy (strongly associated with higher adult BMI) and maternal smoking (weakly-to moderately associated with increasing risk of developing adult obesity for their children). Rooney et al. (2011) also found that maternal smoking and maternal weight gain are main predictors of obesity in early adulthood (19 – 20 years). Across their review of predictors of obesity at three developmental points, Rooney et al. found that maternal obesity was the strongest predictor of obesity at all three points.

### ***Community-level factors***

The variation in evidence for environmental influence on child obesity was also found in literature looking at adult obesity. Reviews found fairly consistent associations between lack of supermarkets and higher BMI within disadvantaged populations (e.g. Lovasi et al., 2009, Cobb et al., 2015) but Cobb et al. again did not find a significant association between the food environment and adult obesity overall.

## **Factors associated with physical (in)activity in children and adolescents**

The review identified a smaller number of sources discussing the factors associated with physical (in)activity, among children, adolescents and adults, than with overweight or obesity. Findings that were identified also mapped onto different levels of the social-ecological model but primarily at an individual, interpersonal and community level.

### ***Individual-level factors***

Findings suggest that physical (in)activity and sedentary behaviour among children and adolescents is associated with age, gender and socio-economic status. For example, Kopcakova et al. (2017), using data from the 2014/15 Health Behaviour in School-aged Children (HBSC) survey, found that younger adolescents, boys, and adolescents from families in higher socio-economic positions across Europe were more likely to meet physical activity recommendations. They also found that older adolescents and boys tend to participate in more excessive screen-based activities.

### ***Interpersonal factors***

Parental behaviours may have an association with child (in)activity at different ages but the evidence is not conclusive. For example, a systematic review by Ferreira et al. (2007) found that the level of physical activity among children increased with that of their father, whether the child was male or female, but the influence of mother's physical activity was more often associated with girls' physical activity than boys'. Gebremariam et al. (2015) found that parental modelling regarding television viewing was an important correlate of children's viewing behaviour and was also correlated with socio-economic position- parents of lower socio-economic position are more likely to model more sedentary behaviours including higher levels of TV viewing, more time watching TV with their child and higher levels of meal consumption during TV viewing. De Vet et al. (2011) however could only identify a consistent association between parent physical activity levels and those of their children – the association was not identified for adolescents.

### **Community level factors**

Among children and adolescents, there was systematic review evidence of positive associations between environmental factors and physical activity including specific school types (i.e. public schools, higher level schools), school facilities for physical activity, neighborhood facilities for physical activity and traffic safety (De Vet et al., 2011). School and neighborhood level factors were more consistently related to physical activity than interpersonal factors, climate or geographic location. A higher perception of the environment as more activity-friendly was significantly associated with greater likelihood that adolescents meet the recommendations for the amount of daily physical activity in four European countries (Kopcakova et al., 2017).

### **Factors associated with physical (in)activity in adults**

#### **Individual-level factors**

As with children and adolescents, socio-economic status (particularly educational attainment) was also found to be associated with physical activity levels in adults, but the relationship was non-linear. Aguirre et al (2016) reviewed Eurostat data that showed women in selected countries in the WHO Europe Region with only primary or lower-secondary education had lower rates of physical activity than those with higher levels of education. However they also found that women with tertiary education were less physically active than those with secondary, suggesting that this relationship is not straightforward – potentially because people with lower incomes have less free leisure time, poorer access to leisure facilities and living environments that do not support physical activity, according to the grey literature (Cavill et al. eds., 2006)

#### **Interpersonal-level factors**

A number of peer-reviewed sources found an association between levels of sedentary behaviour, relationship and parental status. Social support and having a companion for physical activity were found to be convincingly associated with different types of physical activity (Wendel-Vos et al., 2007) while O'Donoghue et al. (2016) found increased amounts of leisure screen time was identified among married or cohabiting couples; having children resulted in less total sitting time.

#### **Community-level factors**

There is some evidence that environmental access influences physical activity levels among adults, although this appears to depend on the measures of activity used. A recent systematic review (O'Donoghue et al., 2016) found that sedentary behaviour was only consistently negatively associated with proximity of green space, with poor weather repeatedly positively associated with total sitting time. Other factors such as neighbourhood SES; neighbourhood walkability; presence of aesthetic features in the environment; close proximity/access to destinations or facilities; and perception of a safe environment were inconsistently associated with sedentary behaviour. In contrast, focusing instead on levels of physical activity, Wendel-Vos et al. (2007) found in their systematic review that access, availability and convenience of recreational opportunities was positively associated with physical activity and that access to physical activity equipment was consistently associated with vigorous activity. Both reviews comment on the limitations of the evidence base posed by the variety of environmental and behavioural measures used to assess relationships.

### **What factors could be of use as early warning indicators of overweight and obesity (and physical (in)activity) prevalence and trends?**

Despite the extensive number of variables of overweight, obesity and physical (in)activity discussed above, and some literature which explored 'predictors' or 'early markers' of

obesity, there was limited evidence in the peer-reviewed and grey literature that discussed which of these variables might work as 'early warning indicators'. The review team therefore approached these questions in different ways by (i) considering variables and existing indicators of child and adult obesity which might be understood (according to the life course model), to be strongly predictive of adult obesity and (ii) discussing measures which might provide 'early' information about obesity trends before release of official statistics. The review team did not identify literature that discussed which variables can be used to predict physical activity trends. Following the definition of indications by Verschuuren et al., 2014 (see Glossary), the review also focused on variables with a concise numerical relationship with either child obesity or adult obesity whilst also suggesting a clear area for intervention.

### **Variables of child and adult obesity and their suitability as early warning indicators**

Variables which, from peer-reviewed evidence, appear to be suitable as early warning indicators include rapid weight gain during childhood; early adiposity rebound; maternal BMI; maternal weight gain and maternal smoking. Brisbois et al. (2012) found that the association between both rapid growth in infancy and early childhood and early adiposity rebound with adult obesity was a strong one – the review by Small et al (2007) also emphasised this association. Closely monitoring children's growth patterns during this period therefore may give parents and clinicians insight in to potential long term risks for children to develop obesity - this could be the target action of this indicator.

Maternal BMI was highlighted by Brisbois et al. and Rooney et al. (2011) as key predictor of obesity in adulthood (although this was young adulthood for Rooney et al.). Brisbois et al. also found a strong association between maternal weight gain and obesity in adulthood. Both can be captured as simple numerical figures (BMI or percentage weight gain) and suggest a key area for action – promoting good dietary and physical activity among pregnant women. Maternal smoking was also identified by both Brisbois et al. and Rooney et al. as a key predictor of adult obesity but Brisbois et al. found that across studies they reviewed, the association was weak to moderate. Nevertheless, this is a health behaviour that can be measured easily and numerically (numbers of women smoking at birth).

Variables that appear less or not at all suitable as early warning indicators include dietary patterns; breastfeeding; genetic factors and ethnicity. The grey literature on existing obesity surveillance highlighted some variables which might be suitable for general trend monitoring, e.g. the European Core Health Indicators (ECHI), which include BMI; fruit consumption; vegetable consumption; breastfeeding; physical activity levels and social support (Public Health Evaluation and Impact Assessment 2013). However, it does not appear that any of these indicators can be used to predict adult obesity.

Genetic factors placing individuals at greater risk of obesity have been identified but do not seem to be an effective and efficient early warning indicator at this time. In their articles on genetic testing and predicting obesity, Ng and Bowden (2013) note that although genetic factors such as the FTO gene have shown significant associations with obesity, the effect is small and varies among populations with different ancestral histories and are not useful for predicting/assessing obesity at a population level. Finally, the associations between other socioeconomic variables and child, adolescent and adult overweight and obesity are too complex to work as simple indicators. Given the different relationships found in high-, low- and mid-income countries with relation to socioeconomic factors and obesity, and the complicated relationship between ethnicity and obesity it would not appear that measuring these variables (that is levels of deprivation and size of different ethnic group populations) would serve as a straightforward indicators of potential obesity trends.

### **Health information providing 'early' indication of obesity trends**

Peer-reviewed literature suggests that while BMI continues to be the standard for measuring obesity, more precise and more novel measurements could serve as early warning indicators for overweight and obesity at a local population level (Gurnani et al., 2015), if the information was gathered by screening children and adults aged from 6 years (as opposed to large-scale population health surveys) (Yao et al., 2013). These include skinfold thickness, waist-to-height ratio (WTHR), waist circumference, waist-to-hip ratio and bioelectrical impedance analysis (Gurnani et al., 2015).

While there are some concerns that BMI is not sensitive enough to accurately indicate obesity for all body types, the grey literature argued that these measures (waist measurements in particular) can be as susceptible to the same criticisms particularly among different ages and ethnicities (Townsend 2009). It argues that BMI remains the best measure of obesity for population surveillance, due to its ease and prevalence of use as well as the evidence base for the links between BMI and ill-health. Nonetheless, it suggests that adding waist measures to population weight monitoring, along with BMI, would enable more accurate description of trends with little difficulty or expense needed to do so, and enable more accurate relative risks of type 2 diabetes, hypertension and CVD to be assessed (Keenan et al., 2011).

### **How could a feasible, effective and efficient early warning monitoring mechanism be put in place to keep track of these issues?**

Just as with the limited usage of the concept of 'early warning indicators', there was therefore little explicit evidence on how an effective and efficient monitoring mechanism that uses such indicators could be implemented. Existing child health or obesity measurement systems give some insight into what is possible, but there was little implementation detail available to assess their feasibility, effectiveness and efficiency objectively, or of how they might be adapted to include other indicators. Suggestions for adaptations made below are not based on the literature but our analysis. This is an area therefore that would warrant further investigation or gathering of expert opinion.

### **Monitoring child obesity variables and trends**

For policy-makers, early warning indicators may be best collected as part of a surveillance system than as part of individual screening as peer-reviewed sources indicated that only the latter enables trends, disparities and causes to be detected at a population level (Longjohn et al., 2010). The grey literature suggests that monitoring and surveillance can be best achieved using population health surveys (WHO, 2012). This can include growth monitoring (measuring heights and weights of children), conducted within the school setting, which has been found to increase detection of conditions such as obesity and was cost effective (Fayter et al, 2007). An example of this kind of programme is England's National Child Measurement Programme (NCMP), which is organised by the national and local authorities responsible for public health in partnership with schools. (PHE, 2016).

Existing population health surveys already incorporate both BMI measurement and other nutritional and physical activity measures of children, which might easily be adapted to include early warning indicators. An example of this is the European Child Obesity Surveillance Initiative (COSI) developed by WHO Regional for Europe (Wijnhoven et al. 2014), which includes a variety of measures including the availability of vending machines on school premises; availability of fruit/vegetable/milk schemes; and frequency of physical education lessons. Nationally representative samples from across the WHO region and standardised weight and height measurements are used, with measurements and analyses conducted according to common protocols. The grey literature (WHO 2012) highlighted that intercountry comparisons of obesity trends can be hindered by differences in BMI calculations so this standardisation process is to be welcomed.

Issues to consider when implementing either growth monitoring or child population surveys include whether to gather explicit parental consent (gathered as part of COSI but not for NCMP); which staff and agencies to appoint to either carry out measurement or co-ordinate analysis (e.g. research institutes or national or international agencies); and balancing need for standardisation with importance of allowing some adaptation to local circumstances (this can effect engagement with the programme). The literature did not provide evidence for which approaches are more effective, but does provide further details of how the surveillance mechanisms are implemented (PHE 2016; Wijnhoven et al. 2014; WHO 2017). Whether systems like this could be adapted to include indicators for early rapid weight gain or adiposity rebound would be an interesting area for further exploration.

### **Monitoring other potential early warning indicators**

There was limited evidence for how to establish an effective and efficient monitoring system of maternal level variables. We did not find examples of national population-level surveillance of maternal BMI or maternal weight gain during pregnancy, and this appeared to be mainly done at an individual level. However, in England maternal smoking, is measured by local health authorities for the Smoking Status at Time of Delivery (SATOD) data collection (NHS Digital, 2017). Local health authorities are given the flexibility to decide on the mechanism for collecting and sharing SATOD data. Further details were not available for assessing whether this is an effective or efficient system; however – it does indicate that maternal smoking is something that could potentially be incorporated into any early warning monitoring mechanism – as good practice lessons could potentially be shared.

### **Systems enabling earlier access to information**

In terms of information that is more readily available than the data from national or international surveys (which can have a significant lag), two North American examples of electronic health or medical record monitoring suggest that it could serve as a real-time surveillance system for obesity trends at a community or local population level (Birken et al., 2017; Davidson et al., 2014). Height and weight are regularly objectively measured and recorded in health records and demographic data may be readily available to track risk in specific populations (e.g., low SES, pregnant women, minority groups, etc.). This would require however, good quality of data collection (accurate and comprehensive completion of measurement) (Birken et al., 2017) and still some element of measuring change over time (Davidson et al., 2014).

## **Conclusion**

There is a wide variety of variables that have been found to correlate with overweight, obesity and physical (in)activity, acting on different levels of the social ecological model. The strongest evidence has been found for individual and interpersonal factors such as birthweight, dietary and physical activity behaviours and parental (particularly maternal) weight status and socioeconomic status. However, sex, ethnicity and location of populations (in terms of national economic circumstances) may need to be taken into consideration. High levels of inconsistencies in measures used (e.g. objective versus subjective), for studying the relationship between overweight, obesity and physical (in)activity and community level factors, (e.g. enablers of healthy eating or physical activity in a neighbourhood) makes the evidence for associations at this level more complex.

Due to the limited amount of evidence found relating to the concept of 'early warning indicators', it was not easy to identify suitable variables that might be used to give some indications of future changes in weight status. However, based on the strength of association with overweight and obesity in adulthood identified by the literature, we propose that the following be considered as potential population-level measures:

- early weight gain;
- early adiposity rebound;
- maternal BMI; and
- maternal weight gain during pregnancy.

Despite a weaker association, maternal smoking status may also be suitable as an indicator – this is measured by at least one national surveillance system.

While population health surveys have been recommended as the best monitoring mechanisms for obesity and obesity-related behaviours, other methods such as electronic health record monitoring may provide data at a quicker rate for local population monitoring and give early indications of trends yet to be established by national-level statistics. Meanwhile, at a whole-population level, existing child obesity surveillance initiatives provide some useful insights into how a feasible early warning monitoring mechanism could be established, but more evidence on their (cost) effectiveness is required. The feasibility of incorporating other potential early warning indicators such as maternal BMI, maternal weight gain during pregnancy and maternal smoking should also be explored in further primary research.

## **Annex 1 Peer-reviewed literature bibliography**

Baidal, W, Locks, L, Cheng, E, Blake-Lamb, T, Perkins, M, Taveras, E. (2016) Risk factors for childhood obesity in the first 1,000 days: A systematic review. 50(6) pp.761-79.

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### Annex 3 Glossary

The following definitions are common definitions that are used across all eight objective areas. Where a study uses a different definition, this is highlighted on an individual basis in the review reports.

Table 1. Definitions of terms used across the reviews

Term	Definition	Source
Adult obesity	An abnormal or excessive fat accumulation that presents a risk to health, with a BMI of 30 or more.	World Health Organisation (WHO) ( <a href="http://www.who.int/topics/obesity/en/">http://www.who.int/topics/obesity/en/</a> )
Adult overweight	An abnormal or excessive fat accumulation that presents a risk to health, with a BMI equal to or more than 25.	WHO ( <a href="http://www.who.int/topics/obesity/en/">http://www.who.int/topics/obesity/en/</a> )
Alcopops	Pre-mixed beverages containing a spirit, wine or malt combined with a non-alcoholic drink.	1. Anderson, P., Suhrcke, M. and Brookes, C. (2012) An overview of the market for alcohol beverages of potentially particular appeal to minors. London: HAPI.
Artificially sweetened beverages (ASBs)	Beverages sweetened with low-calorie or zero-calories sweeteners such as sucralose, aspartame, saccharin, stevia or sugar alcohols.	ICF definition based on all literature identified in objective area B2 literature review
Body Mass Index	A person's weight (in kilograms) divided by the square of his or her height (in metres).	WHO ( <a href="http://apps.who.int/bmi/index.jsp?introPage=intro_3.html">http://apps.who.int/bmi/index.jsp?introPage=intro_3.html</a> )
Child/adolescent obesity	There are different systems available to measure child or adolescent obesity for different ages.  Children under 5 obesity is weight-for-height greater than 3 standard deviations above WHO Child Growth Standards median;  Children aged 5-19 overweight is BMI-for-age	WHO <a href="http://www.who.int/mediacentre/factsheets/fs311/en/">http://www.who.int/mediacentre/factsheets/fs311/en/</a>  (Other definitions are available for different national and international systems).

Term	Definition	Source
	greater than 2 standard deviation above the WHO Growth Reference median.	
Child/adolescent overweight	There are different systems available to measure child or adolescent overweight for different ages.  Children under 5 overweight is weight-for-height greater than 2 standard deviations above WHO Child Growth Standards median;  Children aged 5-19 overweight is BMI-for-age greater than 1 standard deviation above the WHO Growth Reference median.	WHO  <a href="http://www.who.int/mediacentre/factsheets/fs311/en/">http://www.who.int/mediacentre/factsheets/fs311/en/</a>  (Other definitions are available for different national and international systems).
Exercise	Exercise, is a subcategory of physical activity that is planned, structured, repetitive, and purposeful in the sense that the improvement or maintenance of one or more components of physical fitness is the objective.	WHO ( <a href="http://www.who.int/dietphysicalactivity/pa/en/">http://www.who.int/dietphysicalactivity/pa/en/</a> )
Insufficient physical activity	Physical activity that does not meet WHO recommended levels of at least 60 minutes a day of moderate-vigorous activity for children and adolescents and at least 150 minutes of moderate-intensity aerobic physical activity throughout the week for adults.	WHO  <a href="http://www.who.int/mediacentre/factsheets/fs385/en/">http://www.who.int/mediacentre/factsheets/fs385/en/</a>
Physical activity	Any bodily movement produced by skeletal muscles that requires energy expenditure.	WHO ( <a href="http://www.who.int/topics/physical_activity/en/">http://www.who.int/topics/physical_activity/en/</a> )
Physical inactivity	A lack of physical activity	WHO ( <a href="http://www.who.int/dietphysicalactivity/pa/en/">http://www.who.int/dietphysicalactivity/pa/en/</a> )

Term	Definition	Source
Sedentary behaviour	Any waking behaviour characterized by an energy expenditure $\leq 1.5$ metabolic equivalents (METs) while in a sitting or reclining posture.	Tremblay, M. S., et al. (2017). Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. <i>The International Journal of Behavioral Nutrition and Physical Activity</i> , 14, 75. <a href="http://doi.org/10.1186/s12966-017-0525-8">http://doi.org/10.1186/s12966-017-0525-8</a>
Sugar sweetened beverages (SSBs)	Any beverage with added sugars. This includes soft drinks, soda, fruit drinks, punch, sports drinks, sweetened tea and coffee drinks, energy drinks and sweetened milk. These beverages may be sweetened with added sugars such as sucrose (table sugar) or high fructose corn syrup, which is what distinguishes them from 100% fruit juice and beverages with non-caloric sweeteners (e.g., aspartame, saccharin or sucralose).	US Department of Agriculture. 2010. <i>US Department of Health and Human Services. Dietary guidelines for Americans, 2010</i> . 7th edition, Washington (DC): US Government Printing Office

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