VLAAMS INSTITUUT GEZOND LEVEN

Implications of food processing: the role of ultra-processed foods in a healthy and sustainable diet

HEALTH IMPACT, ENVIRONMENTAL IMPACT, AND BEHAVIORAL ASPECTS

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Abbreviations

BMI	Body Mass Index
CRC	Colorectal Cancer
CVD	Cardiovascular Disease
FAO	Food and Agriculture Organization of the United Nations
FAVV	Federaal Agentschap voor de Veiligheid van de Voedselketen
GHGE	Greenhouse Gas Emission
HDL	High-Density Lipoprotein
HFCS	High-Fructose Corn Syrup
LDL	Low-Density Lipoprotein
NCD	Non-Communicable Disease
$NRF_{9.3}$	Nutrient Rich Food Index 9.3
PAH	Polycyclic Aromatic Hydrocarbon
SSB	Sugar-Sweetened Beverages
T2D	Type 2 Diabetes
UPF	Ultra-Processed Food
WHO	World Health Organization

Glossary

Food processing	All methods being used to alter natural foods, either in a context of home-cooking or industrial processing.
NOVA classification	Classification to group foods according to their degree of processing: - Unprocessed or minimally processed foods (I) - Processed ingredients (II) - Processed foods (III) - Ultra-processed foods (IV)
Empty calories	A term which has been attributed to UPFs because of the low nutrient density and high energy density.
Processed meat	An umbrella term for products like ham, salami, bacon, sausages, and minced meat. In general, this meat has been transformed by salting, curing, fermentation, smoking or other processes to improve flavor or preservation. According to NOVA, salted, dried, and smoked meat (e.g. ham, bacon, or pastrami) are classified as processed foods, while other processed meats (e.g. minced meat, sausages, nuggets) are part of the UPF group. - Processed foods (III): salted, dried, and smoked meat (e.g. ham, bacon, or pastrami)

	- Ultra-processed foods (IV): other processed meats (e.g. minced meat, sausages, nuggets)
Plant-based meat alternatives	Plant-based foods which are high in proteins and could serve as an alternative to meat products. There are different types of plant-based meat alternatives: - Whole plant foods (I): legumes - Traditional plant-based meat alternatives (III): tofu, tempé, seitan, breaded legume burgers - High-tech plant-based meat alternatives: (IV) meat-like burgers and sausages based on protein extrusion technologies The first type can be seen as unprocessed or minimally processed, the second type as processed and the third type as ultra-processed.
Satiation and satiety	Both terms are linked to how 'full' or hungry you feel, but each term focuses on other time points: - Satiation plays a role in meal termination: how much do you eat before you feel 'full' and terminate your meal? - Satiety plays a role in meal initiation: how much time is between the previous meal and the next meal? How long does it take before you get hungry again?
The Flemish Institute of Healthy Living (Vlaams Instituut Gezond Leven)	Public health institute of the Flemish speaking part of Belgium (Flanders). Two models developed by the Flemish Institute of Healthy Living are mentioned in this report: - The Food Triangle (Voedingsdriehoek): displays the Flemish food based dietary guidelines, which is supported by additional information on the website of the Flemish Institute of Healthy Living. - The Behavioral Change Wheel (Gedragswiel): summarizes behavioral determinants that play a role in adopting to a certain behavior, e.g. healthy or unhealthy behavior. There is additional information available on the website of the Flemish Institute of Healthy Living.

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Introduction

Food processing has been used for centuries and has many benefits on multiple levels. In the first place, food processing is very important to ensure food safety and to extend shelf life. By nutrient fortification (e.g. adding vitamins) and product reformulation (e.g. lowering salt content), the nutritional composition can be altered in a positive direction, while other processing techniques might have negative effects (e.g. lowering fiber content, nutrient loss). It may also improve the bioavailability of nutrients (e.g. lycopene in cooked/canned tomatoes). Food processing has evolved in the past decades with the introduction of new techniques, ingredients, and packaging methods (European Food Information Council, 2010, 2017; Weaver et al., 2014). The food supply has become more dominated by packaged, highly processed, ready-to-eat foods and beverages. Since the 1990s, this trend was first seen in high-income countries, but later also in middle-income countries and now even globally (Monteiro et al., 2013; S. Vandevijvere et al., 2019; Vergeer et al., 2019). More advanced technologies and ingredients are being used, which often results in hyperpalatable products with generally a high-energy density and low nutritional value (C.A. Monteiro et al., 2019). In 2009, scientists from Brazil introduced the NOVA classification to classify products according to their level of processing, because of their concern regarding health effects. They started to use this method in their food based dietary guidelines and advised their population to avoid 'Ultra-Processed Foods' (UPFs) (Monteiro et al., 2010). At the time, there was no or little evidence on the health effects of UPFs, but due to its known nutritional characteristics (e.g. high levels of fat, sugar and/or salt) and evidence on specific subgroups of UPFs, it was assumed that the consumption of this food group should be avoided (Monteiro et al., 2010). Since 2014, there is growing evidence on specific health effects of UPFs and the possible mechanisms that could explain negative effects of UPFs (Figure 1). Nevertheless, there is a lot of criticism on the NOVA classification and more nuance is needed when using the term 'ultra-processed foods' in guidelines (Fardet & Rock, 2019).
In 2017, the Flemish Institute of Healthy Living included UPFs in the updated 'Food Triangle' and used the term 'UPF' in their communication to the public. However, they did not solely focus on the degree of processing to determine the effect of food on health, as suggested by NOVA, but they combined insights from different scientific perspectives on health and sustainability to formulate guidelines from a more holistic instead of a reductionistic point of view. This report gives an overview of the current scientific knowledge on UPFs and goes beyond the nutritional aspects. It should provide further insights on the effects of UPF consumption and give input for public health interventions.

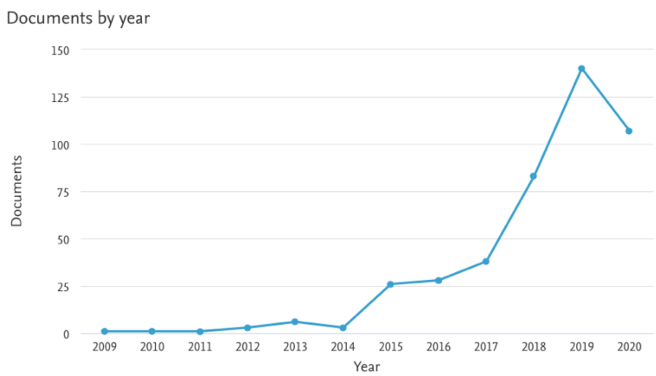

Figure 1: Search results for the term 'Ultra-Processed Food' from database Scopus, retrieved on 24/08/2020

What are ultra-processed foods?

Classification of processed foods

The NOVA classification is a clear and meaningful method to group foods according to their degree of processing and has been used in many scientific articles. It is also a controversial method, especially when being used in public health guidelines (Fardet & Rock, 2019). This classification system describes four groups; unprocessed or minimally processed foods, processed culinary ingredients, processed foods, and UPFs (C.A. Monteiro et al., 2019; Monteiro et al., 2010). In Table 1, common foods and ingredients are classified by NOVA, combining the first and revised version from 2010 and 2019, respectively. 1) **Unprocessed (or natural) foods** are the edible parts of plants, animals, fungi, algae and water. **Minimally processed foods** are natural foods altered by processes that include removal of inedible or unwanted parts, drying, crushing, grinding, filtering, roasting, boiling, non-alcoholic fermentation, pasteurization, refrigeration, freezing, placing in containers, and vacuum-packaging. These foods do not have added salt, sugar, or fat, but might be fortified with vitamins and/or minerals. The processes are designed to preserve natural foods, to make them suitable for storage, and to make them safe, edible, or more pleasant for consumption. Examples are fruits, vegetables, nuts, grains, cereals, milk, and yoghurt. 2) Oils, butter, sugar, and salt are examples of **processed culinary ingredients** and are not meant to be consumed by themselves. They are derived from foods from the first NOVA group or from nature by processes that include pressing, refining, grinding, milling and drying. 3) **Processed foods** are products made by adding salt, oil, sugar or other ingredients from group 2 to foods from group 1, by the use of preservation methods such as canning, bottling, and non- alcoholic fermentation (e.g. bread and cheese). Additives might be added to prolong shelf life and enhance food safety. The processes and ingredients are meant to increase the durability of foods from group 1 and make them more enjoyable by modifying or enhancing their sensory qualities. Examples are canned fruits and legumes, freshly made bread, cheese, sugared cereals, and yoghurt. 4) **UPFs** are formulations of ingredients, mostly of exclusive industrial use (e.g. hydrogenated oils, High-Fructose Corn Syrup (HFCS), flavor and color enhancers, emulsifiers, gelling agents), made by a series of industrial processes, many requiring sophisticated equipment and technology. Used processes are the fractioning of whole foods into substances, chemical modifications of these substances, assembly of unmodified and modified food substances using industrial techniques such as extrusion, molding, and pre-frying. Additives are used at various stages of manufacture to make the final product extra palatable. The end products are packaged, usually with plastic and other synthetic materials. UPFs are typically highly profitable, convenient, and hyperpalatable. Examples are processed meat products, mass-produced packaged bread, sugared cereals and yoghurts with additives, and ready-to-(h)eat products (C.A. Monteiro et al., 2019; Monteiro et al., 2018; Monteiro et al., 2010).

Table 1: Classification of foods and ingredients according to their degree of processing by NOVA

Unprocessed/minimally processed foods	Processed culinary ingredients	Processed foods	Ultra-processed foods
Fruits, vegetables, starchy roots, fungi Fresh, squeezed, chilled, frozen, or dried fruit and vegetables, (sweet) potatoes, fresh or dried mushrooms Fresh or pasteurized fruit and vegetable juices (no sugar, sweeteners or flavor added) Legumes Beans, lentils, chickpeas Grains and cereals Brown, parboiled, or white rice, fresh corn, wheat grain Grits, flakes Nuts and seeds Nuts and seeds without added salt or sugar Meat, poultry, fish and seafood As a whole or in fillets, steaks or other cuts Milk and yoghurt Powdered or pasteurized milk Fresh or pasteurized plain yoghurt Eggs Fresh, powdered, chilled or frozen eggs Herbs and spices Fresh, dried, whole, or powdered Drinking water, coffee and tea	Vegetable oils crushed from seeds, nuts or fruit (olives) Flaxseed oil, sesame oil, olive oil Vegetable oils with added antioxidants Butter and lard Obtained from milk and pork Salt Salt mined from seawater, table salt with drying agents or iodized Sugar, honey, and syrup Sugar and molasses obtained from cane or beet, honey extracted from combs, syrup from maple trees Flour Flour made from corn, wheat, oats Starches Starches extracted from corn and other plants	Canned or bottled vegetables and legumes in brine (salt solution) Salted or sugared nuts and seeds Salted, dried, or smoked meat or fish Ham, bacon, pastrami Canned fish in oil With or without preservatives Fruit in syrup With or without antioxidants Freshly made unpackaged breads and cheeses Breads made from wheat flour, water, salt and yeast Sugared cereals, yoghurt Sugared, but without/few additives Pasta, noodles, couscous Beer, wine and cider[1]	Processed meat products Minced meat, sausages, burgers, hot dogs, poultry and fish nuggets and sticks Sugar sweetened beverages Carbonated soft drinks, energy drinks All sugared/sweetened and with additives Fruit yoghurts and fruit drinks Sugared and with additives Cacao drinks Sweet or savory (packaged) snacks Cookies, cake (mixes), ice-cream, energy bars, chocolate, candies, chips Ready-to-(h)eat meals/products (Frozen) pies, pasta and pizza dishes, French fries, instant soups, sauces, and noodles, desserts 'Health' and 'slimming' replacement meals or products Shakes, powders Mass-produced packaged breads Breads which include emulsifiers or colors Sugared cereals, yoghurt with additives Sugared, with additives to add flavor, color Margarine and other spreads Jams, chocolate spread Baby feed products Infant formulas, follow-on milks, other baby products Whiskey, gin, rum, vodka[1]

Also includes foods made up from two or more items from this group Dried mixed fruits, granola made from cereals with nuts, dried fruit and no added sugar/honey/oil	Also includes ingredients made up from two or more items from this group (these ingredients are typically not consumed by themselves) Salted butter	Also includes foods made up from the two previous groups, without or with only little additives added (mainly to improve food safety)	In general, highly processed foods with sugar, fat, salt added and a long list of ingredients of industrial use

[1] Alcoholic drinks were originally not included in NOVA, but can be considered as processed foods when resulting from fermentation (e.g. beer, wine, cider) and as ultra-processed foods when there is further distillation of the resulting alcohol (e.g. whiskey, gin, rum and vodka).

Nutritional value

In general, UPFs often contain high amounts of fats, especially saturated fats and trans fats, added sugar, and salt, and are low in protein, fiber, micronutrients, and other bioactive compounds (Monteiro et al., 2018). The term ‘empty calories’ has been attributed to UPFs because of the low nutrient density and high energy density (Fardet & Rock, 2019). The Nutrient Rich Food Index 9.3 ($NRF_{9.3}$) has been used to compare nutrient density between products with a different degree of processing. This method uses a quality score by considering qualifying nutrients (protein, fiber, vitamin A, C, and D, calcium, iron, magnesium, potassium) and limiting nutrients (saturated fats, added sugar, and sodium). UPFs had remarkably lower $NRF_{9.3}$ scores than unprocessed foods (Gupta et al., 2019). Even though nutrients like unsaturated fats, other carbohydrates, vitamins, and minerals are not taken into consideration in this score, these results already suggest a lower nutrient quality for UPFs.

The nutrient composition of UPFs is also reflected in the overall diet, affecting diet quality. The Food and Agriculture Organization of the United Nations (FAO) reviewed fifteen studies reporting on the relationship between the dietary share of UPFs and the nutritional quality of overall diets. There was a significant, direct, dose-response association[1] between the dietary share of UPFs and the dietary content of free/added sugar, saturated fat, trans fat, and sodium, as well as the probability of excessive intake of these nutrients. A high intake of these nutrients is associated with negative health effects. On the other hand, they also looked into nutrients that are thought to have a protective effect on NCDs. For protein, fiber, potassium, phytoestrogens, and multiple micronutrients, there was a significant, inverse, dose-response association with the dietary share of UPFs and an increased risk of insufficient intake for potassium and fiber (C.A. Monteiro et al., 2019).

These results suggest that the UPF consumption has no added value to diet quality. One study even concluded that the replacement of non-UPFs with UPFs has a deteriorating effect on diet quality (C.A. Monteiro et al., 2019). However, due to the diversity in energy and nutrient density among UPFs, some studies question that maybe not only the degree of processing, but rather the nutrient composition of each product should be considered in terms of health effects (Poti et al., 2017; Vergeer et al., 2019). Especially because energy dense and nutrient poor products exist in both the UPF group and groups with a lower degree of processing (Vergeer et al., 2019).

In general, we could conclude that most UPFs have a rather negative nutritional composition and that UPF consumption is even associated with an overall lower diet quality. Nevertheless, it should be noted that the group of UPFs is very diverse regarding energy content and nutrient composition and that the level of processing should not be the only criteria to draw up guidelines. The different subcategories of UPF products should also be considered when making statements on UPF consumption and health.

[1] Dose-response associations show that there is an association between the level of exposure (the dose) and the response. In this specific example, the higher the dietary share of UPFs, the higher the dietary intake of sugar, saturated fat, etc.

Other properties

Besides a rather negative nutritional composition, UPFs also have other properties in common which are able to affect consumption. The health effects linked to some of these properties are described in one of the next chapters on 'Overconsumption and risk for obesity'. Due to processing, the so called 'food matrix'[2] has changed as there has been food breakdown and/or fractioning, often resulting in more liquid and softer textures. Food breakdown involves physical breakdown of larger pieces into smaller pieces (e.g. mixing fruit into a smoothie), while food fractioning is defined as separating different parts of the original product (e.g. removing the bran and germ from flour to produce white flour) (Fardet & Rock, 2019; Forde et al., 2020). Not only the added sugars, but also the breakdown or fractioning of food ingredients explain why these products on average have a higher glycemic index than unprocessed foods (Fardet & Rock, 2019). UPFs are generally designed to be hyperpalatable, which is achieved by the processing itself, but also by adding additives to intensify the product smell, color, and taste (C. A. Monteiro et al., 2019). Additionally, UPF products are typically meant to be convenient and ready-to-consume, with only little preparation left for the consumer. Over the years, standard portion sizes, the availability, and the variety of these products have increased. On top of that, many UPF products are highly profitable and strongly promoted with attractive and persuasive marketing (C. A. Monteiro et al., 2019; Poti et al., 2017; Robinson & Kersbergen, 2018).

Health impact

There is emerging evidence on the health impact of UPFs. First, we describe the impact of UPF consumption on the development of non-communicable diseases with mainly observational studies, but also one RCT. Next to describing the health impact of UPFs as one group, we also describe some specific food groups: processed meat, Sugar-Sweetened Beverages (SSB), alcoholic drinks, and plant-based meat alternatives. Besides the development of diseases, it is thought that UPFs seem to promote overconsumption because of the presence of certain food properties, contributing to the risk of developing obesity. Lastly, we describe some food safety issues that require extra attention when discussing UPFs.

Development of non-communicable diseases

<u>Ultra-processed foods as one group</u>

A recent systematic review with meta-analysis, based on thirteen cohort and ten cross-sectional studies, examined the association between the UPF consumption and health status in adults. The meta-analysis from cohort studies showed statistically significant associations between the highest UPF consumption and all-cause mortality, cardiovascular and cerebrovascular disease incidence and/or mortality, overweight and obesity, and depression. Similar trends were found in the cross-sectional studies, where the highest UPF intake was significantly associated with overweight/obesity, high waist circumference or abdominal obesity, metabolic syndrome, and reduced HDL-cholesterol levels. The positive associations with hypertension, hyperglycemia, and hypertriglyceridemia were not significant (Pagliai et al., 2020).

[2] The food matrix comprises physical and sensorial aspects of foods. A food product can contain the same nutrients, but these nutrients might be present in a different food matrix: e.g. apples versus apple juice.

Another recent publication also investigated the relation between UPF consumption and health. This study did not perform a systematic search but did include other relevant studies than the previously mentioned review. First, they did include studies on children and adolescents. In two studies, UPF consumption was related to an increase in total cholesterol, LDL-cholesterol, and waist circumference in children from preschool to school age. In a group of adolescents, there seemed to be a link between UPF consumption and the prevalence of asthma and wheezing, but not with trajectories of Body Mass Index (BMI) and percentage of body fat mass. Secondly, they confirmed that UPFs are associated with all-cause mortality, obesity, cardiovascular and metabolic diseases, and depression. They even mentioned significant dose-response associations for these outcomes. Lastly, they included results on other health outcomes in relation to UPF consumption. They found significant associations for overall and breast cancer, but not for prostate and Colorectal Cancer (CRC), for gastrointestinal disorder, e.g. irritable bowel syndrome and functional dyspepsia, and even for frailty in an elderly population (C.A. Monteiro et al., 2019).
The evidence from these reviews suggests a consistent negative health impact for high UPF consumption on overweight/obesity and Non-Communicable Diseases (NCDs). All previously mentioned associations are derived from observational studies, which is considered as evidence with limited strength without any information on causality. However, the first randomized controlled trial, investigating the effect of UPF consumption, has recently been published. The unprocessed and ultra-processed diets were matched for energy density, macronutrients, fat, sugar, sodium, and fiber and participants were exposed to each of these diets for 14 days in a cross-over design study, in random order. During the ultra-processed diet, participants gained weight due to increased energy intake, while they experienced weight loss during the unprocessed diet (Figure 2)s (Hall et al., 2019). This supports the findings from observational studies, but more research is needed to further investigate the causal effect of UPF on obesity and NCDs, with sufficient control of confounding.

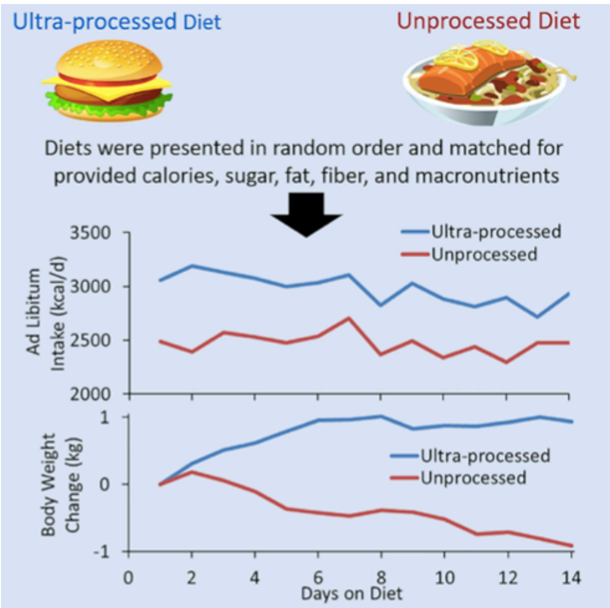

Figure 2: Graphical abstract of the first RCT studying the effect of ultra-processed food consumption on energy intake and weight change (Hall et al., 2019)

Specific food groups

Certain food groups within UPFs have been investigated more extensively. **Sugar-Sweetened Beverages** (SSB) comprise carbonated and non-carbonated soft drinks, fruit juices, and sport drinks with high amounts of caloric sweeteners and a low

nutritional value. A recent systematic review and meta-analysis describes the effect of SSB on overweight/obesity and other health outcomes. The association with weight gain and obesity is very strong and can probably be explained by decreased satiety and incomplete compensation of the ingested calories from liquids. In other words, people consume extra calories from SSB, but they do not reduce their energy intake later on the day to compensate for the ingested calories (Malik & Hu, 2019). SSB consumption has also been linked to Type 2 Diabetes (T2D), Cardiovascular Diseases (CVDs), and metabolic syndrome and there is emerging evidence that this effect is not only mediated via obesity. There were also positive, but weaker, associations for the risk between T2D and CVDs and juices and artificially sweetened beverages (Malik & Hu, 2019). SSB have been associated with an increased risk for biliary tract cancers (Larsson et al., 2016), while the evidence for CRC is less conclusive (Yuan & Giovannucci, 2020). Overall, there was a modest association between cancer mortality and SSB consumption (Malik et al., 2019).
Suggested mechanisms for the effect of SSB on T2D and cardiometabolic risk are linked to the moderate-to-high glycemic index of SSB, the ingestion of fructose together with glucose via HFCS and its metabolic effects on hepatic de novo lipogenesis, insulin resistance, atherogenic dyslipidemia, and the accumulation of visceral and ectopic adipose tissue (Malik & Hu, 2019). Regarding the association with biliary tract cancers, the increase in blood glucose and insulin concentrations and also the link with obesity and T2D could play a role (Larsson et al., 2016).

Processed meat is another group that has been studied in relation to health. Processed meat is an umbrella term for products like ham, salami, bacon, sausages, and minced meat. In general, this meat has been transformed by salting, curing, fermentation, smoking or other processes to improve flavor or preservation. According to NOVA, salted, dried, and smoked meat (e.g. ham, bacon, or pastrami) are classified as processed foods, while other processed meats (e.g. minced meat, sausages, nuggets) are part of the UPF group. In this paragraph, all processed meats are considered as one group. A systematic review and meta-analysis on processed meat and CRC included 29 prospective observational studies. Overall, there was a significant increased risk for CRC. However, when separating colon cancer and rectal cancer, only colon cancer showed an increased risk (Händel et al., 2020). Compounds that are thought to play a role in the carcinogenic effect of processed meat are: heterocyclic amines, nitrosamines, N-glycolylneuraminic acid, Polycyclic Aromatic Hydrocarbons (PAHs), and dietary heme iron (Jeyakumar et al., 2017).
Another, non-systematic, review focused not only on CRC, but also on other cancers and health outcomes. The evidence for CRC is convincing, but there is only limited and inconsistent evidence for the association between other cancers (e.g. esophageal adenocarcinoma, gastric cancer, liver cancer, and bladder cancer) and the consumption of processed meat (Boada et al., 2016). Regarding T2D, evidence from epidemiological studies strongly suggests a positive association with the consumption of processed meat. Proposed mechanisms involve the effect of the high protein and fat content on insulin sensitivity and insulin action (via mTOR) (Boada et al., 2016). There is also evidence for the effect of processed meat on CVDs, but the amount of studies separating the effect of processed versus unprocessed meat is rather limited. Nevertheless, the high sodium, nitrate, and saturated fatty acid content of these products could support a positive association between processed meat and CVDs (Boada et al., 2016).

An excessive consumption of **alcohol** is consistently associated with several NCDs, while it is often stated that a moderate consumption could have some beneficial health effects. Reduced risks for CVDs, T2D, and dementia and improved metabolic markers have been observed in moderate drinkers. However, causality of this suggested protective effect has not been shown (Goel et al., 2018; Hendriks, 2020). Because alcohol has a relatively high energy density (7 kcal/g), alcohol consumption could contribute to the development of overweight and obesity, even when moderate (Traversy & Chaput, 2015). Excessive alcohol consumption, e.g. heavy drinking, binge drinking, and alcohol abuse, have been associated with CVDs, alcohol liver disease, pancreatitis, different types of cancers, malnutrition, and brain diseases (Hendriks, 2020).

Because of the high environmental impact of animal-based products and the negative health effects of red and processed meat, there has been an increased demand for **plant-based meat alternatives**: going from whole plant foods to processed and ultra-processed foods. However, there has been only limited research on the health effects of these products, especially the more recent types which are often highly processed. Plant-based meat alternatives are not described by NOVA as processed or ultra-processed. According to the basic definitions from the NOVA categories, some products might be considered as processed (e.g. the more traditional products such as tempé, tofu, seitan and breaded legume burgers) and others ultra-processed (e.g. the more high-tech products such as meat-like burgers and sausages based on protein extrusion technologies). A recent review defines the innovative (high-tech) plant-based meat alternatives as ultra-processed as they often contain high amounts of salt and additives compared to unprocessed meat. The composition of these products can differ to a large extent. As they are designed to replace meat, they often have relatively comparable amounts of calories, protein and iron. However, not all products are fortified with vitamin B12, iron, and/or zinc. Their content of saturated fats is on average lower than that of beef, but similar to or higher than that of poultry and pork. Diets replacing meat with plant-based meat alternatives do not necessarily reflect a healthier diet. However, diets rich in whole plant foods have been associated with better health outcomes. It is not clear whether fractioned legumes (e.g. pea protein), often used as a base for high-tech plant-based meat alternatives, have the same or similar nutritional and health benefits. Soy food and soy protein consumption has been associated with improved lipid profiles, moderately improved measures of bone health, reduced menopausal symptoms and risk on type 2 diabetes, and modestly decreased risk on breast cancer. As whole plant-based foods deliver more beneficial nutrients compared to processed products with isolates or extracts, whole foods are most often recommended. Many plant-based meat alternatives contain one or more allergens. Therefore, caution is needed for consumers with allergies. More research is needed on the health effects of plant-based meat alternatives (Curtain & Grafenauer, 2019; Santo et al., 2020).

Overconsumption and risk for obesity

Some food properties (see chapter 'What are ultra-processed foods?' > 'Other properties') of UPFs are thought to promote overconsumption on UPFs and thus energy. Satiation, satiety, eating rate, addictive-like responses and reward signaling, oral processing, and taste or sensory exposure could play a role in increasing energy intake from UPFs and are described in the following paragraphs. These proposed mechanisms, related to the properties of foods could contribute to the development of obesity and other NCDs through overconsumption of UPFs and energy. Figure 3 gives a visual overview on the following paragraphs.

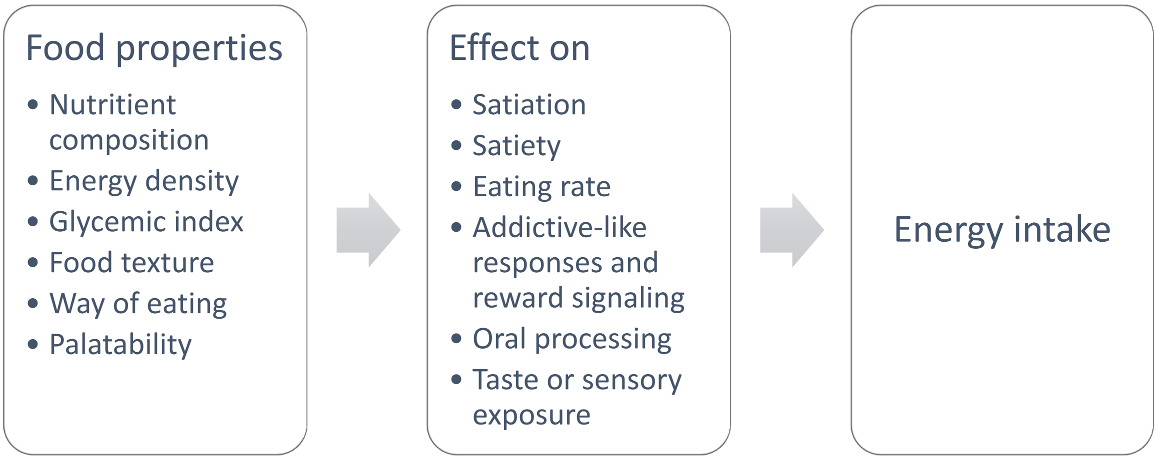

Figure 3: Overview on food properties which can affect energy intake via effects on satiation, eating rate, etc.

Multiple aspects of UPFs might contribute to both a lower satiating and satiety level (Fardet, 2016). Satiation plays a role in meal termination, while satiety determines how long it takes for a person to initiate the next meal. Different levels of satiation and satiety have been associated with **protein, carbohydrates, and fat**. Proteins seem to increase satiation and satiety, while fat seems to have the lowest effect (Morell & Fiszman, 2017; Tremblay & Bellisle, 2015). This is in accordance with evidence that people regulate their food intake upon protein need instead of energy, i.e. the protein leverage hypothesis (Gosby et al., 2014). The protein leverage hypothesis has even been tested in relation to UPFs and seems to promote energy overconsumption on carbohydrates and fat to reach the absolute amount of protein needed (Martínez Steele et al., 2018). Next, people tend to overeat on high-fat meals, i.e. passive overconsumption, which might even be enhanced by the presence of salt (Bolhuis et al., 2016; Rolls, 2009, 2017). Following the satiating and satiety effect of the nutrients itself, there is also an effect from the **energy density** (kcal/g) of a meal. People tend to overeat on high energy density meals or diets, independently from fat content. Adding water and fibers to a meal will decrease the energy density, while the addition of fat will increase the energy density. Figure 4 compares a high energy density meal with a low energy density meal, both containing 1575 kcal. A high energy density meal will always lead to a higher energy intake, whether the energy is obtained from carbohydrates or fat (Rolls et al., 1999).

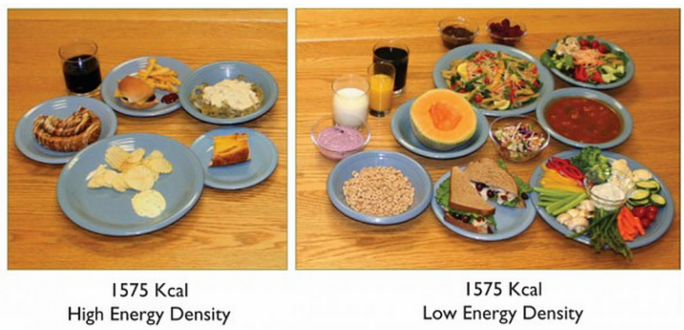

Figure 4: High versus low energy density meal, both containing 1575 kcal. (B.J. Rolls)

Fibers are low in metabolizable energy and certain types of fiber (e.g. insoluble fibers) are known to have a positive effect on satiety. Not only through their viscosity and gelling effect, but also by increasing the oral processing time and lowering the energy density of foods. Altogether, fibers are thought to decrease food intake

(Hervik & Svihus, 2019). The **glycemic index** of foods indicates how the blood glucose levels will change after ingestion of a specific food. High glycemic foods lead to a high peak in blood glucose level, with a relatively rapid decline afterwards. On the other hand, low glycemic foods have a lower increase in blood glucose level and a gradual, slow decrease afterwards. The drop in glucose level from high glycemic foods or meals has been associated with hunger feelings and the initiation of a meal (Bornet et al., 2007). However, there are inconsistent results and it remains unclear whether there is a direct effect of the glycemic index on satiety (Geliebter et al., 2013; Niwano et al., 2009). Aspects of **food texture** that are highly affected by the level of processing, and could have an effect on satiation and satiety, are food form (liquid versus solid), viscosity (thin versus thick), structural complexity (low versus high), and aeration (non-aerated versus aerated). Gels have a low complexity and the addition of particles can increase complexity (e.g. yoghurt with granola pieces). Aeration is achieved by adding air to a product, e.g. spongy cake, carbonated drinks, whipped cream. Across studies, there is a large variety in food texture manipulations and methodological approaches, which makes it difficult and complex to make general conclusions. Nevertheless, solid form, higher viscosity, higher structural complexity, and aerated foods are thought to suppress appetite and hunger feelings and to decrease energy intake (Stribiţcaia et al., 2020). A meta-analysis was able to show a significant decrease in hunger with solid compared to liquid foods, a significant increase in fullness with high-viscous compared to low-viscous foods, and a borderline significant decrease of energy intake with solid compared to liquid foods (Stribiţcaia et al., 2020). The results are promising, but more research is needed. Possible mechanisms are linked to gastric emptying rate, post-ingestive feedback, oral processing time, taste or sensory exposure and eating rate (Forde, 2018).

Eating rate has been suggested to be relatively stable within an individual (Forde, 2018). However, research shows it can be altered by properties of food, even affecting energy intake. In general, higher eating rates are associated with higher energy intakes, while lower eating rates with lower energy intakes (Forde, 2018; Robinson et al., 2014). Moreover, a fast eating rate seems to have the largest effect on energy intake when a high-**energy density** meal is consumed compared to a low-energy density meal (Argyrakopoulou et al., 2020). In comparison to unprocessed or minimally processed and processed foods, UPFs tend to have a significantly higher eating rate (mean difference, 7.4 ± 0.9 g/min) with also a higher energy intake (Hall et al., 2019). Energy intake rate (kcal/min) combines energy density with eating rate. It should be noted that there is a wide range of energy intake rates among different UPFs and not all UPFs have a higher eating rate than products with a lower degree of processing. Nevertheless, there seem to be more UPFs with a higher energy intake rate compared to lower processed food groups, as shown in Figure 5 (Forde et al., 2020). Regarding **food texture**, liquid and soft foods are eaten at a higher eating rate compared to solid and hard foods, which is visible in Figure 6 (Forde, 2018; Viskaal-van Dongen et al., 2011).

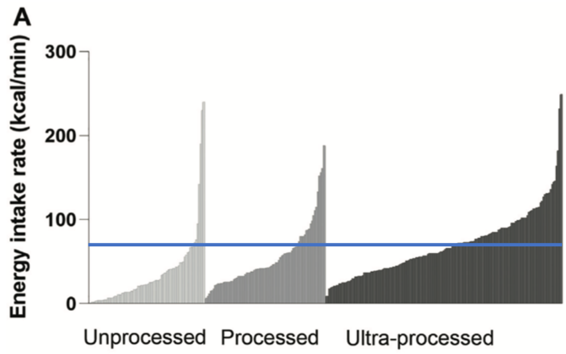

Figure 5: Energy intake rates (kcal/min) ranked within each NOVA classification from low to high for the 3287 foods from unprocessed (light gray), processed (gray), and ultra-processed (black) foods separately (Forde et al., 2020), adjusted.

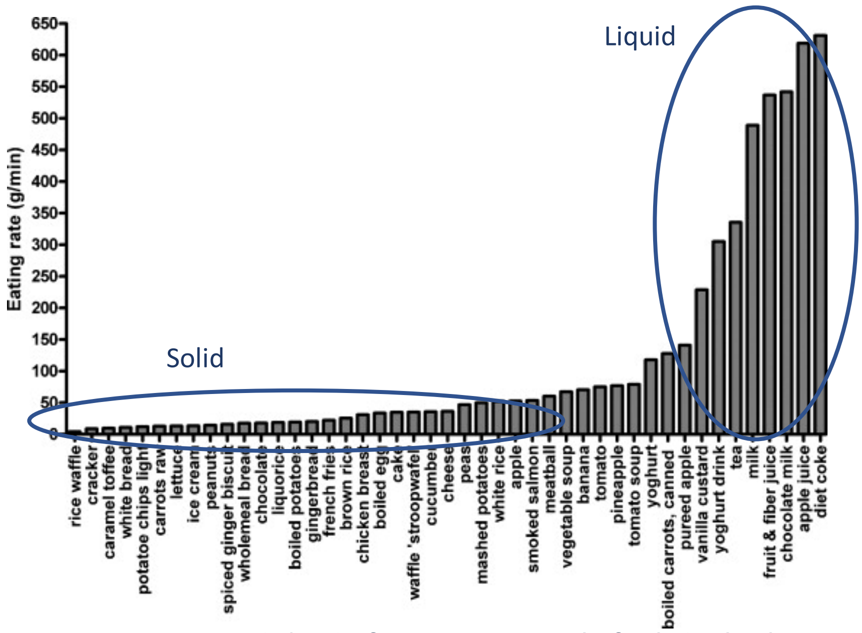

Figure 6: Eating rate (g/min) of 45 common Dutch foods (Viskaal-van Dongen et al., 2011), adjusted.

Not only food texture, but also the **way of eating** affects eating rate. Drinking a smoothie with a spoon instead of a straw decreases eating rate. Besides that, a slower eating rate is directly related to oral processing (time). An increase in the number of sips or bites, chews per unit of food and oral processing time results in a lower eating rate (Mosca et al., 2019; Zijlstra et al., 2009). Actually, it is probably the prolonged taste or sensory exposure that is responsible for the decrease in food intake with higher eating rates (Lasschuijt et al., 2017; Robinson et al., 2014; Zijlstra et al., 2009). Next to that, both eating rate and oral processing (e.g. frequency of chewing) are thought to influence several satiation and satiety hormones. A slower eating rate also seems to be related to a slower gastric emptying rate (Robinson et al., 2014). Overall, eating rate seems to mainly affect satiation (food intake within a meal) and only to a lower extent satiety (energy intake in subsequent meals) (Argyrakopoulou et al., 2020).

The **palatability** of a food describes to which extent a food is liked, when combining properties like taste, smell, texture, and mouth feeling. The higher the palatability, the more the food is generally liked. Evidence from a review shows that palatability is positively associated with food intake within a meal (satiation). The effect on subsequent food intake (satiety) is less clear (Sørensen et al., 2003). Another review, focusing on food addiction, concluded that highly processed, hyperpalatable foods with combinations of fat and sugar are likely to enable addictive-like responses. **Fat content and glycemic index** also seem to play a role. Sugar is often thought to have addictive potential, but this association has mainly been shown in animal studies and not in human studies (Pursey et al., 2017). **Food additives**, used to enhance flavor, color, and aroma, are also thought to contribute to the addictive-like response (Pursey et al., 2017). Both **fat and sugar** content have been associated with reward signals to the brain, especially when the consumption is excessive (Fushiki, 2014; Olszewski et al., 2019; Pursey et al., 2017). It is not clear whether the liking of high palatable foods as described above results in decreased liking of other foods with a natural or more explicit taste (e.g. broccoli or chicory).

Inattentive eating seems to have a negative effect on satiety cues. Distraction during the consumption of food, e.g. eating in front of the television, even increases food intake and disturbs the memory of the amount of food that has been consumed (Morris et al., 2020). This is also one of the suggested mechanisms to play a role in overconsumption of UPFs. Probably because they are **convenient and easy to consume**, especially in front of the television (Poti et al., 2017).

In summary, the nutrient composition, energy density, glycemic index, food texture, the way of eating foods, and palatability clearly play a role in satiation, satiety, eating rate, addictive-like responses and reward signaling, oral processing, and taste or sensory exposure, affecting energy intake (Figure 3). The presence of certain properties of UPFs suggests not only an overconsumption of these products itself, but also an overconsumption on total energy. However, similar to the conclusion for the nutritional value of UPFs, there is a large diversity of properties that could or could not be attributed to specific UPF products. Additionally, the mechanisms of properties of foods are complex and combinations of certain properties may have larger or smaller effects on energy intake. Nevertheless, it is clear that properties play a role in energy intake and evidence suggests that there is an increase in energy intake when there is larger UPF consumption.

Food safety

Even though food processing aims to improve food safety, food systems have become more complex and there remains a food safety risk in every step of production, processing, distribution, retailing, handling, and eventually consumption. The World Health Organization (WHO) stated that there is an increased food safety risk in Europe with globalization and increased travel and trade (World Health Organisation, 2017). Therefore, they call for effective and efficient prevention and control of food borne diseases. Not only microorganisms can cause these diseases, but also chemicals, toxins, radioactivity, and even physical agents such as little metal or plastic pieces (World Health Organisation, 2017).

Every extra step in the food chain comes with an additional food safety risk, which should be monitored during the entire food chain (Gallo et al., 2020; World Health Organisation, 2017). Typically, UPFs are the result of multiple industrial processes where several ingredients, from sugar and fat to a wide range of additives, have been added (C.A. Monteiro et al., 2019; Monteiro et al., 2018). The **general food safety issues** are obviously also applicable for UPFs. Typically, UPFs have undergone processes resulting in improved food safety, preservation, and shelf life. Especially at the end of the supply chain, when the product ends up with the consumer, processed foods are considered to have a lower food safety risk during storage, preparation, and consumption (Gallo et al., 2020; World Health Organisation, 2017). However, there are some specific aspects that require extra attention. UPFs contain artificial compounds which are not or less present in foods with a lower degree of processing. First, there is the unintentional **formation of certain compounds during processing**. For example, during heating processes, acrylamide and PAHs can be formed (Gallo et al., 2020). Acrylamide is present in starchy foods that have been heated at high temperatures (e.g. frying, baking, grilling), especially at low humidity. It is formed from sugars and proteins with high asparagine level. French fries, potato chips, biscuits, and coffee contribute the most to adults dietary intake of acrylamide, while meat, dairy and seafood products have lower levels of acrylamide (Adani et al., 2020). The formation of acrylamide cannot be avoided, but it could be limited by controlling the roasting conditions (Gallo et al., 2020). Acrylamide is classified as a possible carcinogen and has already been related to breast cancer, ovarian cancer, and endometrial cancer (Adani et al., 2020). Acrylamide has also been associated with an increased risk of CVD (Pagliai et al., 2020). More research is needed to confirm causal associations. PAHs are a group of lipophilic compounds that are known to be carcinogenic. The most toxic one is probably benzopyrene. Again, these compounds are formed during heating processes such as smoking, grilling, roasting, and frying. Additionally, there seems to be accumulation of PAHs from contaminated feed, air, and water in fat particles in meat, milk products, and seafood. The largest contributors of PAHs from dietary intake are contaminated fats and oils, which are also used in industrial processes. PAHs were also found in processed meat and seafood, smoked and grilled cheeses, dairy milk, tea, coffee, plant milks, (toasted) bread, and cereals. It is striking how different types of bread, cereals, and amounts of fat affect the PAHs levels (Singh et al., 2020). Another compound of interest is acrolein, which is formed during fat heating and has been associated with CVD (Zirak et al., 2019). Nitrate is a compound that occurs naturally in vegetables and water. (Sodium) nitrate and nitrite are also used as additives for preservation of processed meat and cheese. Vegetables, especially raw spinach, beets, celery, and lettuce contribute the most to nitrate intake, whereas both vegetables and processed meat products largely contribute to nitrite intake. Nitrate is not harmful, while nitrite is a more toxic compound and can be converted into nitrosamines in presences of secondary amines. Nitrosamines have been associated with an increased cancer risk and are classified by IARC as possibly carcinogenic (Kalaycloğlu & Erim, 2019; Karwowska & Kononiuk, 2020). The level of nitrosamines in processed meat is relatively low in Europe and depends on processing conditions (Flores & Toldrá, 2021). It should be noted that there are also beneficial effects of nitrate/nitrite regarding CVD (Karwowska & Kononiuk, 2020).

Next, there is often a long list of **additives** which are added to enhance palatability and shelf life. Examples are the abovementioned nitrate and nitrite in processed meat products, but also food coloring, non-caloric sweeteners, flavor enhancers, and emulsifiers. There is a strict regulation for the use of additives in industry and only approved additives are allowed to be used (positive list). However, little is known about the long-term health effects or the health effect of combining several additives. There are concerns regarding the impact on the digestive epithelium and the microbiome (Fardet & Rock, 2019). It has been suggested that the intake of artificial compounds, e.g. additives, can partly explain the increased prevalence of food allergies. They might be able to trigger an allergic response by altering the microbiome (Lee et al., 2020). Specific food allergies in response to additives are also possible but are rather rare. Especially in combination with other comorbidities, such as asthma and chronic idiopathic urticaria, additives may trigger certain adverse reactions (Valluzzi et al., 2019).

There are also examples from **compounds which are present in packaging** but seem to migrate to foods. Bisphenols and phthalates, present in plastic packaging, have endocrine disrupting properties These compounds are not chemically bound which enables the migration to food. One study was able to show higher phthalate urinary concentrations with a higher UPF consumption and lower phthalate and bisphenol urinary concentration with a higher consumption of unprocessed or minimally processed foods (Buckley et al., 2019).

Next to exposure to these compounds from dietary intake, there is also a contribution of environmental pollution and smoking to total exposure. Altogether, these compounds might have a significant impact on population's health. The previous mentioned compounds are not exclusively present in UPFs and their presence depends on the type of processing, the conditions (e.g. temperature, humidity) of processing, and the product itself. There is more research needed to be able to draw conclusions for UPFs specifically and to discover more compounds with possible (long-term) negative health effects.

Environmental impact

The environmental impact of food will be described in another document which will be published in 2021 by the Flemish Institute of Healthy Living. That document will focus on the environmental impact of foods and how that knowledge is implemented in the food-based dietary guidelines from the Food Triangle. Therefore, we limited this chapter to a brief introduction on the environmental impact of UPFs and we refer to the document being published in 2021.

Studies on the environmental impact of UPFs are limited. These rarely focus on the entire process (Life Cycle Analysis, LCA), while they should include all aspects going from the production of food ingredients, to processing, storage, packaging, transport, retail, preparation, consumption, and ending with waste disposal and recycling (Fardet & Rock, 2020; Molina-Besch et al., 2019). More research is needed to reveal the total environmental impact of UPFs. Nevertheless, a recent review gathered relevant data on food system sustainability and UPFs, and other UPF-like food groups such as junk food and discretionary food[3] (Fardet & Rock, 2020). A reduction of UPF consumption could play a role in the transition to a more sustainable food system by reducing Greenhouse Gas Emissions (GHGE), energy demand, water use, biodiversity loss, degradation of land, soil, and water, pollution, deforestation, and the use of fertilizers, pesticides, and packaging without reducing diet quality. However, when limiting UPF consumption, it remains highly important to stimulate substitution by minimally processed plant-based foods and to limit substitution by animal-based foods. Otherwise, the efforts being made will not necessarily result in improvements in environmental parameters (Fardet & Rock, 2020).

Cultural and socio-economic impact

Cultural and socio-economic aspects should not be neglected when describing the impact of foods. UPFs are associated with a **low level of social life** as these foods are often consumed in isolated situations, e.g. when watching television. In developed countries, these products are highly consumed by **poor and low educated**

[3] Discretionary foods are similar to UPFs and are described as energy dense foods and drinks that are high in saturated fats, sugars, salt and/or alcohol and are not necessary to provide the nutrients that the body needs.

people, while the opposite seems to be true in developing countries where people buy UPFs to **show** their increasing **wealth**. The replacement of cooking and **culinary traditions** by the consumption of UPFs is also an increasing concern. Lastly, large UPF companies might **threaten small farmers and producers** as they are not able to compete with the low prices from those UPF products (Fardet & Rock, 2020).

Behavior

Consumption of processed foods in Belgium

The Belgian Food Consumption Survey of 2014 gives information on the consumption of processed foods and the degree of processing according to NOVA. In the Belgian population (3 to 64 years), 36.4% of total consumption could be attributed to UPFs and 42.2% to unprocessed and minimally processed foods. The proportion of energy intake from UPFs was 29.9% (32.6% after exclusion of misreporters) and for unprocessed and minimally processed foods 21.3%. According to age, there was a significant higher proportion of energy intake from UPFs in young children (3 to 9 years, 33.3%) compared to adolescents and adults (29.2% and 29.6%, respectively). There were no significant differences in UPF consumption for gender, socio-economic population groups, and between people with a normal weight, overweight, or obesity. However, the proportion of energy intake from consumption of unprocessed and minimally processed foods was higher in women and individuals with long-term education. People who consumed more than two meals a day with their family, consumed a higher proportion of energy from unprocessed or minimally processed foods. For the total population (3 to 64 years), processed meat products (14.3%), cakes, pies and pastries (8.9%), dry cakes and sweet biscuits (7.7%), and carbonated soft drinks (6.7%) contributed the most to the dietary share of UPFs. The biggest contributors for unprocessed and minimally processed foods were pasta, rice and other grains (19.8%), fruits (18.5%), potatoes (9.4%) and chicken (7.8%). There were no remarkable differences in consumption of particular food groups among age groups by gender (Stefanie Vandevijvere et al., 2019). Unfortunately, there was no data reported for the Belgian elderly population.

Determinants of consumer behavior

Approximately 30% of the Belgian daily energy intake is derived from UPFs (Stefanie Vandevijvere et al., 2019). However, little is known about consumer behavior regarding UPFs. The Behavior Change Wheel ('Het Gedragswiel') was developed at The Flemish Institute of Healthy Living, which summarizes behavioral determinants that play a role in adopting to a certain behavior, e.g. healthy or unhealthy behavior (Figure 7). People need **competences** to be able to set or change their behavior and **motives** for actually wanting to set or change their behavior. Lastly, they need a

context which makes it possible and natural to set certain behaviors (Vlaams Instituut Gezond Leven, 2020).

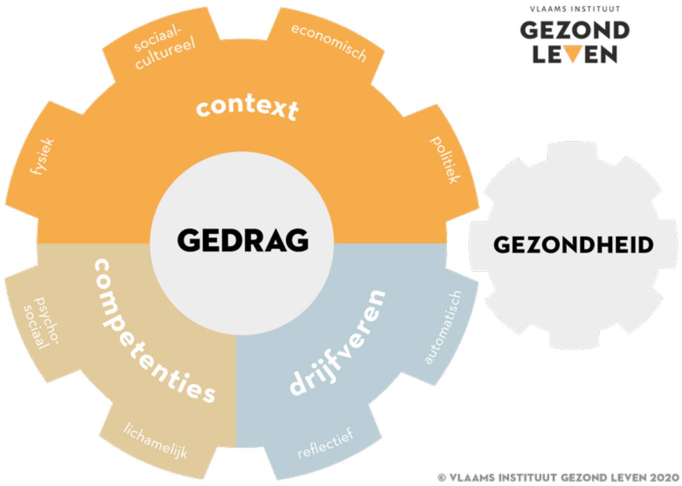

Figure 7: Het Gedragswiel (Vlaams Instituut Gezond Leven, 2020)

This model serves as a starting point to describe several aspects of UPFs in relation to consumer behavior and gives structure to the following paragraphs. The following paragraphs are not complete but attempt to display possible behavioral determinants related to UPFs, either on an individual level or contextual level.

<u>Individual determinants: competences and motives</u>
In 2019, The Flemish Institute of Healthy Living did an online survey on **nutrition knowledge** and opinion of the 'Food Triangle'. More information on the Food Triangle can be found on the website of the Flemish Institute of Healthy Living. In general, the Flemish population was able to estimate the recommended consumption frequency of most foods. However, there was limited knowledge on recommendations for nuts, red meat, frozen vegetables, canned lentils, potatoes, and coconut oil. Especially the recommendations for processed and ultra-processed foods were not clear. The perception that all processed foods are unhealthy is not in line with the recommendations of the Food Triangle. Almost 40% believes that all processed foods are unhealthy and 20% is not sure (Vlaams Instituut Gezond Leven, 2019). Another Belgian study investigated determinants for nutrition knowledge in a group of 18 to 39 year old women. Better nutrition knowledge was seen in women with a higher educational level, non-smoking behavior, and higher occupation status. Older women in this study population had better nutrition knowledge compared to younger women (De Vriendt et al., 2009).

Even though there are many cooking books and online recipes available, it is not clear whether Belgian people have sufficient **cooking skills** to prepare healthy meals. Having insufficient cooking skills is one of the reasons that people give to explain why they do not cook healthy meals or why they do not eat vegetarian meals (Mullee et al., 2017; Wolfson et al., 2016). Interventions often focus on improving the cooking skills of participants as this could improve their diet quality (Wolfson et al., 2016). However, other aspects also play a role and should not be neglected: planning, organization and enjoyment of cooking. Next to not knowing what healthy foods and diets mean (see paragraph 'nutrition knowledge'), lack of time (see paragraph on 'convenience') and the inability to afford fresh ingredients (see paragraph on 'cost') are other barriers for home cooking and preparing healthy meals (Wolfson et al., 2016).

Many people experience time scarcity, e.g. working parents and students who combine work and studying. Little time is left to provide food and to eat when combining work with raising children and keeping up with social life and leisure activities. Buying **convenient** foods and meals may lower the time and effort needed for preparing a meal, but it may also have its effect on grocery shopping and cleaning the kitchen and dishes afterwards. Next to saving time, avoiding unpleasant activities and reducing effort clearly play a role as well. Regarding the eating moment itself, people tend to combine different activities with eating, e.g. watching television, working, or driving, to save time (Casini et al., 2019; Jabs & Devine, 2006). On average, the Belgian population spends little time on the preparation of their breakfast (7 minutes). People spend more time on their lunch (15 minutes) and evening meal (33 minutes). 63% of the total population spends less than 10 minutes on their lunch and 38% spends more than 30 minutes on their evening meal (Bel, 2015). Especially young people, single males, people with a higher level of education, and families where the meal preparer works out of home seek convenient foods, also healthy convenience foods such as cut vegetables. However, not all people are willing to pay more to save time. One study defined three types of people: ‘quickies’ who are willing to pay more to save time, ‘foodies’ who pay more for the alternative which implies more preparation time, and ‘indifferent people’ who do not value time to influence their food choice (Casini et al., 2019). A Belgian report on the trends and innovations in the food system confirms the growing need of convenient food products. Online grocery shopping and home delivery are also ways to provide food in a more convenient way (Van Buggenhout et al., 2016). It is not clear whether people choose more healthy or unhealthy convenient foods. UPFs are designed to be convenient, but not all convenient foods are per se ultra-processed.

The palatability of foods contributes to the pleasure of eating and might be a motive to eat or to choose certain food products. **Palatability** comprises more aspects than solely ‘taste’ and covers smell, texture, mouth feeling etc. As described before, UPFs are often designed to be hyperpalatable (C.A. Monteiro et al., 2019). However, in the RCT from Hall et al., pleasantness and familiarity did not differ between the unprocessed and ultra-processed diet. Nevertheless, it should be noted that this was a highly controlled experiment, different from a real-life setting (Hall et al., 2019). **Food preferences** differ among individuals and are influenced by both genetic and environmental determinants. In a Dutch study, male participants showed a higher preference to meat and spices, while females showed a higher preference for fruit. With higher age, liking increased for meat, fish, and vegetables, while liking decreased for savory and sweet snacks, and drinks (Vink et al., 2020). Regarding food preferences for comfort foods, there is also a difference in age and gender. Males seem to prefer warm, hearty, meal-related comfort food, while females choose snack-related comfort foods (e.g. chocolate and ice-cream). Younger people also seek snack-related comfort food and older people prefer meal-related comfort food (Wansink et al., 2003). Apparently, some parents do not always buy or prepare the foods they prefer, but they compromise with the preferences of their children to avoid conflicts. Examples of compromised dishes are frozen pizza, spaghetti Bolognese, omelets, oatmeal porridge, and sausages (Alm, 2016). It remains unclear whether UPFs are (perceived) more palatable to consumers or not and whether there is a difference in food preference, when compared to unprocessed or processed foods. Maybe it depends on the products or meals being compared.

An online survey with more than 30,000 participants from 63 different countries reported on consumer attitudes or perception towards certain ingredients and foods. There is a specific focus on **additives and processing**, which is highly relevant for the topic of UPFs. Apparently, consumers want to go back to the basics, focusing on simple ingredients, and less artificial and processed foods. Globally, only 44% trusts industrially prepared foods. A large part of the European population says they avoid specific ingredients in their foods: antibiotics or hormones used in animal products (65%), artificial preservatives (61%), artificial flavors (60%), artificial colors (60%), and genetically modified organisms (59%). They primarily avoid these ingredients because of the perceived impact on their health. In Germany and the United Kingdom, this trend is reflected in the sales, but for Belgium this remains unclear. People seem to be concerned about their health and they seek ‘simple foods’, but they also want products to be tasty, convenient, and cost effective (Nielsen Company, 2016). In line with the previously mentioned report, there is a Belgian trend of going ‘back to basics’, as consumers value the absence of additives, the country of origin, buying local products, and authenticity (Van Buggenhout et al., 2016).

Consumers are getting more conscious about the **environmental impact** of their food and food packaging. A recent report from the European Consumer Organisation confirms that consumers are willing to change towards a more sustainable food pattern, but they experience barriers to actually do so. People tend to underestimate the environmental impact of their own food behavior but seem to be aware of the general environmental impact of food habits. It remains unclear to which extent and in how many people this is actually affecting their food choices and purchases (Dauwe, 2017; The European Consumer Organisation, 2020).

Food processing and packaging is important for **food safety** and to improve shelf life. From the previous paragraphs, it seems like consumers could have negative perceptions towards processed foods and additives. During the corona crisis, the sales of packaged fruits and vegetables increased, while the sales for unpackaged fruits and vegetables decreased. Consumers were afraid of getting infected with the virus via their food products (Mertens, 2020). Apparently, the shelf life is something that is remarkably taken into consideration when buying foods (Moreira et al., 2019). Nevertheless, it is not clear whether Belgian consumers generally highly value the food safety aspects of processing and packaging when making food choices.

Product information on the packaging describes ingredients, nutrient values, food labels and sometimes even food claims which could affect consumers quality perception of the product (Dauwe, 2017). However, the ability to read and understand food labels determine whether food labels can support consumers to make better food choices or not. Consumers indicate that they do not always check food labels when buying foods because of a lack of time and excessive information on packaging. They think the labels are often confusing and too small (Deakin, 2011; Moreira et al., 2019). Front of pack labeling can either be based on nutrient profiling systems (e.g. Nutri-score) but can also be based on other product characteristics such as being organic, being free of added sugars, containing whole grains, and quality certificates. Some labels are more effective than others, but they could be able to guide the consumer and help them to make food choices (El-Abbadi et al., 2020). Products with a ‘natural’ or ‘organic’ claim sell better than similar products without the claim, even when both products are actually similar in other characteristics. A natural, organic chocolate bar would for example sell better than a chocolate bar without these claims (Nielsen Company, 2016). The Nutri-score has been implemented in Belgium and is shown to be effective in France to support consumers to make healthier food choices (Egnell et al., 2018).

Contextual determinants: food environment

To our knowledge, there is no scientific data available on Belgian food environments to describe the **availability or accessibility** of UPFs. One study investigated food inaccessibility in Flanders. They concluded food deserts are rare and occur in industrial estates, outer city social housing projects and garden cities. Especially physically immobile (e.g. elderly people) and socioeconomically immobile (e.g. people in poverty) are at risk for food inaccessibility (Cant, 2019). Higher residential density neighborhoods seem to have the most obesogenic food outlets available. The study that made this conclusion, obtained virtual audit data (e.g. Google Street View) from Ghent (Belgium), London (Great Britain), Paris (France), Budapest (Hungary), and The Randstad (The Netherlands). Ghent, Budapest, and The Randstad had a lower residential density, more green areas and a very low percentage of streets with food and recreational facilities, compared to huge cities as London and Paris (Feuillet et al., 2016). Nevertheless, this does not necessarily imply that there are little obesogenic food outlets or there is a low availability of UPFs in Belgian food environments. There is some variability in the availability of UPFs in supermarkets across different countries, but generally there seem to be high levels of snack and soft drink displays (Thornton et al., 2013).

A recent study on the **cost** of diets in Belgium showed that those with a larger caloric contribution of UPFs are cheaper than diets with more unprocessed or minimally processed foods. Additionally, households with lower education levels spent less money on food and spent a smaller part of their food budget on unprocessed or minimally processed foods (Vandevijvere et al., 2020). Data from the Belgian Food Consumption Survey were used in the analyses. Prices for out-of-home meals were not available but were estimated from costs from ingredients. On average, the price per 100 kcal for unprocessed or minimally processed foods (€1.29) was significantly more expensive compared to UPFs (€0.55) and processed foods (€0.43) (Table). The total available budgets for different household educational levels were not reported. Nevertheless, the average daily dietary costs and costs per 2000 kcal were reported for different age groups for males and females with different household educational levels. The average dietary cost per 2000 kcal increased significantly with education levels in males and females and in all age groups, except for young boys. Households with higher education levels seem to spend more money on food (Vandevijvere et al., 2020). Regarding the contribution of different food groups to daily dietary cost, the largest part of the budget goes to unprocessed or minimally processed foods in all age groups, apart from the adolescents who spend more budget on processed foods. The lowest contribution of unprocessed or minimally processed foods to daily dietary cost was found in male adolescents (29.5%), while female adults were responsible for the highest contribution (42.3%). 21.9 to 29.9% of the total budget went to UPFs, with the highest contribution coming from young children (29.9%). The remaining part of the dietary cost was spent on processed foods. While household education level was not associated with the contribution of UPFs to the daily dietary cost, a higher education level was linked to a higher contribution of unprocessed or minimally processed foods (Vandevijvere et al., 2020).

Table 2: Data on prices per 100 kcal and percentage of daily dietary cost for different food groups according to their degree of processing (Vandevijvere et al., 2020)

	Unprocessed or minimally processed foods	Processed foods	Ultra-processed foods
Price per 100 kcal (€)	1.29	0.43	0.55
Percentage of daily dietary cost (%)	29.5 to 42.3	Not reported	29.5 to 29.9

Food marketing seems to be effective in promoting both unhealthy and healthy foods (Vukmirovic, 2015). Nevertheless, unhealthy foods seem to get more attention than healthy foods in terms of marketing (Fleming-Milici & Harris, 2020; Hallez et al., 2020; C. A. Monteiro et al., 2019). A wide range of marketing strategies are used to promote foods: food packaging, social media, billboards, event sponsorship, product placements, and television commercials. Attractive food packaging, as often used for UPFs, will draw more attention from consumers and might lead to purchasing the product, even though this was not planned beforehand (Dauwe, 2017). Packaging might not only influence what people decide to eat, but also how much is eaten, for example through portion size (Hallez et al., 2020). There is a lot of concern regarding marketing of food products for children and adolescents. Especially because many of the highly marketed products are often ultra-processed and unhealthy foods, and because this age group is very sensitive to visual cues to be influenced towards these types of food. It has even been stated that marketing aimed at children and adolescents is linked to rates of obesity and long-term health effects (Fleming-Milici & Harris, 2020; Hallez et al., 2020). A Belgian study investigated child-directed strategies on food packages in the supermarket. Almost 90% of all products with child-directed marketing were considered to be unhealthy. Per package, multiple strategies were used to increase the persuasive effect on children. The authors ask policy makers to monitor child-directed marketing strategies (Aerts & Smits, 2019). There is also emerging evidence on the effects of food marketing via social media, especially of unhealthy foods and in adolescents and young adults (Murphy et al., 2020). Not only children and adolescents are affected by food marketing strategies. Even though the evidence for adults is less consistent, they are probably also influenced by food marketing. It is thought that adults developed skills to recognize the persuasive intent of food packages (Hallez et al., 2020). A review on the effect of food advertising in adults showed that not all adults are equally sensitive to advertisements (Vukmirovic, 2015).

Conclusion

UPFs are the result of complex industrial processes, where sugar, fat, and/or salt and additives have been added. These products are generally characterized by a rather negative nutritional composition. They are thought to promote overconsumption through the effect of food properties (e.g. energy density, food texture, palatability) on for example satiation, satiety, and eating rate. Negative health effects have been reported in observational studies and the first RCT showed significant weight gain after a two-week intervention of following an ultra-processed diet. More research is needed to confirm causal effects, but for some UPF subgroups, the evidence is already stronger (e.g. processed meat and SSB). Studies investigating the environmental impact of UPFs are limited. Nevertheless, they suggest that a reduced consumption of UPF could contribute to the transition towards a more sustainable food system. In Belgium, the consumption of UPFs contributes to approximately 30% of the total energy intake. Many possible behavioral determinants linked to UPF consumption have been described: e.g. nutrition knowledge, cooking skills, consumers attitude towards additives/processing/packaging, convenience, cost, availability, and food marketing.

It is recognized that the group of UPFs is very diverse in multiple aspects which makes it difficult to make general conclusions based on solely the degree of processing. Therefore, it seems appropriate to conclude that the degree of processing should be considered as a criterium but not the only criterium when considering the health and environmental effects of food, e.g. for developing food based dietary guidelines. The consensus that unprocessed and minimally processed foods are preferred over UPFs is strong and can be put forward as a leading principle in food choice. For processed foods and UPFs the effect of the degree of processing and its effect on the nutritional value of foods should be considered (positive, neutral or negative). Even within the group of UPFs consumers can be guided to make the better choice. To put this knowledge into practice, the behavioral determinants (competences, motives, and context) related to UPF consumption should be taken into account. Contextual determinants could be tackled by policy makers.

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