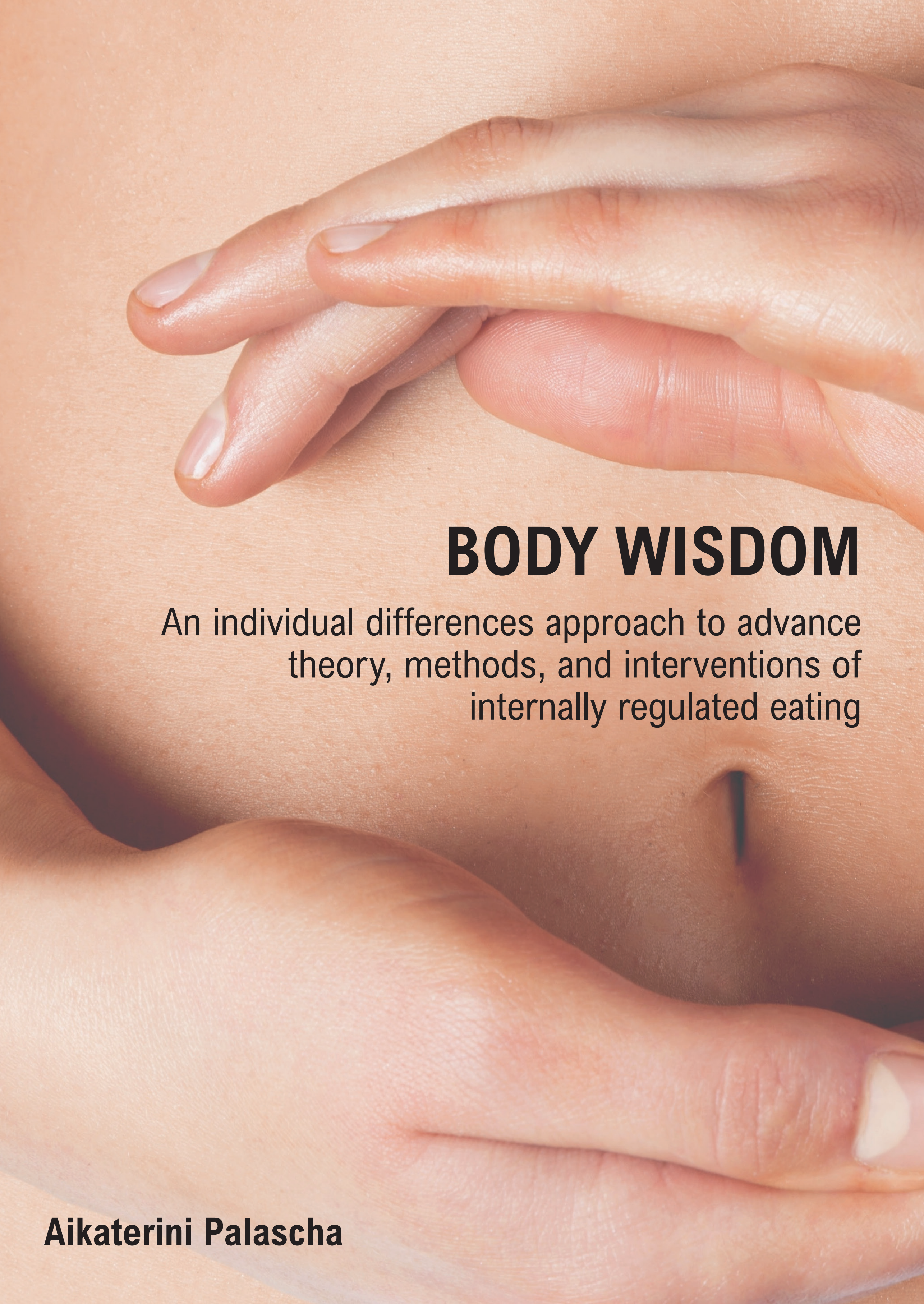

BODY WISDOM

An individual differences approach to advance theory, methods, and interventions of internally regulated eating

Aikaterini Palascha

PROPOSITIONS

1. A non-restrictive relationship with food prevents rather than leads to overeating. (this thesis)

2. Perception of satiation signals is less malleable than perception of hunger signals. (this thesis)

3. Subjective interpretation of objective findings is key to scientific progress.

4. Research is the process of becoming aware of what remains unknown.

5. Pre-registration of research proposals can undermine research quality.

6. Public health would benefit if dietitians also obtain a degree in psychology.

Propositions belonging to the thesis, entitled:

Body wisdom: An individual differences approach to advance theory, methods, and interventions of internally regulated eating

Aikaterini Palascha

Wageningen, 3 September 2021

Body Wisdom

An Individual Differences Approach to Advance Theory, Methods, and Interventions of Internally Regulated Eating

Aikaterini Palascha

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Body Wisdom

An Individual Differences Approach to Advance Theory, Methods, and Interventions of Internally Regulated Eating

Aikaterini Palascha

Thesis

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Prof. Dr A.P.J. Mol,

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Chapter 1

General Introduction

‘There is more wisdom in your body than in your deepest philosophy’

Friedrich Nietzsche (German philosopher)

‘Be moderate in order to taste the joys of life in abundance’

Epicurus (Ancient Greek philosopher)

Eating provides the fuel for a living body, is a source of pleasure, and a means for social exchange. Yet, for many of us eating is experienced as a struggle. This struggle is reflected in the multiple and complex decisions we take every day about when, what, and how much to eat, in efforts to stick to rich and healthy food repertoires, in chronic efforts to reduce dysfunctional eating tendencies (e.g., emotional eating), or in dealing with eating disorders or chronic conditions that require major lifestyle changes (e.g., obesity and associated diseases).

It is no wonder that eating has become so difficult nowadays. A combination of societal and environmental changes that have taken place over the last decades, combined with our innate dispositions to prefer high-energy foods and to eat in an opportunistic manner (Birch, 1999; Pinel et al., 2000), create a fertile ground for this eating-related struggle. For example, in recent years we face an increased societal pressure for thinness that leads many people to feel dissatisfied with their body's shape and weight (Rodgers et al., 2015). At the same time, the modern food abundant environments consistently promote overconsumption and sedentary behaviour (Lake & Townshend, 2006). These changes contradict each other because the former increases the demand for thinness while the latter limits the opportunity to achieve thinness. As discussed later, these contradictory changes pose important challenges to our eating behaviour.

Yet not everyone is affected by these challenges to the same extent. Even under these circumstances some individuals manage to regulate their eating effectively as they achieve to eat healthily and maintain normal weights (Joki et al., 2017; Swan et al., 2018). Thus, some people seem to have an adaptive response to the changing circumstances. While there are several routes to effective regulation of food intake, this thesis focusses on internally regulated eating, a non-restrictive and intuitive form of self-regulation that is grounded on responsiveness to bodily signals of hunger and satiation. In the following sections, the societal and environmental changes that make self-regulation of food intake a difficult task nowadays are discussed, different perspectives on effective self-regulation are outlined, and the concept of internally regulated eating is introduced, followed by the aims and outline of this thesis.

1.1. Societal pressure for thinness

Modern societies have become increasingly obsessed with the thin body. The so-called *thin ideal* is promoted in almost every form of media from magazines to TV shows, movies, and social platforms. This culturally accepted norm influences our attitudes about our bodies and our eating behaviours. For example, internalization of the thin body ideal has been found in prospective studies to increase social appearance comparison and body dissatisfaction already in young ages (Rodgers et al., 2015). In turn, body dissatisfaction predicts dietary restraint (Dunkley et al., 2001), disordered eating behaviours, and psychological distress (Johnson & Wardle, 2005).

Concern about weight is widespread in today's societies. In a large and representative community sample of Dutch consumers 63% of both males and females were identified as dieters and dieting reflected mainly a heightened concern about weight rather than an actual restriction of food intake (de Ridder et al., 2014). Weight control behaviours are also very widespread. For instance, more than 70% of consumers were found to exhibit behaviours such as eating low-calorie food, limiting sweets and snacks, or eating smaller portions in a cross-sectional study with Dutch adults (20-40 years old) (Wammes et al., 2007) and similar findings have been observed also in other populations (French et al., 1999). It is difficult to imagine that such behaviours are driven only by appearance concerns. Many individuals try to regulate their eating driven mainly by health, ideological, or other personal motives (Lindeman & Stark, 1999). Yet for others dissatisfaction with body size and shape is more influential and different motives are often intertwined (Lindeman & Stark, 1999; Pelletier et al., 2004).

Furthermore, the obsession about weight and thinness translates into stigmatization of overweight and obese individuals and weight stigma discourages health behaviour change (Brownell et al., 2005). According to the cyclic obesity and weight-based stigma model, weight stigma induces stress, which in turn elicits a series of behavioural, physiological, and emotional responses (e.g., comfort eating, increased cortisol levels, feelings of shame), which associate with weight gain and difficulty in weight loss (Tomiyama, 2014). This is supported by evidence showing that weight stigma associates with exercise avoidance (Vartanian & Shaprow, 2008) and behavioural tendencies that increase food intake such as binge eating (Haines, 2006). Unfortunately, bias towards increased weight is a widespread phenomenon and has even been documented among health professionals who treat obesity and eating disorders (Puhl et al., 2014; Schwartz et al., 2003).

In general, therefore, it seems that the societal pressure for thinness creates a general anxiety around eating and weight (in some individuals more than others) that may impede adherence to healthy eating and healthy lifestyles.

1.2. Environmental pressure for overconsumption

At the same time, in many societies worldwide the environment has gradually transformed to what is called *toxic* or *obesogenic* environment, characterized by an abundance of energy dense, highly processed, palatable food that is easily accessible, inexpensive, and widely promoted (Lake & Townshend, 2006). Responsiveness to food-related cues from the environment can promote overeating and gradually lead to weight gain (Boutelle et al., 2020).

Specifically, it has been shown that external cues from the food and eating environment challenge the internal appetite system of energy regulation across the full spectrum of the food consumption process, thereby potentially leading to overconsumption (Bilman et al., 2017). For example, the mere sight or smell of palatable food or certain habits such as eating by the clock can trigger meal initiation even in the absence of hunger (Smeets et al., 2010; van't Riet et al., 2011). Moreover, cues from the eating environment such as using large dinnerware (plates, spoons, etc.) or eating from large packages or portion sizes can lead to overeating by setting an enlarged norm about what is considered an appropriate amount to eat (van Ittersum & Wansink, 2012; Zlatevska et al., 2014). Considering the trend towards larger portion sizes of energy-dense food products that has been observed over the last decades (Steenhuis et al., 2010), these findings have serious implications from a public health perspective. Furthermore, during the consumption stage, external cues such as increased meal variety or palatability have the capacity to hinder the development of satiation, thereby leading to higher food intake (Brondel et al., 2009; de Castro et al., 2000). Finally, external distractions such as eating with other people or while watching TV have been consistently shown to lead to overconsumption by disrupting the attention paid to the eating process, the perception of internal signals of satiation, and the encoding of the meal in working and episodic memory (de Castro & de Castro, 1989; Higgs & Spetter, 2018).

Therefore, multiple factors related to the food's increased palatability, saliency, and presentation but also factors related to the context in which such food is consumed today can increase our food intake. Next to that, individuals nowadays face a limited opportunity to be physically active. The development of urbanization associates strongly with the reduction in physical activity, which also contributes to weight accumulation (Abbade & Dewes, 2015). Taken together, the above evidence suggests that several environmental changes that have taken place over the last decades pose important challenges to the effective regulation of food intake and to the maintenance of healthy body weights.

1.3. Perspectives on effective self-regulation of food intake

Although the regulation of food intake has become a difficult task nowadays for the reasons described above, there are people who manage to eat healthily and in moderation, thereby maintaining normal weights, adequate nourishment, and healthy attitudes towards food. Effective regulation of food intake can take several forms. Some individuals manage to impose a sustained control over their eating via cognitive decisions about which types of foods and which quantities will assist them in achieving their long-term health goals (Chambers & Swanson, 2012). For example, it has been shown that successful dieters, defined as those who score high on restrained eating and low on disinhibited eating, are driven by strong top-down cognitive processes, which allow them to supress the representation of food in their working memory, thereby maintaining a reduced attention towards food cues (Higgs et al., 2015). This is consistent with evidence indicating that exposure to tempting food can sometimes activate long-term health goals and promote, rather than hinder, goal-directed behaviour (Fishbach & Shah, 2006; Kroese et al., 2009). It has also been suggested that these top-down processes likely operate in an automatic manner and outside of conscious awareness (Fishbach et al., 2003).

For a different segment of individuals, self-regulation takes a more flexible and intuitive form. For example, narrative inquiries with individuals who eat healthily and maintain normal weights over lifetime portray an eating style that is characterized by awareness and consciousness while eating, eating healthily without too much effort, eating regular meals of suitable size, responding to bodily signals of hunger and satiation, having experiential rather than factual knowledge about food, and maintaining a flexible and permissive (rather than prescriptive or restrictive) relationship with food, whereby food is not merely seen as means to achieve health but is also associated with pleasure and enjoyment (Joki et al., 2017; Swan et al., 2018).

Still, these arguably different approaches do not have fixed boundaries. For example, some level of flexible restriction is also seen in some weight maintainers who generally take a flexible and permissive approach to self-regulation (Joki et al., 2017). For example, it has been found that lifelong weight maintainers are less vigilant with self-weighting, have a more relaxed attitude towards weight gain, and do not monitor their diet as rigidly as individuals who are maintaining a weight loss, although the former also seem to practice effortful control over their eating in some cases (Chambers & Swanson, 2012).

A large amount of research is being devoted to understanding effortful forms of self-control of eating behaviour. Traditional health behaviour models and social psychological theories are heavily used to explain self-control success or failure. Interventions that emerge from these models aim to motivate individuals make sustainable lifestyle changes through goal setting, reasoning, planning, and self-monitoring (Mann et al., 2013; Reed et al., 2016). In a related vein, a large body of research focuses on structuring the food and eating environment (e.g., eating atmospherics, consumption norms, nudging) in such a way that it assists (rather than impedes) individuals in their self-control efforts (Leng et al., 2017; Wansink, 2004). In contrast, considerably less attention has been paid to more flexible and permissive forms of eating regulation. Flexibility in eating regulation has mainly been studied from the perspective of flexible eating restraint, which still qualifies as a restrictive cognitive-based way of eating. Flexible eating restraint is characterized by portion control, ceasing meals cognitively to avoid weight gain, eating slowly to avoid overeating, compensating for forbidden foods, and being conscious about food and appearance (Westenhoefer, 1991). Instead, the combination of a relaxed attitude towards eating with emphasis on eating enjoyment and an intuitive body-based strategy for making eating-related decisions (e.g., responding to internal bodily signals of hunger and satiation) has been studied less extensively despite its potential to lead to effective self-regulation, psychological health, and weight stability (Schaefer & Magnuson, 2014).

1.4. The emergence of internally regulated eating

Internally regulated eating fits within the general trends in positive psychology and positive health, which are interested in positive human characteristics (strengths and virtues) and in processes that contribute to resilience, optimal functioning, and health, defined as a state beyond the mere absence of disease (Gable & Haidt, 2005; Seligman, 2008). Internally regulated eating started to gain attention in research and practice around the 1980s in parallel with the feminist and anti-dieting movements and as a response to the growing body of evidence on diet failure (Mann et al., 2007). Pioneer contributions on the concept appeared initially in the self-help literature (Hirschmann & Munter, 1988; Schwartz, 1982; Tribole & Resch, 1995) but also in the scientific realm (Herman & Polivy, 1983). Several related concepts gradually emerged such as *attuned eating*, *normal eating*, *natural eating*, *demand feeding*, or the *non-diet approach,* all pertaining to eating in a pleasurable and non-restrictive way, and in response to bodily signals of hunger and satiation. Internally regulated eating was introduced as an alternative paradigm addressing the gaps and failures of the traditional paradigm of weight management (Gast & Hawks, 1998; Robison, 1997). This new paradigm was based on the assumptions that low weight is not tautological to health, that the cultural pressures for thinness exacerbate the normal differences in size and shape among individuals, that dieting systematically leads to weight gain, psychological impairment, and increased risk for eating disorders, and that health is a multidimensional concept incorporating not only physical but also psychological, mental, spiritual, and social components (Robison, 1997). The accumulation of research findings supporting these assumptions gradually gave rise to the body acceptance and Health-at-Every-Size (HAES) movement within which internally regulated eating was embedded (Avalos & Tylka, 2006; Bacon & Aphramor, 2011; Tylka et al., 2014).

Early intervention programs started to emerge, promoting awareness of internal signals of hunger and satiation, enjoyment of eating, permissive eating, self-reliance, abandonment of restrictive eating, consciousness of emotional and external triggers of eating, and body acceptance. Several of these approaches led to significant improvements in psychological, behavioural, and weight-related outcomes in clinical and non-clinical samples (Carrier et al., 1994; Craighead & Allen, 1995; Omichinski & Harrison, 1995; Polivy & Herman, 1992; Roughan et al., 1990). For instance, a six-week intervention for binge eating disorder was conducted to cultivate awareness of binge triggers and cues of hunger and satiety, self-forgiveness, savouring food while eating, and to prevent relapse via the practice of mindfulness (i.e., focussed attention in the present moment in a non-judgemental way). The intervention led to significant reductions in frequency and severity of binges, depression, and anxiety, as well as to increased sense of control over eating (Kristeller & Hallett, 1999). These, together with other, promising early results were further corroborated by cross-sectional research and intervention studies showing that this style of eating regulation is not only associated with improved outcomes but also leads to them (Bruce & Ricciardelli, 2016; Christoph et al., 2021; Clifford et al., 2015; Hazzard et al., 2021; Quansah et al., 2019; van Dyke & Drinkwater, 2014). However, it is still generally agreed that the concept of internally regulated eating warrants further research.

Specifically, research in the domain of internally regulated eating has heavily evolved from an applied point of view while limited attention has been paid to understanding the key attributes of this internally regulated eating style from a theoretical perspective. Theorizing in this field has mainly focussed on the antecedents (e.g., body appreciation, body acceptance by others) rather than the building blocks of internally regulated eating (Augustus-Horvath & Tylka, 2011; Avalos & Tylka, 2006). Hence, there is currently a need for theoretical models that can explain how the key attributes of internally regulated eating associate with or support each other and through which mechanisms they influence food intake regulation and other health outcomes. In relation to that, the psychological mechanisms that underly effortless forms of self-regulation are not yet well understood (but see Dijker, 2019). For example, the processes by which a relaxed and enjoyable relationship with food may facilitate, rather than impede, individuals in eating self-regulation remain unclear.

Furthermore, without a clear grip on the concept of internally regulated eating, the measures we use to assess it in the population are of limited value. For example, existing self-report measures of internally regulated eating have been found to share considerable amounts of variance with measures of restrained and emotional eating (Barrada et al., 2020). This raises questions regarding the way that the constructs that these measures assess have been conceptualized and/or operationalized. Thus, the development of comprehensive theoretical models of internally regulated eating will also drive the development of appropriate measures to assess this construct.

Finally, there seems to exist considerable variation and lack of consistent terminology in the narratives concerning internally regulated eating, which hinders the comparability of evidence between different research lines. For example, inconsistent definitions and limited theoretical accounts of non-dieting approaches that promote eating by internal cues of hunger and satiation have been recognised as potential reasons for inconsistent findings in systematic reviews (Clifford et al., 2015; Schaefer & Magnuson, 2014). It is apparent, therefore, that this field is highly fragmented and lacks a solid theoretical basis, which in turn impacts assessment and application.

Advancing this field is important because it addresses effective regulation of food intake from the perspective of *ability*, meaning, how individuals can use their own competences to achieve self-regulation. According to the motivation, opportunity, ability (MOA) model (Brug, 2008), the adoption of healthy eating requires individuals to be motivated (i.e., goals and intentions), to operate in an environment that facilitates their intentions, and to have the necessary abilities or skills to eat healthily. Thus, ability works synergistically with motivation and opportunity for the effective regulation of food intake (Fig 1). As discussed earlier, research has extensively investigated the role of motivation and opportunity for the effective self-regulation of food intake, while the role of ability has mainly been researched from the perspective of skills that aid cognitive control (e.g., calorie counting, portion control, meal planning, factual knowledge about healthy eating). However, ability in managing eating can also take other forms such as having agency, flexibility, and self-awareness, which remain understudied.

1.5. Aims and scope of this thesis

This thesis embraces the multiformity of existing research on internally regulated eating and uses it to build an integrated theoretical framework of internally regulated eating style, which is then used as a basis to advance its measurement and application. It takes an individual-differences approach because the aim is to identify and quantify the characteristics that comprise this eating style. Importantly, these characteristics are occurring naturally in the population, so all individuals can be considered as possessing them. Yet the degree of these characteristics varies among individuals but also within individuals (e.g., as a result of important life changes). Understanding the characteristics that underpin the internally regulated eating style can be used as a starting point for the development of appropriate methodology to assess it in the population but also for the design of interventions that will promote it as a strategy for eating regulation, health, and well-being. This thesis addresses specifically the following research questions:

1. Which are the individual difference characteristics that underpin the internally regulated eating style, how do they associate with each other, and how do they lead to effective regulation of food intake?
2. How can we quantify these individual difference characteristics in the population?
3. To what extent does sensitivity to bodily signals of hunger and satiation (trait) manifest itself in behavioural tasks (state)?
4. To what extent is perception of bodily signals of hunger and satiation (state) affected by focused attention to the body?

Chapter 2 entitled *Assembling the Building Blocks of Internally Regulated Eating Style* addresses the first research question. In this chapter, a comprehensive theoretical framework of internally regulated eating style is developed. This framework delineates the key individual-difference characteristics of internally regulated eating style (as identified in existing literature), the hypothesized relations between them, and the potential mechanisms by which they contribute to the effective regulation of food intake. This chapter lays the conceptual foundation of this thesis and drives the research presented in the following chapters (Fig. 1.1.).

Chapter 3 entitled *Development and Validation of the Multidimensional Internally Regulated Eating Scale (MIRES)* addresses the second research question. It presents the rigorous process of developing and validating a self-report measure of internally regulated eating style to be used for the assessment of this eating style in the general population. In a series of studies with college and community samples from various countries, evidence on the scale's wide range of psychometric properties is provided.

Chapter 4 entitled *Trait vs. State Sensitivity to Bodily Signals of Satiation and Hunger: a Tale of Construct Validity* zooms into one of the core characteristics of internally regulated eating style, sensitivity to bodily signals of satiation and hunger, to address the third research question. It discusses two pre-registered studies that contrasted sensitivity to bodily signals as a trait (self-reported scores) and as a state (incidental, momentary behavioural responses). This was intended as a stringent test of construct validity for the self-report measures.

Chapter 5 entitled *Unveiling the Effect of Mindfulness on Perception of Bodily Signals of Satiation and Hunger* is an extension of Chapter 4, addressing the last research question of this thesis. A second experimental group (i.e., mindfulness group) was added in each study of Chapter 4, thereby turning the studies into quasi experiments. Chapter 5 addresses whether and to what extent a brief mindfulness intervention (i.e., focussed attention to the body) influences individuals' ability to perceive bodily signals of satiation and hunger.

Finally, Chapter 6 concludes this thesis by providing an overview of the main findings and their implications for research and practice. Limitations of the conducted research and potential pathways for future research are also discussed.

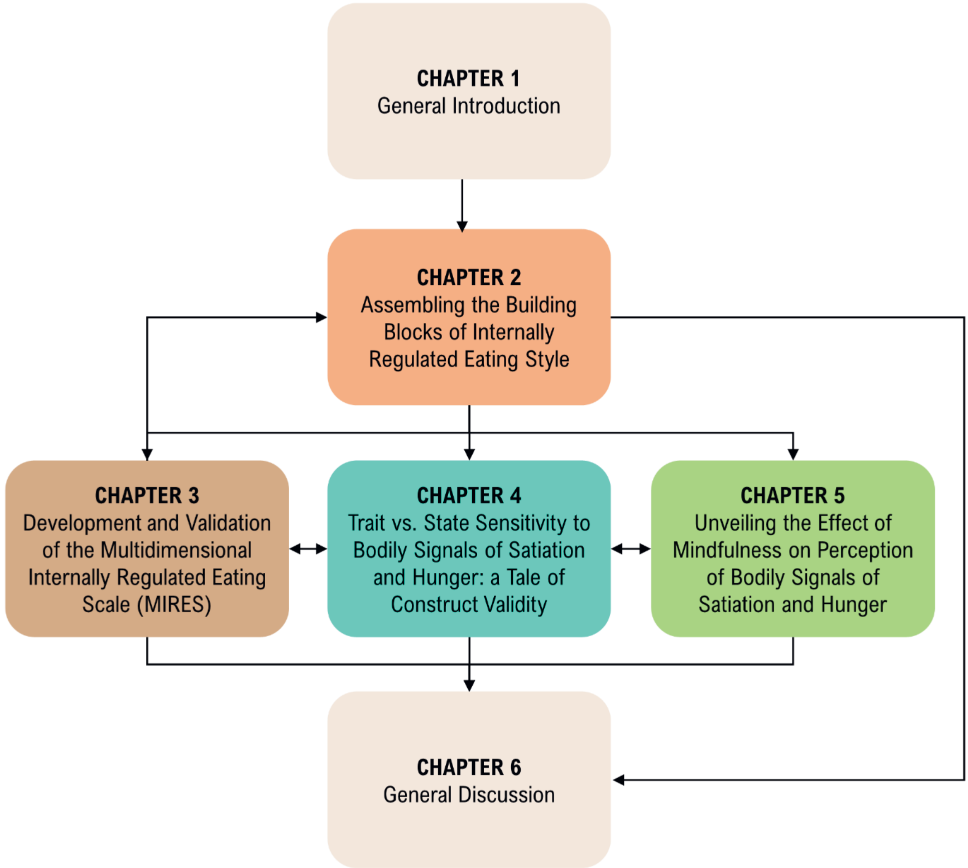
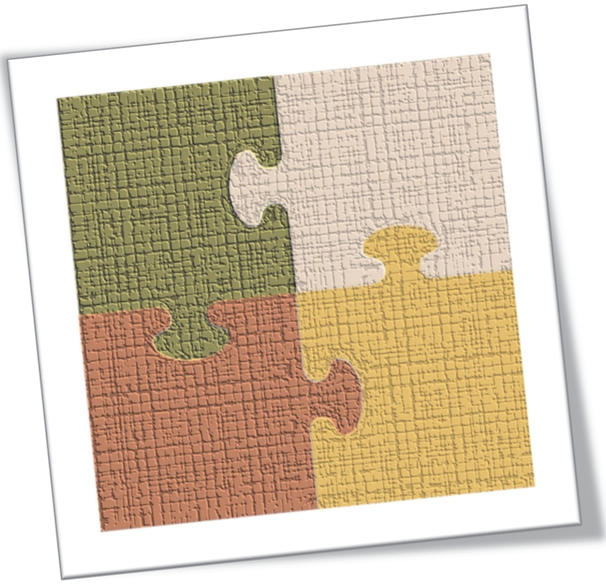


Fig. 1.1. Schematic outline of the present thesis

Chapter 2

Assembling the Building Blocks of Internally Regulated Eating Style



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Abstract

Internally regulated eating style, the eating style that is driven by internal bodily sensations of hunger and satiation, is a concept that has received increasing attention in the literature and health practice over the last decades. The various attempts that have been made so far to conceptualise internally regulated eating have taken place independently of one another, and each sheds light on only parts of the total picture of what defines internally regulated eating. This has resulted in a literature that is rather fragmented. More importantly, it is not yet clear which are the characteristics that comprise this eating style. In this paper, we identify and describe the full spectrum of these characteristics, namely, sensitivity to internal hunger and satiation signals, self-efficacy in using internal hunger and satiation signals, self-trusting attitude for the regulation of eating, relaxed relationship with food, and tendency to savour the food while eating. With this research, we introduce a common language to the field and we present a new theoretical framework that does justice not just to the full breadth of characteristics that are necessary for the internally regulated eating style but also to the associations between them and the potential mechanisms by which they contribute to this eating style.

2.1. Introduction

Humans are equipped with a highly sophisticated energy regulation system that provides signals about when to start and stop eating (Broberger, 2005; de Graaf et al., 2004). Although several environmental, genetic, and developmental factors pose challenges to our everyday efforts to regulate eating (Bilman et al., 2017; Birch et al., 1987; Stevenson et al., 2015), some people do relatively well in listening to and acting upon these internal bodily signals in a confident, relaxed, and enjoyable way.

Prior research has shown that the tendency to eat in response to physiological signals of hunger and satiation (i.e., internally regulated eating style) associates with lower BMI (small to medium effect sizes have been reported (Keirns & Hawkins, 2019; Moy et al., 2013)), better psychological outcomes (e.g., higher body appreciation, self-esteem, emotional awareness, life satisfaction, psychological flexibility; lower depression, anxiety, perfectionism, dichotomous thinking, preoccupation with food), and better behavioural outcomes (e.g., lower restrained, emotional, and external eating, unhealthy weight-loss practices, eating disorder symptomatology; higher eating self-efficacy, proactive coping, autonomy) (Anderson et al., 2016; Bruce & Ricciardelli, 2016; Linardon & Mitchell, 2017; Sairanen et al., 2015; Tylka & Wilcox, 2006; van Dyke & Drinkwater, 2014; Warren et al., 2017). Evidence from intervention studies further corroborates these positive findings (Allen & Craighead, 1999; Clifford et al., 2015; Goode et al., 2018; Jospe et al., 2017a; Mellin et al., 1997; Schaefer & Magnuson, 2014; Schnepper et al., 2019; Tanco et al., 1998; Ulian et al., 2018; van Dyke & Drinkwater, 2014; Warren et al., 2017), although with respect to weight it seems that internally regulated eating mainly results in weight maintenance and to a lesser extent in weight loss (small effect sizes have been reported (O'Reilly et al., 2014)). The impact on energy intake, dietary quality, and other physical indicators of health (e.g., blood pressure, lipids, and glucose) is less clear, although improvements have also been documented in those domains (Ciampolini et al., 2010a; 2010b; Clifford et al., 2015; Goode et al., 2018; Greene et al., 2012; Lohse et al., 2012; Miller et al., 2012; Psota et al., 2007; Schaefer & Magnuson, 2014; Smith & Hawks, 2006; van Dyke & Drinkwater, 2014).

Although we are still far from making firm conclusions about the effects of this eating style, this body of evidence suggests that it can have beneficial effects. Internally regulated eating style has received considerable attention in the literature but in a highly fragmented manner, as many research groups have tried to conceptualise this eating style from their own theoretical lenses. Concepts such as intuitive eating, eating competence, mindful eating etc. have emerged in the literature and practice, which all refer to eating styles that are driven by internal hunger and satiation cues. For example, Tribole and Resch (2012) originally defined intuitive eating as the type of eating that is based on physiological cues of hunger and satiety rather than on emotional or external cues. They positioned intuitive eating as an eating style with a strong anti-diet mentality, connection with and responsiveness to internal signals of hunger, fullness, and food selection, relaxed relationship with food, non-responsiveness to emotional hunger, body appreciation, and appreciation of the food's sensory qualities. Tylka and colleagues (Tylka, 2006; Tylka & Kroon van Diest, 2013) brought the concept of intuitive eating forward by describing and measuring some key elements: unconditional permission to eat, eating for physical rather than emotional reasons, reliance on internal hunger and satiety cues, and body-food choice congruence (the extent to which individuals match their food choices with their bodies' needs).

Eating competence also falls within the boundaries of internally regulated eating. Eating competence is defined as being 'positive, comfortable, and flexible with eating and matter-of-fact and reliable about getting enough to eat of enjoyable and nourishing food' (Satter, 2007). Individuals who score high on the eating competence self-report measure are those who have positive attitudes about food and eating, experiment with new food and learn to accept it, respond to internal signals of hunger and satiety, and have good meal planning skills. Eating competence is built on two main pillars: permission (choosing and eating food that is liked in adequate amounts to satisfy hunger) and discipline (eating family-style meals at predictable times). Thus, it differs from intuitive eating in that it focuses more on responsiveness to satiation signals for meal termination and to a lesser extent on responsiveness to hunger signals for meal initiation. In fact, those who practice eating competence learn to tolerate hunger at reasonable levels to adhere to the social structure of meals and snacks.

A third prominent and increasingly studied concept related to internal regulation of eating is mindful eating. Mindful eating is based on the application of mindfulness techniques to regulate eating. The conceptual foundation for mindful eating was provided by a group of researchers who developed a treatment for binge eating disorder; the Mindful-Based Eating Awareness Training (Kristeller et al., 2006; Kristeller & Hallett, 1999). Based on this conceptualisation, cultivation of mindful eating incorporates bringing attention to the eating experience in a non-judgmental manner, savouring the food and appreciating its sensory qualities, being aware of hunger and satiety sensations, and making food choices based on both liking and health (Kristeller & Wolever, 2010).

Finally, several intervention programmes promote internally regulated eating but do not fall under the three main research streams mentioned above. For example, the Appetite Awareness Training (Allen & Craighead, 1999) aims to re-establish and enhance sensitivity and responsiveness to internal signals of hunger and satiety and to overcome self-perpetuating maladaptive cycles of overeating that result from dietary restraint, emotional, and other situational cues. An extension of this programme also involves the reduction of reactivity to food cues that predict food intake (Boutelle et al., 2017). There is also a sensory-based nutrition intervention that, next to promoting eating in response to internal hunger and satiety cues, aims to build a non-restrictive relationship with food and to amplify, with sensory education, the pleasure that is associated with eating (Gravel et al., 2014).

As can be seen, the concept of internally regulated eating has gone into many directions and described by different terminologies, while limited efforts have been made to see this literature from a panoramic perspective (Kerin et al., 2019; Winkens et al., 2018). Therefore, it is still not clear which are the key characteristics that enable individuals to stick to this internal, body-based eating style. While each of the previous attempts to understand the internally regulated eating style has shed light only on parts of the total picture, analysing them together at a more integrated level would do more justice to the full complexity of the concept.

In this paper, we synthesise the full breadth of characteristics that are necessary for the internally regulated eating style, we provide definitions for these characteristics, and we specify hypotheses about how they relate to each other and how they contribute to this eating style. We focus on individual-difference characteristics that form a general tendency (eating style) and not on particular behaviours that manifest as a result of this tendency. This is important because eating behaviours vary substantially depending on situational factors, while the dominant eating style of individuals is more stable over time and predictive of the broader pattern of someone's eating behaviour (Ajzen, 1987). Thus, we position internally regulated eating style as a general tendency that is underpinned by five individual-difference characteristics; namely sensitivity to physiological signals of hunger and satiation, self-efficacy in using physiological signals of hunger and satiation to determine when and how much to eat, trust on the body's physiological processes for the regulation of eating, and the tendencies towards food legalising and food enjoyment. We believe it is necessary to understand the trait-like characteristics that work as preconditions for the internally regulated eating style and the mechanisms by which these characteristics support individuals in maintaining this eating style.

In achieving the aims above we make the following scientific contributions: first, we contribute to the integration of a rather fragmented literature; second, we introduce a common language to the field by providing definitions for the full breadth of characteristics that define the internally regulated eating style; and third, we build a theoretical framework that does justice not only to the full spectrum of characteristics of the internally regulated eating style but also to the associations between them. This is important because concepts in this domain have not always been properly defined and limited efforts have been made to hypothesise and justify the potential associations between them. This work highlights the characteristics that individuals should maintain or improve to be able to adhere to this eating style, and at the same time the areas that should be addressed by health professionals in order to promote this eating style among their clients. The theoretical framework presented here can be used to develop comprehensive measures of internally regulated eating style and to design lifestyle interventions for the promotion of physical and psychological health.

2.2. What is internally regulated eating?

Hormonal, neural, and mechanical signals that are coordinated through the brain are translated into subjective sensations of hunger and satiation that signal when to start and stop eating. Hunger and satiation become noticeable with visceral sensations in the abdominal area (e.g., hollow sensation, growling sounds, gastric contractions, gastric distension) but also with more generalised physical (e.g., fatigue, weakness, discomfort), affective (e.g., desire to eat, decline in pleasantness or reward value of the food), and cognitive changes (e.g., lack of concentration, thoughts about food, lack of interest in food) (Murray & Vickers, 2009). These components can act synergistically to form an integrated feeling of hunger or satiation, respectively, but they can also influence our behaviour on their own. For example, patients whose stomach has been removed still report feeling hungry or full despite the lack of visceral cues (Kamiji et al., 2009). Similarly, individuals may experience visceral symptoms of hunger without a desire to eat at that specific moment due to stress, negative emotions, or because they are busy (Murray & Vickers, 2009).

Visceral and broader physical (bodily) sensations of hunger and satiation are particularly relevant for internally regulated eating. Individuals who regulate their eating internally determine when and how much they eat based on sensations of this kind, that is, they initiate eating when they experience moderate bodily signs of hunger and cease eating upon experience of moderate bodily signs of satiation (Carrier et al., 1994; Carroll et al., 2007; Craighead & Allen, 1995; Hawley et al., 2008; Higgins & Gray, 1998; Omichinski & Harrison, 1995; Tanco et al., 1998; Tribole & Resch, 2012). This narrower control of eating prevents individuals from experiencing extreme states of hunger and fullness. Affective or cognitive signals can of course co-occur with physical ones when initiating or ending a meal; however, responding to the former in the absence of the latter is not compatible with internally regulated eating. It can be argued that sometimes it is difficult to distinguish physical from affective or cognitive signals. For example, palatable foods can impact appetite control and increase the sensation of hunger (Erlanson-Albertsson, 2005). However, it is important to consider that hunger is commonly measured with self-reports that capture a rather integrated feeling of hunger (e.g., how hungry do you feel at the moment?) (Blundell et al., 2010) rather than its physical component per se. Therefore, it remains a possibility that physical hunger is distinguishable from non-physical forms of hunger if it is explicitly evaluated. In the rest of the paper, we use the terms *internal* or *physiological cues/signals* to refer to the physical component (bodily sensations) of hunger and satiation.

2.3. Which are the key components of the internally regulated eating style?

The ability to sense/perceive and interpret the signals that the body generates in response to hunger and satiation is a central characteristic of the internally regulated eating style. Existing conceptualisations of internally regulated eating refer to this as 'the ability to clearly recognize the physical signs of hunger, satisfaction, and fullness' (Hawks et al., 2004), 'differentiation of physiological (stomach) hunger and psychological (mouth) hunger signals' (Higgins & Gray, 1998), 'sensitivity to hunger and satiety cues' (Boutelle et al., 2017), or 'bringing awareness to sensations of physical hunger and different types of satiety (stomach fullness and sensory-specific satiety)' (Kristeller & Wolever, 2010). We use the term sensitivity to physiological signals of hunger and satiation to refer to this competence.

In turn, individuals also need to be able to use physiological signals of hunger and satiation to decide when and how much to eat. We use the term self-efficacy in using physiological signals of hunger and satiation to refer to the perception of ease (or difficulty) in using internal signals of hunger and satiation to decide when and how much to eat. While previous research has focused heavily on the concept of responsiveness to internal signals of hunger and satiation, which is a behavioural characteristic (e.g., ‘responding to the internal regulators of hunger, appetite, and fullness’ (Satter, 2007), ‘heightened responsitivity to internal cues, both hunger and satiety’ (Craighead & Allen, 1995), ‘readiness to eat in response to internal physiological hunger signals’ (Tylka, 2006)), we position self-efficacy as the individual-difference characteristic that is determinative for responsiveness.

Furthermore, individuals also need to have a sense of trust that the body can manage the regulation of eating itself without the need for external or cognitive control. This attitude supports individuals in resorting their eating decisions to their internal feedback. We use the term internal trust to refer to this attitude, which is in line with previous references to this characteristic (e.g., ‘trust these signals to guide their eating behaviour’ (Tylka, 2006), ‘trust in their internal hunger and satiety cues and reliance on these cues to guide their eating behavior’ (Tylka & Kroon van Diest, 2013), ‘relaxed self-trust about managing food and eating’ (Satter, 2007), ‘self-reliance in the development of a nondieting lifestyle’ (Omichinski & Harrison, 1995), ‘rely on signals of hunger and satiety from their own bodies’ (Tanco et al., 1998)).[1]

Another important feature of the internally regulated eating style is to have a relaxed relationship with food and particularly a relaxed attitude towards indulgent food. We use the term food legalising to refer to this attitude, a term that has also been used by other authors in the field (e.g. ‘“legalising” of all foods’ (Higgins & Gray, 1998), ‘all food is legalized’ (Omichinski & Harrison, 1995)). Food legalising has been conceptualised in various ways in previous research. For example, some refer to it as ‘there are no taboo foods or restrictions on eating’ (Hawks et al., 2004), ‘refusal to label certain foods as forbidden’ (Tylka, 2006), or ‘be “given permission” to eat previously forbidden foods’ (Tanco et al., 1998), while others use more general terms such as ‘being comfortable with food behaviors’ (Satter, 2007), or ‘spontaneity and the enjoyment of food without anxiety, guilt or concerns about compulsive or “out-of-control” eating’ (Higgins & Gray, 1998).

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[1] Self-efficacy and internal trust may look similar to each other; nevertheless, the two are conceptually distinct. Self-efficacy can be conceptualised as a competence (i.e., how easy it is for someone to use internal signals of hunger and satiation to decide when and how much to eat), while internal trust is an attitudinal characteristic (i.e., to what extent someone trusts his/her body to guide his/her eating).

The last characteristic that completes the profile of those who have the tendency to regulate their eating internally is the tendency to derive pleasure from eating by appreciating the sensory qualities of the food that is consumed. We use the term food enjoyment to refer to this characteristic, which has also been part of existing conceptualisations of internally regulated eating and has been referred to as 'savoring and enjoying food' (Kristeller & Wolever, 2010), 'being able to pay attention to food and self during the process of eating' (Satter, 2007), 'identification of tastes in a variety of foods' (Gravel et al., 2014), 'looking at the food, holding the food, smelling the food' (Boutelle et al., 2017). An overview of the key characteristics of the internally regulated eating style can be found in Table 2.1.

Overall, we argue that some individuals are more sensitive, self-efficient, confident, relaxed, and appreciative compared with others, but the intensity of these features can also vary within individuals depending on life changes and special circumstances. In the following sections, we discuss existing evidence on these characteristics, we explain why all are necessary conditions for the internally regulated eating style, and we theorise about how they relate to each other and how they contribute to internally regulated eating style, providing supportive evidence when available.

2.3.1. Sensitivity to physiological signals of hunger and satiation

Individuals differ substantially in the sensations they experience when they are fed or fasted. While most people report gastric sensations before and after meals, some fail to do so (Friedman et al., 1999; Hams & Wardle, 1987; Monello & Mayer, 1967). Individual differences are also observed in the ability to detect visceral sensations associated with hunger and satiation, in how pleasant/unpleasant people find such sensations, and in how they respond to changes in their visceral states. For example, Whitehead and Drescher measured sensitivity to stomach contractions in twenty healthy individuals and found that half of them displayed perceptual accuracy significantly better than chance (Whitehead & Drescher, 1980). Besides, individuals who reported feeling both abdominal tension and abdominal sounds performed better in the visceral perception task compared with those who reported only one or none of these symptoms. Sepple and Read (1989) found that seven out of ten healthy males had <20% of a standardised meal in their stomach when self-reported hunger started to increase, while the rest started feeling hungry with fuller stomachs. This indicates between-individual variability in the hunger threshold. Similarly, Stephan et al. (2003) showed that healthy, normal-weight individuals whose stomach was distended with a water-inflated gastric balloon reached the same subjective sensation of fullness with volumes ranging between 300 and 1175ml. Comparable variability was reported by van Dyck et al. (2016) who employed a water load task, instead of the classic barostat procedures, to assess the satiation threshold of individuals. Thus, some individuals are able to perceive subtle changes in their internal states of hunger and satiation faster than individuals who are less perceptive of their inner experiences.

Table 2.1. Key individual-difference characteristics of internally regulated eating style

Sensitivity to physiological signals of hunger and satiation
The ability to sense/perceive and interpret the signals that the body generates in response to hunger and satiation
Self-efficacy in using physiological signals of hunger and satiation
The perception of ease (or difficulty) in using internal signals of hunger and satiation to decide when and how much to eat
Internal trust
The tendency to trust that the body can manage the regulation of eating itself without the need for external or cognitive control
Food legalising
The relaxed relationship with food and particularly the relaxed attitude towards indulgent food
Food enjoyment
The tendency to derive pleasure from eating by appreciating the sensory qualities of the food that is consumed

Some scholars have expressed the view that increasing awareness of internal cues of hunger and satiation may pose a challenge to food intake regulation and lead to overconsumption because individuals may be unable to distinguish between homeostatic (i.e., related to energy depletion) and hedonic (i.e., related to food cues) drivers of eating (Martin et al., 2017). This is supported by evidence showing that the homeostatic system of energy regulation can be easily overridden by hedonic cues in the food and eating environment (Lee & Dixon, 2017). Nevertheless, there is an increasing body of evidence from experimental and intervention studies that indicates that increased attention to internal bodily sensations while eating leads to reduced consumption of snacks (Jordan et al., 2014; Marchiori & Papies, 2014) and better compensation for previous consumption (van de Veer et al., 2016). Ciampolini and colleagues have shown that training individuals to link their subjective feeling of hunger to an objective marker (blood glucose levels), with the purpose of re-learning to identify physical hunger and responding to it, leads to positive outcomes (e.g., reduced premeal blood glucose, insulin sensitivity, blood glucose peaks, energy intake, and body weight) (Ciampolini & Bianchi, 2006; Ciampolini et al., 2010a; 2010b). Furthermore, obese individuals and those with eating disorders (e.g., bulimia, binge eating disorder) show a reduced ability to detect hunger and satiation signals as indicated by the fact that their hunger and fullness ratings are not consistent with changes in the size of preloads they consume in laboratory experiments (Craighead & Allen, 1995; Hadigan et al., 1992; Sysko et al., 2007). Results from neuroimaging studies also show a negative association between BMI and brain activity relevant for perception of mechanical distention in the stomach, suggesting that obesity associates with insensitivity to satiation signals (Wang et al., 2008). Evidence from the interoception literature further confirms that obesity and eating disorders are characterised by significant interoceptive deficits (Herbert & Pollatos, 2014; Jenkinson et al., 2018; Klabunde et al., 2017). Taken together, the above evidence suggests that sensitivity to internal hunger and satiation signals, which can be seen as a domain-specific type of interoception (i.e., the ability to perceive/sense changes in the internal state of the body), is an adaptive competence that associates with improved health outcomes.

2.3.2. Self-efficacy in using physiological signals of hunger and satiation

According to the theory of planned behaviour, self-efficacy (i.e., perceived behavioural control) is an important determinant of intention to perform a behaviour and of behaviour per se (Ajzen, 1991). Self-efficacy in the eating domain has mainly been studied from the perspective of perceived competence with losing weight or sticking to dieting goals (Clark et al., 1991; Glynn & Ruderman, 1986), and several studies have confirmed that eating self-efficacy is a reliable predictor of weight loss behaviour (National Institutes of Health, 1998). To our knowledge, self-efficacy in using internal signals of hunger and satiation has not been studied in the existing literature. Extrapolating the above evidence, we suggest that if individuals find it is easy to rely on their internal signals to self-regulate their eating, they are more likely to do so. Some preliminary evidence suggests that higher eating self-efficacy is associated with higher scores on intuitive eating (Young, 2010), and self-efficacy has been found to be a predictor of non-dieting behaviour (Leske et al., 2017). Furthermore, we expect that there are individual differences in how easy it is for people to start eating only when feeling physically hungry and to stop eating when feeling comfortably satiated. The individual differences that have been documented for behavioural tendencies such as disinhibited eating (Stunkard & Messick, 1985) or eating in the absence of hunger (Tanofsky-Kraff et al., 2008) suggest that some people tend to chronically override their hunger and satiation signals, while others manage not to do so.

Several pieces of evidence indicate that coupling eating with internal signals of hunger and satiation has positive effects on food intake regulation and weight outcomes. Individuals who said their habitual eating was not related to hunger or fullness sensations scored higher on disinhibited eating and showed lower meal-induced changes in hunger/fullness sensations after consumption of fixed meals in the laboratory compared with individuals whose eating was habitually related to hunger and fullness sensations (Barkeling et al., 2007). Similar evidence has been documented for children. In a laboratory study with pre-schoolers, it was found that only children who were prompted to eat based on internal cues of hunger and satiety managed to respond to the energy density cues of preloads and to compensate for prior intake, while children who were prompted to eat according to schedule and to clean their plates to receive rewards did not show evidence of energy compensation (Birch et al., 1987). Finally, the literature on appetitive traits that associate with weight has identified satiety responsiveness as a food avoidance appetitive trait, which associates inversely with energy intake and BMI (Carnell & Wardle, 2007).

2.3.3. Internal trust

To regulate eating internally, individuals need to have a sense of trust on the body's physiological processes for eating regulation. This trust should underlie both decisions about starting eating (i.e., trusting that the body has physiological processes to self-regulate the initiation of eating to avoid the aversive state of hunger) and stopping eating (i.e., trusting that the body has physiological processes to self-regulate the cessation of eating to avoid the aversive state of fullness). We call this tendency *internal trust* because the individual has to shift the focus internally and trust that the body can manage the regulation of eating itself, without the need for cognitive or external rules.[2]

Individuals who reported trusting their bodies to tell them how much to eat were less likely to engage in unhealthy and extreme weight control behaviours (e.g., skipping meals, inducing vomiting) as measured with self-reports in a cross-sectional study with 2287 adults (Denny et al., 2013). Furthermore, reliance on internal cues to drive eating associates negatively with eating disorder symptomatology, body shame, poor interoceptive awareness, and BMI, while positive associations have been documented with measures of psychological health such as satisfaction with life, self-esteem, optimism, and body appreciation (Madden et al., 2012; Tylka, 2006; Tylka & Kroon van Diest, 2013). More general, body trust, an important dimension of interoceptive awareness, associates positively with measures of body awareness and negatively with measures of anxiety, body dissociation, and difficulties with emotional regulation (Mehling et al., 2012). Taken together, these results provide support for the adaptive nature of a self-trusting attitude not only in the domain of eating but also in more general terms.

2.3.4. Food legalising

Due to our innate preference for sweet and energy-dense foods that is evolutionary advantageous in periods of food scarcity, it is difficult for many individuals to resist highly palatable foods that are easily encountered in modern societies (Lowe, 2003). In fact, the heightened responsiveness to hedonic cues is recognised as an important contributing factor to obesity (Lowe & Butryn, 2007). Consequently, several scholars and health practitioners promote the idea of cognitive self-control as a means of managing cravings for palatable food and maintaining a balanced and healthy diet. For example, it has been found that focusing on the long-term health outcomes of unhealthy eating associates with inhibition of reward activity in the brain (Hare et al., 2011). Cognitive self-control is effective for some individuals (Wing & Hill, 2001). Nevertheless, for other individuals, it is ineffective and may even have adverse

[2] In some cases, using cognitive or external control over eating may be an attempt to compensate for pre-existing deficits in perception of hunger and satiation (Klabunde et al., 2017). In these cases, external or cognitive control may help individuals to regulate their eating.

effects. For example, it has been shown that the attempt to stick to restrictive intake norms (i.e., imposed rules governing eating behaviour) can have a counter-regulatory effect by ultimately leading to overconsumption (Birch et al., 2003; Herman & Polivy, 2007; Woody et al., 1981). This effect – also called Abstinence Violation Effect (Curry et al., 1987) – has been documented in studies with restrained eaters (Herman & Mack, 1975; Woody et al., 1981) and is attributed to the feeling that the diet has been violated due to either the energy content of the food that breaks the diet or to the mere consumption of a forbidden food. However, similar effects have been observed also among other population groups. Mann and Ward (2001) have shown that prohibiting the consumption of a food, making it look like a “forbidden fruit”, leads to stronger desires for that food among college students. Similarly, Raynor and Epstein (2003) found that short-term food deprivation increases the reinforcing value of food among non-restrained female adults. This response pattern can be explained not only by the reactance theory, which suggests that individuals react negatively (i.e., they desire the forbidden fruit) when they feel their freedom is constrained in some way (Brehm, 1966), but also by the commodity theory, which poses that decreasing the availability of a stimulus increases its perceived value (Brock, 1968).

To prevent individuals from exerting maladaptive coping strategies as a means of compensating for indulgent consumption, internally regulated eating paradigms take to a small or larger extent a libertarian stand to food. All foods, healthy or unhealthy, are allowed and there are no taboo foods to be avoided. In addition, indulgent consumption is treated as an overwhelming experience filled with satisfaction rather than as a regretful situation followed by guilt (Tribole & Resch, 2012). This relaxed attitude is assumed to represent a more balanced and healthy relationship with food and eating. An unrestrained relationship with food may seem counterintuitive, considering that palatable foods activate the reward system and prolong consumption through a delay in the experience of satiety (Erlanson-Albertsson, 2005). However, there is evidence that this *dédiabolisation* of unhealthy or indulgent food may gradually lead to habituation with these foods, that is, a decrease in behavioural and physiological responses after repeated exposure to the same food (Epstein et al., 2009; 2011). Through this process, even palatable foods do not seem so exciting or tempting after a while because the individuals know that they can consume them any time they want (Tribole & Resch, 2012). Thus, legalising food may eventually lead to weaker desires for potentially tempting food. In this way, food legalising can fit within contemporary views of self-control, which posit that successful self-control may not always result from effortful inhibition of desires but can be rather attributed to effortless processes such as experiencing the temptation (e.g., to eat a palatable but unhealthy food) as less overwhelming or tempting in the first place (Gillebaart & de Ridder, 2015). For example, Hofmann et al. (2012) showed that individuals with high self-control reported weaker desires for temptations compared with individuals with low self-control.

Furthermore, it has been found that less relaxed attitudes about food and eating (e.g., eating-related guilt, preoccupation with food) and the coping behaviour that usually accompanies such attitudes (e.g., effortful monitoring of the diet) increase cognitive load and limit the amount of available cognitive resources (Green et al., 1997). This is important because disruptions in cognitive function (e.g., working memory capacity, attention) associate with problems with appetite control and weight gain (Gunstad et al., 2020; Higgs & Spetter, 2018). Instead, a carefree relationship with food, in which individuals are unencumbered by food preoccupations and avoidance efforts, could actually prevent individuals from wasting cognitive resources and assist them in using the available ones to attend and respond to their internal signals of hunger and satiation.

Interventions that have been supplemented with food legalising-like components have shown improvements in attitudes about food, responsiveness to food cues in the environment (i.e., external eating), eating disorder symptoms, self-control, depression, anxiety, body shape concerns, body image, spiritual well-being, food obsessions, flexibility and variety of food choices (Higgins & Gray, 1998; Richards et al., 2017; Tanco et al., 1998; Young, 2010). In addition, a correlational self-report study found that giving oneself an unconditional permission to eat whatever food one desires at any moment is associated not only with lower BMI, disordered eating, body shame, and body surveillance, but also with higher self-esteem and body appreciation (Tylka & Kroon van Diest, 2013). Finally, in the study of Kuijer and Boyce (2014), it was found that participants who associated chocolate cake with celebration (compared with those who associated it with guilt) reported higher perceived behavioural control over eating and were more successful in maintaining their weight over a period of 18 months. Thus, taking a flexible approach to eating may prove to be an important determinant of healthy eating (Swan et al., 2018).

2.3.5. Food enjoyment

Today's modern societies are characterised by busy lifestyles whereby eating may go unnoticed several times during the day. Under such circumstances, people may frequently eat quickly or distractedly and therefore not fully appreciate the sensory qualities of the food and the pleasure that accompanies the eating occasion. In more extreme instances, people who struggle with eating-related problems (e.g., anorexia) may even view food as an enemy rather than as a source of pleasure. Internally regulated eating paradigms embrace the idea of food enjoyment, as they emphasise the importance of pleasure and satisfaction in eating that can be achieved by savouring the food while attending to and appreciating its sensory qualities (Gravel et al., 2014; Kristeller & Wolever, 2010; Omichinski & Harrison, 1995; Satter, 2007; Tribole & Resch, 2012).

Mindfulness-based experiments and interventions that use strategies such as present moment awareness targeted at the sensory qualities of food being consumed have reported positive consequences on food intake, cravings for highly palatable foods, eating behaviour (e.g., emotional and external eating), and psychological variables such as body appreciation (Arch et al., 2016; Bush et al., 2014; Higgs & Donohoe, 2011; Mason et al., 2016; Robinson et al., 2014; Schnepper et al., 2019). For example, in a series of experiments, Arch and colleagues showed that tuning in to the sensory experience leads to higher enjoyment and lower energy intake of unhealthy foods (Arch et al., 2016). In contrast, eating under distraction (e.g., while watching television) consistently leads to higher energy intake in the same but also in subsequent meals (Robinson et al., 2014). Furthermore, self-reported eating with awareness has been associated with lower BMI (Framson et al., 2009). Various mechanisms have been proposed to explain the effects of focused attention to the food while eating on food intake, including the enhanced impression of the eating episode in episodic memory, the reduction in eating automaticity, or the prioritisation of sensory-specific satiation (i.e., decline in pleasure we obtain from eating a particular food as we eat) over physical satiation (Tapper, 2017). The focus on sensory stimulation as a means of deriving pleasure from eating seems to be crucial for the positive effects mentioned above, since food enjoyment independent of sensory amplification, as captured, for example, by the enjoyment of food subscale of the Adult Eating Behaviour Questionnaire, is identified as a food-approach trait that associates positively with energy intake (Carnell & Wardle, 2007).

2.4. A theoretical framework of internally regulated eating style

When individuals lack either sensitivity to or self-efficacy in using internal signals of hunger and satiation, they cannot engage in internally regulated eating. These are core competences that are needed for the internally regulated eating style. Sensitivity is a prerequisite for self-efficacy. Sensitivity and self-efficacy are, nevertheless, distinct competences because there may be other factors that prevent highly sensitive individuals from using their bodily sensations to self-regulate their eating (e.g., time constraints, unavailability of food, limited trust on the effectiveness of these signals). In turn, self-efficacy may impact sensitivity through reciprocal interaction and feedback. For instance, a person who finds it easy to use internal signals of hunger and satiation to determine when and how much to eat may routinely engage in such behaviour and this may aid the connection with the inner experience and improve sensitivity to internal, bodily signals (Bacon et al., 2005; Bégin et al., 2019; Bush et al., 2014; Cole & Horacek, 2010; Gravel et al., 2014; Stunkard & Fox, 1971).

Internal trust is another prerequisite for the internally regulated eating style because it directs attention to the body and its internal processes. If individuals do not trust their bodies' self-regulatory abilities for eating, they may be inclined to draw their attention towards outside of the body and resort to cognitive or external rules to guide their eating behaviour. The lack of internal trust may further impact sensitivity and self-efficacy. In support to this, it has been found that body trust, a more generalised version of trust, associates negatively with body dissociation and positively with attention regulation (i.e., the ability to sustain and control attention to body sensations) (Mehling et al., 2012). Thus, lacking internal trust may be accompanied by the feeling of being dissociated from the body and the signals it produces, while heightened internal trust may shift attention towards inside the body and make individuals more attentive to changes in their internal states. The perceptual accuracy hypothesis of the self-awareness theory, which posits that self-focused attention increases the capacity to perceive bodily signals, further supports our assertion (Gibbons et al., 1979). In turn, sensitivity and self-efficacy may gradually increase internal trust through positive learning mechanisms. Finally, internal trust may even have a moderating role between sensitivity and self-efficacy because the lack of internal trust could act as a barrier to responding to internal signals that an individual accurately perceives.

Food legalising is another necessary condition for the internally regulated eating style. In the absence of a relaxed attitude towards indulgent food, individuals may be inclined to impose cognitive or external control on their eating as a means of avoiding indulgent consumption or in order to compensate for it. Thus, a different eating style would emerge (e.g., restrained eating). As we discussed previously, food legalising provides a permissive environment for the effective perception and responsiveness to internal signals of hunger and satiation by saving cognitive resources that could be wasted otherwise (e.g., when having a cognitively controlled strategy to eating). In this way, food legalising supports sensitivity to and self-efficacy in using internal signals of hunger and satiation.

Finally, we suggest that food enjoyment aids individuals to stay in tune with the eating experience and the accompanied sensations, leading, thus, to a more precise regulation according to internal signals. It has been shown that sensory characteristics of the food (e.g., thickness, creaminess) interact with the food's energy content in determining its satiating capacity (Yeomans, 2015). This is because sensory cues create expectations about the satiating capacity of the food, which prepare the appetite system for the ingested nutrients, and when such expectations are confirmed by internal feedback, there is an increase in the efficiency of nutrient processing (Yeomans & Chambers, 2011). This highlights the inter-connectedness of the sensory experience while eating with the ingestive processes that take place in the body and corroborates our argument for the important role of food enjoyment in the internally regulated eating style.

To wrap up, a set of five individual-difference characteristics work as necessary and only jointly sufficient conditions for the internally regulated eating style. We hereby propose the following inclusive definition of internally regulated eating style, which builds on earlier definitions of related constructs (Tribole & Resch, 2012; Tylka, 2006). **Internally regulated eating style is the general tendency to eat in response to physiological signals of hunger and satiation, which is underpinned by a specific set of individual-difference characteristics; namely, sensitivity to physiological signals of hunger and satiation, self-efficacy in using physiological signals of hunger and satiation to determine when and how much to eat, trust on the body's physiological processes for the regulation of eating, and the tendencies towards food legalising and food enjoyment (Fig. 2.1.)**.

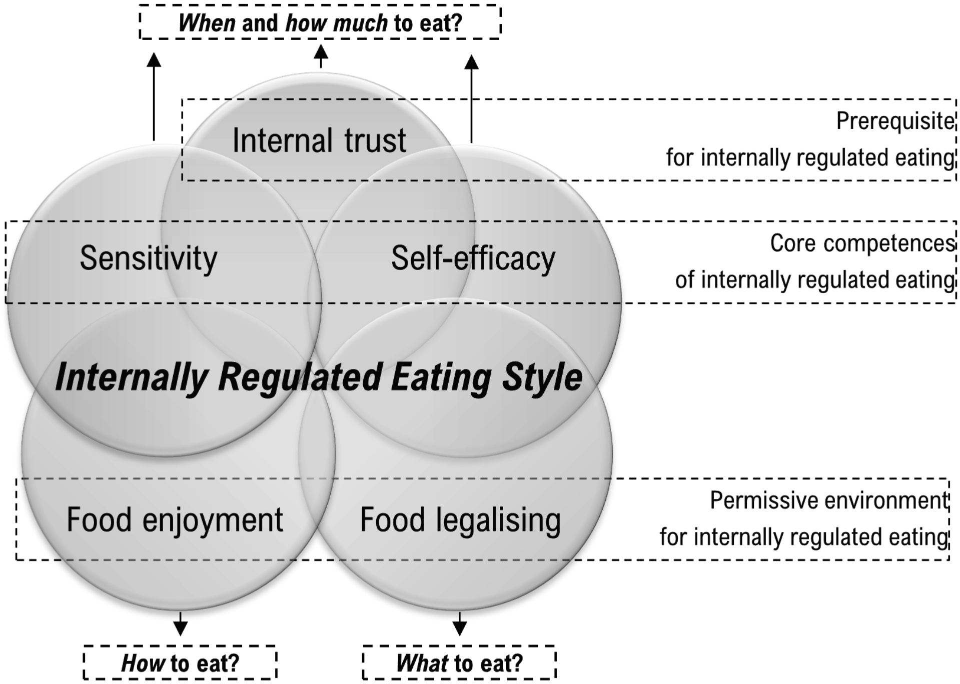


Fig. 2.1. Theoretical framework of internally regulated eating style. Five individual-difference characteristics comprise the internally regulated eating style. Sensitivity to physiological signals of hunger and satiation and self-efficacy in using physiological signals of hunger and satiation are core competences of internally regulated eating, food legalising and food enjoyment provide a permissive environment for listening and responding to internal signals of hunger and satiation, and internal trust is a prerequisite for engaging in this internal, body-based eating style.

The theoretical model presented above is particularly relevant for adults, although it is consistent with models that have been developed for children such as the trust model proposed by Satter (1986). The model is applicable for individuals who have at least some basic connection with their internal signals of hunger and satiation. Those with diminished ability to perceive such signals (e.g., individuals with eating disorders) should first be subjected to training to relearn and reconnect with their own bodily sensations. With respect to states of energy balance, the internally regulated eating style is particularly relevant for weight maintenance and prevention of further weight gain, although weight loss can also be achieved if individuals stabilise their eating behaviours at an energy intake level that is lower than their current energy needs (Clifford et al., 2015; Schaefer & Magnuson, 2014). Thus, internally regulated eating can facilitate the prevention and to a lesser extent the treatment of obesity. Nevertheless, the stabilisation of eating behaviours and particularly the reduction of maladaptive behaviours such as eating in the absence of hunger or disinhibited eating that can be achieved with internally regulated eating (Cloutier-Bergeron et al., 2019; Miller et al., 2014; Proffitt Leyva & Hill, 2018; Schaefer & Magnuson, 2014) are relevant not only for obese and overweight individuals but also for those with binge eating disorder who may have normal weights. Finally, the eating pattern that emerges with internally regulated eating, that is, frequent small meals, can also be helpful for individuals with specific medical conditions such as those with gastrointestinal disturbances or diabetes (Wheeler et al., 2016).

2.5. How does internally regulated eating fit within existing theories of self-regulation and eating behaviour?

Dual-system theories that make a distinction between a rational system that requires effortful deliberation and an intuitive system that operates automatically and effortlessly have been used extensively to understand eating behaviour and self-regulation failure (Ainslie, 1975; Hofmann et al., 2009; Loewenstein, 1996; Metcalfe & Mischel, 1999). These theories take the general stance that effective regulation of eating can be achieved when individuals manage to resist short-term impulses (e.g., not eating the cake) for the sake of their long-term health goals (e.g., weight loss). Thus, they promote top-down strategies for the regulation of eating behaviour with an emphasis on cognitive control. According to these models, visceral urges (e.g., hunger, pain, or pleasure) are disruptive influences for self-regulation (Yang et al., 2012).

On the other hand, emerging theories of self-regulation, such as the theory of embodied cognition, propose that all cognitive processes are fundamentally grounded in their physical context and that bodily states play an important role in cognition and decision-making (Petit et al., 2016). This theory supports the notion of embodied self-regulation, namely that bodily states facilitate (instead of inhibit) self-regulation and that people should take them into account to help them achieve their long-term goals. Likewise, contemporary models of appetite control suggest that the distinction between a hedonic and a homeostatic system of energy regulation should be abandoned and that we should focus on the inter-connectedness of metabolic, reward, and cognitive processes that impact appetite regulation and food intake (de Araujo et al., 2020; Higgs et al., 2017). These models underline the important role that metabolic signals have on appetite control, either via their effects on cognitive processes such as memory, attention, and learning (Higgs et al., 2017), or via neural processes that take place at an unconscious level (de Araujo et al., 2020). This stream of literature sets the scene for better understanding internally regulated eating. Our hypothesised mechanisms, by which the characteristics of the internally regulated eating style facilitate cognitive processes that are important for the effective regulation of food intake (internal trust increasing attention to the body and its signals, food legalising preventing cognitive resources from being wasted, food enjoyment increasing episodic memory of meals), are in line with these models.

More specifically, we use the boundary model of eating, introduced by Herman and Polivy (1983), to describe how internally regulated eating leads to effective regulation of food intake. The boundary model suggests that food intake is regulated within two boundaries: one that corresponds to hunger and one to satiety[3]. Biological pressures drive individuals to eat in order to keep within these boundaries and prevent the aversive states of hunger and fullness. The area between the boundaries is called *zone of biological indifference*, and this is where appetitive pressures – that is, social, cognitive, and other psychological influences (food palatability, social pressures, etc.) – mainly determine food intake.

Various eating styles can be conceptualised using the boundary model of eating. For example, it has been suggested that restrained eating can force the hunger and satiety boundaries apart (wider zone of biological indifference) because the person eats in response to something other than the body's signals (e.g., self-imposed or externally imposed eating rules) and this makes the individual gradually less sensitive to such signals (Herman & Polivy,

[3] Herman and Polivy (1983) use the term satiety (i.e., the process that leads to the inhibition of eating between meals) in the original paper, although the term satiation (i.e., the process that leads to meal cessation) is more accurate because the satiety boundary is relevant for meal termination. In this paper, we use the original term as proposed by the authors, but we acknowledge the difference between the two processes. Furthermore, the boundary model illustrates hunger and fullness in the same continuum, which can be misinterpreted as hunger and fullness were different sides of the same process. While we want to keep with the original representation of the model, we want to clarify that we do not support this notion and we acknowledge that hunger and fullness are distinct processes, as indicated by existing literature (Blundell et al., 2010).

1983). In support to this, Koch and Pollatos (2014) have shown in a prospective study with children that a diminished ability to detect bodily sensations (i.e., interoceptive deficits) is an outcome of obesity and dysfunctional eating tendencies such as external eating. This means that individuals become insensitive to internal signals if they do not use them in structuring their eating behaviours. While the hunger and satiety boundaries are still relevant for restrained eaters, they are less relevant for patient groups such as those with anorexia nervosa or binge eating disorder, as the former tend to override the hunger boundary (when engaging in extreme fasting) and the latter override the satiety boundary (when engaging in disinhibited eating). Similarly, when eating in the absence of hunger (i.e., a form of disinhibited eating), individuals override the hunger or satiety boundary (or both) as they tend to initiate eating while being in the zone of biological indifference or continue eating despite being in the aversive state of fullness (Tanofsky-Kraff et al., 2008). Emotional eating and external eating have a similar pattern because individuals initiate eating or overeat in response to emotional and environmental cues either in the presence or absence of hunger (van Strien et al., 1986). Thus, there are several eating styles that violate either one or both the hunger and satiety boundaries.

In turn, we propose that internally regulated eating brings the hunger and satiety boundaries closer together (Fig. 2.2.) because individuals who have this as their dominant eating style are inclined to initiate eating in response to early, moderate signals of hunger (the hunger boundary is displaced to the right) and to terminate meals in response to early, moderate signals of satiation (the satiety boundary is displaced to the left). In the same way that individuals lose touch with their bodily signals when they consistently ignore or override them (Koch & Pollatos, 2014), connection with those signals can become stronger if individuals consistently pay attention and respond to them (Bacon et al., 2005; Bégin et al., 2019; Bush et al., 2014; Cole & Horacek, 2010; Gravel et al., 2014; Stunkard & Fox, 1971). Importantly, responding to moderate and not extreme internal signals is a critical element for the effective regulation of food intake. For example, with respect to hunger, it has been found that the longer the fasting the greater the activation of reward valuation of palatable food in the brain (Stice et al., 2013), which may lead to overconsumption (Berridge, 1996; Stice et al., 2011).

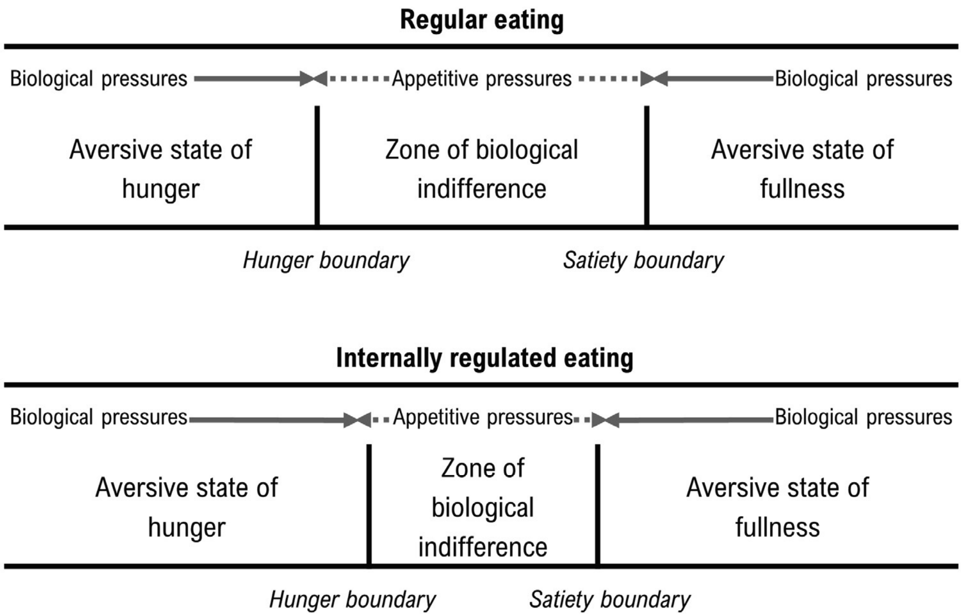


Fig. 2.2. The boundary model adjusted for internally regulated eating. Internally regulated eating brings the hunger and satiety boundaries closer together because the individual is more strongly inclined to initiate eating in response to early, moderate signals of hunger (the hunger boundary is displaced to the right) and to terminate meals in response to early, moderate signals of satiation (the satiety boundary is displaced to the left). This results in a narrower zone of biological indifference and, in turn, in a smaller latitude for appetitive pressures to exert their influences.

More specifically, we propose that the individual-difference characteristics we identified in this research enable individuals to maintain a narrow zone of biological indifference. Heightened sensitivity reduces the thresholds for perceiving hunger and satiation signals, which means that these can be perceived at early stages before their intensity increases. In addition, individuals with heightened self-efficacy should be able to initiate meals at early stages of hunger and terminate meals at early stages of satiation. Thus, sensitivity and self-efficacy work together in maintaining a narrow zone of biological indifference. Through attentional and other cognitive processes (discussed above), internal trust, food legalising, and food enjoyment further support the maintenance of a narrow biological indifference zone, through their effects on sensitivity and self-efficacy. In this narrower control of food intake, the biological pressures that keep consumption within the two boundaries are more prominent and determinative for food consumption, leaving thus, a smaller latitude for appetitive pressures to exert their influences. This is not to say that internally regulated eaters are not susceptible to the effects of emotional or environmental factors that impact eating behaviour and food intake (e.g., negative emotions, food temptations). Such factors are challenging for everyone. Instead, we take the position that despite occasional fluctuations, those individuals are generally less responsive to such cues (Clifford et al., 2015; Schaefer & Magnuson, 2014; Ulian et al., 2018; Warren et al., 2017). The five individual-difference characteristics they have (particularly food legalising) support them in getting back on track after deviations.

2.6. Discussion

Internally regulated eating is a concept that has been receiving increasing attention in the literature and health practice over the last decades, but in a highly fragmented way. In this paper, we identified and delineated the key individual-difference characteristics that form the internally regulated eating style, considering streams of literature that had not been sufficiently integrated that far. Next to providing definitions and available scientific evidence for each of these characteristics, we formulated hypotheses about their inter-relationships and about the mechanisms by which they contribute to this eating style. The theoretical framework presented in this paper suggests that the internally regulated eating style leads to a more precise tuning of food intake within the states of hunger and satiation by listening and responding to moderate hunger and satiation signals in a confident, relaxed, and enjoyable way. This superordinate conceptualisation of internally regulated eating style may be the starting point in finding the common ground between different streams of literature that share the main underlying concept and in facilitating the alliance of forces to promote a healthy and sustainable eating style.

In our model, a set of five individual-difference characteristics that support each other form the internally regulated eating style. Sensitivity to physiological signals of hunger and satiation is a prerequisite for self-efficacy in using such signals to determine when and how much to eat and these two competences associate positively with each other. Internal trust is also necessary because it directs attention towards inside the body and its processes, has a bi-directional relationship with sensitivity and self-efficacy and is further assumed to work as a moderator between them. Food legalising is another critical element as it provides a permissive environment for the effective perception and responsiveness to internal signals of hunger and satiation. Finally, food enjoyment completes the profile of the internally regulated eating style as it sets the scene for a more precise regulation according to internal signals. Thus, all five characteristics have their particular roles and are all necessary for the internally regulated eating style. This is a novel conceptualisation that adds to what is already known in the literature because it highlights the inter-connectedness of the internally regulated eating style characteristics.

Next to this main hypothesis regarding the inter-connectedness of the five characteristics, in this paper, we generated several hypotheses that can be tested with empirical research. For example, we hypothesised that food legalising prevents cognitive resources from being wasted and in this way provides a permissive environment that allows individuals to focus on their bodily sensations and use them in their eating-related decisions. To test this mechanism, researchers could conduct causal-chain experiments to examine how food legalising impacts the amount of available cognitive resources and, in turn, how the availability of cognitive resources impacts the perception and responsiveness to internal signals of hunger and satiation. In a similar way, it could be tested whether the effects of internal trust on perception and responsiveness to internal signals are mediated by attention processes.

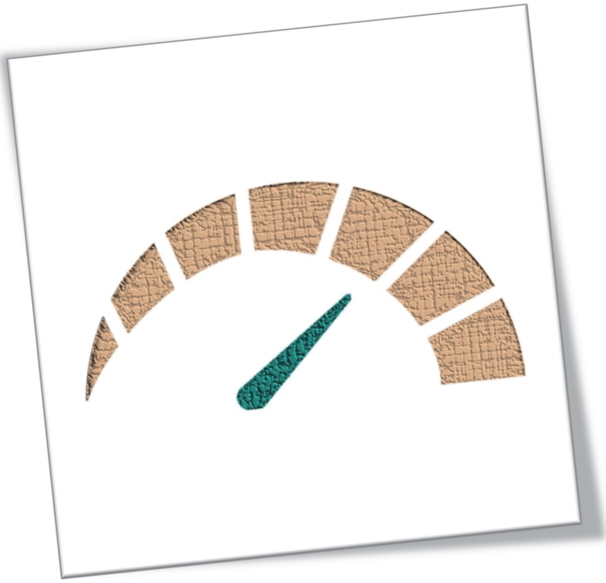
The novel conceptualisation of internally regulated eating style also opens new avenues for the measurement of this eating style. Currently, there is no adequate scaling instruments to assess the characteristics we have identified in this research. The development of measures to capture these characteristics would not only improve our understanding of the concept and its correlates but will also open the field for experimentation. The use of quick and inexpensive measures of individual-difference characteristics to identify and classify individuals may work as a starting point in the study of eating behaviour, followed by a more elaborate exploration of actual behaviour (which, in turn, is more variant and not always representative of the individual's dominant eating style). Once such instruments are available, researchers can use them to explore the interrelations between the characteristics of the internally regulated eating style and the extent to which they are predictive of health outcomes.

Finally, the main practical contribution of this paper is that it portrays the most important areas to intervene in order to promote the internally regulated eating style. Strategies like coupling subjective sensations of hunger and satiation with objective markers can be used to enhance sensitivity to and self-efficacy in using these signals to regulate food intake (Ciampolini & Bianchi, 2006; Ciampolini et al., 2010a; 2010b). This could be done in combination with strategies aimed at increasing the awareness and reducing the responsiveness to external or emotional cues of food intake (Boutelle et al., 2017; Provencher et al., 2007) since such cues can have an important influence on food intake. Strategies that cultivate independence and self-reliance can be used to enhance internal trust, food habituation strategies, like repeated exposure to indulgent food, can be used to reduce the hedonic responses to such foods and prevent counter-regulatory behaviours that usually follow their consumption (Epstein et al., 2011), and mindful eating strategies like present-moment awareness during eating can be used to cultivate food enjoyment (Kristeller & Wolever, 2010).

There is abundant room for further progress in understanding internally regulated eating. Potential pathways for future research could be to investigate the psychobiological factors that influence the development and maintenance of the internally regulated eating style, to explore moderating factors that facilitate or prevent individuals in/from engaging in internally regulated eating, and to fully elucidate the long-term consequences of internally regulated eating on physical, psychological, behavioural, and dietary outcomes. The current paper may provide a theoretical basis for future investigations on this topic.

Chapter 3

Development and Validation of the Multidimensional Internally Regulated Eating Scale (MIRES)



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Abstract

In this paper, we describe the systematic development and validation of the Multidimensional Internally Regulated Eating Scale (MIRES), a new self-report instrument that quantifies the individual-difference characteristics that together shape the inclination towards eating in response to internal bodily sensations of hunger and satiation (i.e., internally regulated eating style). MIRES is a 21-item scale consisting of seven subscales, which have high internal consistency and adequate to high two-week temporal stability. The MIRES model, as tested in community samples from the UK and US, had a very good fit to the data both at the level of individual subscales but also as a higher-order formative model. High and significant correlations with measures of intuitive eating and eating competence lent support to the convergent validity of MIRES, while its incremental validity in relation to these measures was also upheld. MIRES as a formative construct, as well as all individual subscales, correlated negatively with eating disorder symptomatology and weight-related measures (e.g., BMI, weight cycling) and positively with adaptive behavioural and psychological outcomes (e.g., proactive coping, body appreciation, life satisfaction), thereby, supporting the criterion validity of the scale. This endeavour has resulted in a reliable and valid instrument to be used for the thorough assessment of the features that synthesize the profile of those who tend to regulate their eating internally.

3.1 Introduction

Internally regulated eating (IRE), which can be broadly defined as eating in response to internal, bodily sensations of hunger and satiation, is considered an adaptive way of eating with positive effects on physical, psychological, behavioural, and dietary outcomes (Bruce & Ricciardelli, 2016; Clifford et al., 2015; Schaefer & Magnuson, 2014; Ulian et al., 2018; van Dyke & Drinkwater, 2014; Warren et al., 2017). IRE has been addressed from various specific theoretical perspectives including, but not limited to, those of intuitive eating (Tribole & Resch, 2012), eating competence (Satter, 2007), and mindful eating (Kristeller & Wolever, 2010). Palascha et al. (2020a) recently reviewed these various conceptualisations of IRE to conclude that none of them captures IRE style (i.e., the general inclination towards eating in response to internal/physiological signals of hunger and satiation) comprehensively. The authors conceptualised an integrated model with the key dimensions of IRE style and the relationships between them. The Palascha et al. model suggests that five individual-difference characteristics (detailed below) work as necessary and only jointly sufficient conditions for the manifestation of the IRE style.

Existing measures of IRE, such as the Intuitive Eating Scale 2 (IES-2) (Tylka & Kroon van Diest, 2013), the Eating Competence Satter Inventory 2 (ecSI-2) (Krall & Lohse, 2011), the Mindful Eating Questionnaire (MEQ) (Framson et al., 2009), and the Mindful Eating Scale (MES) (Hulbert-Williams et al., 2014) have made impactful contributions, but have failed to capture the full complexity of IRE and the inter-connectedness between the characteristics that define the IRE style. Therefore, there is a need for new measures to assess IRE to its full complexity and potential. The Multidimensional Internally Regulated Eating Scale (MIRES) is proposed to quantify the five individual-difference characteristics that collectively form the IRE style. The present paper reveals the systematic development and validation of the MIRES, a short and easily administered 21-item scale.

In this research we followed a stepwise, theory-based and empirically driven process to develop and validate the MIRES (Fig. 3.1.). Next to testing the scale's structure, internal consistency, measurement invariance, and temporal stability, we also examined its content, construct, discriminant, convergent, criterion, and incremental validity. In the next section, we present briefly the conceptual model of the key characteristics of the IRE style, followed by a description of the operationalisation of constructs into subscales. For a more complete overview of the conceptual model, including evidence on why each characteristic of IRE style is considered adaptive, see Palascha et al. (2020a).

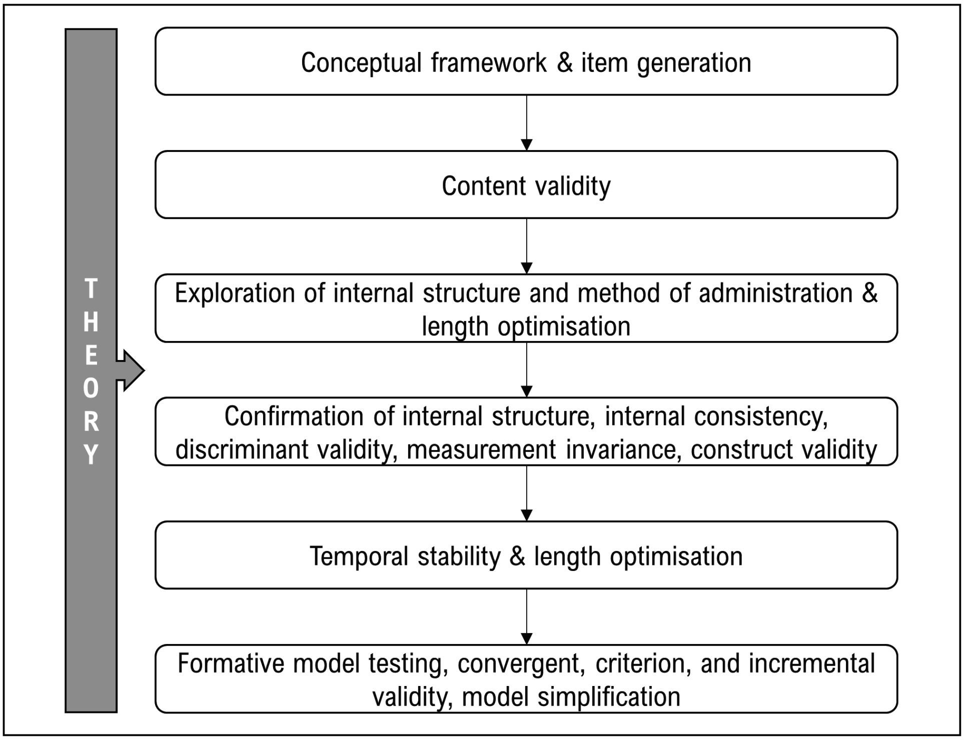


Fig. 3.1. Steps in the development and validation of MIRES

3.2. Conceptual definitions and operationalisation

Collectively the concept of IRE implies that individuals are sensitive to bodily signals of hunger and satiation, have self-efficacy in using those signals to determine when and how much to eat, trust these bodily signals to guide eating, and have a relaxed and enjoyable relationship with food and eating. *Sensitivity to physiological signals of hunger and satiation* (SH and SS, respectively) is defined as the ability to sense/perceive and interpret the physiological signals that the body generates in response to hunger and satiation. *Self-efficacy in using physiological signals of hunger and satiation* (SEH and SES, respectively) is defined as the perception of ease or difficulty in using physiological signals of hunger and satiation to decide when and how much to eat. *Internal Trust* (IT) refers to the tendency to trust the body's physiological processes for the regulation of eating. *Food Legalising* (FL) is defined as the tendency to have a relaxed relationship with food and particularly a relaxed attitude towards indulgent food. Finally, *Food Enjoyment* (FE) concerns the tendency to derive pleasure from eating by attending to and appreciating the sensory qualities of the food that is consumed.

IT, FL, and FE are operationalised as uni-dimensional constructs in our model (Appendix 3.1.). Since hunger and satiation are different processes, Sensitivity to hunger signals (SH) and Sensitivity to satiation signals (SS) are operationalised as distinct constructs. The same holds for Self-efficacy in using hunger signals (SEH) and Self-efficacy in using satiation signals (SES). Furthermore, sensitivity and self-efficacy may vary across challenging situations such as when emotional or external cues are salient (Herman & Polivy, 2007; Macht, 2008; Zlatevska et al., 2014). Therefore, we operationalised each of the constructs mentioned above along three dimensions: under 1. neutral conditions, i.e., when individuals are calm, relaxed, and without much distraction (SH: Neutral, SS: Neutral, SEH: Neutral, SES: Neutral), 2. under emotional prompts, i.e., when negative emotions are salient (SH: Emotional, SS: Emotional, SEH: Emotional, SES: Emotional), and 3. under external prompts, i.e., when external influences, such as a distracting environment, are salient (SH: External, SS: External, SEH: External, SES: External). Since individuals may respond differently to positive and negative emotions, we decided to narrow down to negative emotions. Additionally, high-arousal emotions are assumed to have a universal effect by suppressing eating, while there is more variability in how individuals respond to emotions of moderate arousal (Macht, 2008). Therefore, only moderate arousal emotional states were selected for the emotional context (i.e., sadness, loneliness, boredom). Regarding the external prompts context, there is a variety of external factors that influence our eating in different ways (e.g., portion sizes, mealtime schedules, eating with others, availability of tasty food, eating in a busy or distracting environment). Given this heterogeneity, we decided to select a single external cue, eating under distraction, because it regards a generic cue that is representative of the process by which several external cues influence eating behaviour (i.e., when "noise" from the external environment is salient) and is relevant for both hunger and satiation.

3.3. Model specification

Since the characteristics of the IRE style are not interchangeable—all of them are necessary for the IRE style to manifest—we treated the IRE style as a formative construct.

Formative constructs are formed by the combination of their indicators and causality is assumed to flow from the indicators to the construct (Diamantopoulos & Siguaw, 2006). Conversely, a reflective construct exists independently of the indicators that are used to measure it and causality flows from the construct to the indicators. Thus, the IRE style is formed by the totality of its seven defining constructs, while each of these constructs is a reflective one (uni-dimensional or decomposed to measurable sub-dimensions).

3.4. Methods

Through interactive discussions within the author team, we generated a pool of 103 items, which were purported to measure the individual-difference characteristics of the IRE style. Existing measures of intuitive eating (Hawks et al., 2004; Tylka & Kroon van Diest, 2013), eating competence (Krall & Lohse, 2011), mindful eating (Framson et al., 2009; Hulbert-Williams et al., 2014), and interoceptive awareness (Mehling et al., 2012) were used for inspiration during item generation. Researchers in the field of nutrition and experts evaluated and enriched the content of the initial item pool, which then underwent two rounds of pretesting with college samples. This preliminary work helped us to identify the most appropriate and relevant items for the constructs under study, to sort out the internal structure of the scale, to optimise its length, and to identify the most appropriate method for its administration. Starting from the structure obtained from this preliminary work, we examined the scale's internal consistency, confirmed its internal structure with Confirmatory Factor Analysis (CFA), and tested its two-week temporal stability and several types of validity (i.e., construct, discriminant, convergent, criterion, and incremental) in broad samples of consumers from the UK and US (Table 3.1.). This research was conducted according to the guidelines laid down in the Declaration of Helsinki and complied with the Netherlands Code of Conduct for Research Integrity. Written consent was obtained for all survey participants. Participants who were recruited via market research agencies had previously consented to participate in the panel of the agency. This research was approved by the Social Sciences Ethics Committee of Wageningen University and Research. The data of this project can be found here (Palascha et al., 2020b).

3.4.1. Measures

Internally regulated eating. MIRES was administered with 7-point Likert-type response scales (1 = "Completely untrue for me" to 7 = "Completely true for me") (see Appendix 3.2. for information on administration of the MIRES). The MIRES items were developed and tested in the English language.

Table 3.1. Overview of sample characteristics

	UK sample (*N = 974*)	UK sub-sample (*N = 213*)	US sample (*N = 1200*)
Gender			
Males	417 (42.8)	102 (47.9)	590 (49.2)
Females	557 (57.2)	111 (52.1)	610 (50.8)
Age			
18 – 24	105 (10.8)	16 (7.5)	183 (15.3)
25 – 34	174 (17.9)	27 (12.7)	253 (21.1)
35 – 44	214 (22.0)	42 (19.7)	255 (21.3)
45 – 54	235 (24.1)	58 (27.2)	277 (23.1)
55 – 65	246 (25.3)	70 (32.9)	232 (19.3)
Education level			
Low	94 (9.7)	20 (9.4)	84 (7.0)
Middle	438 (45.0)	101 (47.4)	360 (30.0)
High	442 (45.4)	92 (43.2)	756 (63.0)

Values are presented as counts (percentages).

A necessary condition for identification of formative models is the addition of at least two reflective measures that are caused directly or indirectly by the formative construct (Bollen & Davis, 2009). Thus, to achieve identification when testing the complete formative model we also developed six items that were reflective of the higher-order factor IRE style. We use the abbreviation *RI* (Reflective items) to refer to these items in the rest of the paper. Cronbach's alpha for the RI was .90 and Average Variance Extracted (AVE) was .61. Uni-dimensionality of the RI factor was supported by the good model fit (χ^2 (9) = 110.68, p < .001, CFI = .98, TLI = .96, RMSEA = .10, SRMR = .03) and the high factor loadings (.68 - .85).

Intuitive eating. We measured intuitive eating to test the convergent and incremental validity of MIRES. The 21-item IES-2 (Tylka & Kroon van Diest, 2013) was used to measure the four constructs of intuitive eating, namely, Unconditional Permission to Eat (UPE), Eating for Physical Rather Than Emotional Reasons (EPR), Reliance on Hunger and Satiety Cues (RHSC), and Body Food Choice Congruence (BFCC). Items were administered on a 5-point scale (1 =

"Strongly disagree" to 5 = "Strongly agree"). Cronbach's alphas were .69 (UPE), .87 (EPR), .93 (RHSC), and .88 (BFCC).

Eating competence. We also measured eating competence to test the convergent and incremental validity of MIRES. The 16-item Eating Competence Satter Inventory 2.0 (ecSI-2) was used to measure the four constructs of eating competence (Krall & Lohse, 2011; Lohse, 2015); Eating Attitudes (EatAtt), Food Acceptance (FoodAccept), Internal Regulation (IntReg), and Contextual Skills (ContSkills). Items were administered on a 5-point scale (1 = "never" and 5 = "always") and responses were used as continuous variables in this study. Cronbach's alphas were .88 (EatAtt), .75 (FoodAccept), .84 (IntReg), and .83 (ContSkills).

Eating disorder symptomatology. The Binge Eating Scale (BES) and the Restrictive Eating Scale (RES) of the Multifactorial Assessment of Eating Disorder Symptoms (MAEDS) (Anderson et al., 1999) were used to assess the frequency of manifesting binge eating and restrictive eating behaviours. Items were administered on a 7-point frequency scale (1 = "Never" to 7 = "Always"). Two items from each subscale were dropped before data collection ("I crave sweets and carbohydrates" because it regards a behaviour that is non-specific for binge eating and had a low item-total correlation in the original study; "I am too fat" because it reflects a belief rather than a behaviour; "I eat 3 meals a day" because it is the only item with negative item-total correlation and because for some people it may seem as a stringent behaviour, while for others as an adaptive one; "I hate to eat" because it was deemed extreme and had a low item-total correlation in the original study). Cronbach's alphas for the adapted scales were .91 (BES) and .87 (RES). The fit of the RES model was initially unacceptable. Thus, we allowed for correlated error terms between the two items on fasting that have similar wording. BES and RES were measured to assess the criterion and incremental validity of MIRES.

Proactive coping. The 8-item Proactive Coping Scale (PCS) of the Proactive Coping Inventory, as adapted by Gan et al. (2007), was used to measure cognitions and behaviours related to self-regulatory goal attainment. Items were administered on a 4-point scale (1 = "Not at all true" to 4 = "Completely true"). The PCS model fit was improved by allowing for correlated error terms between the items that refer to dealing with challenges as there is word congruence among them. We further removed the two reverse-scored items after data collection because of low item-total correlations (.184 and .165, respectively). The adapted PCS had a Cronbach's alpha of .88. PCS was measured to assess the criterion and incremental validity of MIRES.

Adaptive eating behaviours. Two adaptive eating behaviours from the Adult Eating Behaviour Questionnaire (AEBQ) were assessed (Hunot et al., 2016). Satiety responsiveness (SR) assesses with four items the tendency to respond to internal satiety signals. Slowness in eating (SE) measures with four items the tendency to consume meals at a slow pace. Items were administered on a 5-point scale (1 = "Strongly disagree" to 5 = "Strongly agree"). Cronbach's alphas were .81 (SR) and .72 (SE). SR and SE were measured to assess the criterion and incremental validity of MIRES.

Body appreciation. Body appreciation was measured with the 10-item Body Appreciation Scale-2 (BAS-2) (Tylka & Wood-Barcalow, 2015). The scale assesses the tendency of individuals to accept, respect, and have favourable opinions towards their bodies Responses were measured on a 5-point scale (1 = "Never" to 5 = "Always"). Its Cronbach's alpha was .96. BAS-2 was measured to assess the criterion and incremental validity of MIRES.

Self-esteem. To assess self-esteem, we used the Single-Item Self-Esteem scale (SISE) (Robins et al., 2001), which consists of a single item "I have high self-esteem" administered on a 5-point scale (1 = "Not very true of me" to 5 = "Very true of me"). Using test-retest data over three points in time and following the procedure suggested by Heise (1969), developers have obtained a reliability score of .75 for SISE. The scale's reliability was not estimated in this study due to the lack of repeated measurements. SISE was measured to assess the criterion and incremental validity of MIRES.

Life satisfaction. The 5-item Satisfaction With Life Scale (SWLS) (Diener et al., 1985) was used to measure global cognitive judgments of one's life satisfaction. Items were administered on a 7-point scale (1 = "Strongly disagree" to 7 = "Strongly agree"). Cronbach's alpha was .92. SWLS was measured to assess the criterion and incremental validity of MIRES.

Weight-related measures. Current weight and height were reported in pounds and feet/inches, respectively. Values were transformed to kilograms and meters and were used to calculate Body Mass Index (BMI). Highest and lowest weight during the last four years, excluding periods of pregnancy or sickness, was also reported. Based on subtraction of these values a variable called Maximal Weight Change (MWC) was calculated. Individuals whose MWC was <4kg were classified as with stable weight. Individuals whose MWC was ≥4kg were asked additional questions on their weight trajectory and were categorised into 1. those who gained weight (≥4kg increase in weight without significant fluctuations; fluctuations of ≥4kg were considered significant), 2. those who lost weight (≥4kg decrease in weight without significant fluctuations; fluctuations of ≥4kg were considered significant), or 3. those whose weight cycled (weight had fluctuated with gains and losses of ≥4kg). Weight cyclers also reported number of intentional weight losses and unintentional weight gains of ≥4kg during the last four years. Responses were used to calculate a measure of Weight Cycling Severity (WCS). These measures were also measured to assess the criterion and incremental validity of MIRES.

3.5. Analysis and Results

To confirm the scale's internal structure with CFA and to test several properties of its subscales (i.e., internal consistency, discriminant validity, measurement invariance, construct validity) we administered MIRES to a nearly representative sample (in terms of gender and age) of UK adults (N = 1380) that was recruited via a market research agency (exclusion criteria were pregnancy and lactation, history of eating disorders, diabetes, or bariatric surgery, and current use of appetite-enhancing or appetite-suppressing medication). Data were checked for violations of normality (acceptable skewness values were below 2 in absolute value and acceptable excess kurtosis values below 3 in absolute value) and presence of multivariate outliers (i.e., values outside the boxplots of the Mahalanobis distances for raw scores and residuals). No violations of normality were observed for the variables. After exclusion of multivariate outliers (N = 20) and those who failed an attention check question (N = 386) the sample was skewed towards females and older individuals (Table 1). Given that 195 parameters were to be estimated in the CFA model, the sample size (N = 974) was adequate to get reliable estimates based on the 5:1 participants-to-parameter ratio (Tinsley & Tinsley, 1987).

3.5.1. Internal structure and consistency

The Lavaan package (Rosseel, 2012) in R (version 3.4.1) (R Core Team, 2018) was used to conduct CFA with the Maximum Likelihood estimation. Adequacy of fit was determined by four indices (CFI > .95, TLI > .95, RMSEA < .06, SRMR < .08) (Bentler, 1990). The structure of MIRES was examined in a sequential process in which individual first-order factor models were tested before subscales were combined into higher-order constructs. The multi-factor model including all MIRES subscales provided a very good fit to the data (χ^2 (1040) = 2567.43, $p < .001$, CFI = .97, TLI = .97, RMSEA = .04, SRMR = .04) and all standardised factor loadings were high (above .70) and significant (Appendix 3.3.). A number of measurement-model modifications were made when testing this model. First, because the items in the sensitivity and self-efficacy subscales were asked in triple (across three contexts), method effects were accounted for by allowing error terms between identical items to be correlated. Second, because the conceptual distinction between contexts re-appeared in the sensitivity and self-efficacy subscales, we also accounted for context effects by allowing the disturbance terms of the first-order factors referring to the same context to correlate with each other (e.g., SH: Neutral, SS: Neutral, SEH: Neutral, SES: Neutral). Composite reliabilities and AVE were calculated according to Fornell and Larcker (1981). Reliabilities of the MIRES first- and second-order factors ranged between .84 and .96, and AVE was as low as .64 and as high as .88 (Table 3.2.).

3.5.2. Discriminant validity of constructs

Several alternative models were fitted and compared to show the discriminant validity of the sensitivity and self-efficacy constructs (Table 3.3.). First, to test whether sensitivity and self-efficacy are truly distinct from each other we compared two pairs of alternative models: one for hunger and one for satiation. Starting with hunger, in one model the three SH subscales (SH: Neutral, SH: Emotional, SH: External) loaded on a second-order factor SH and the three SEH subscales (SEH: Neutral, SEH: Emotional, SEH: External) loaded on another second-order factor SEH. In the alternative model, the two second-order factors were collapsed into one factor. The alternative model had significantly lower fit. The same was the case for the distinction between SS and SES.

In a similar way, we tested the discriminant validity of hunger and satiation constructs by comparing two pairs of alternative models: one for sensitivity and one for self-efficacy. The alternative model, in which SH and SS were collapsed into one factor, was significantly worse compared to the model where the two factors were distinct. The same was the case for SEH and SES. Finally, the conceptual distinction between different contexts of sensitivity and self-efficacy was tested. For each second-order construct (SH, SS, SEH, and SES), we compared the fit of a three-factor model in which each item loaded to its respective context versus an alternative model in which the three factors were collapsed into one factor. In all cases, the fit of the alternative model was significantly worse.

Table 3.2. Descriptive statistics, composite reliabilities, and AVE for the MIRES first- and second-order factors

	M	SD	Composite reliability	AVE
First-order factors				
IT	4.52	1.68	.94	.80
FL	4.43	1.79	.91	.71
FE	5.34	1.32	.94	.75
SH: Neutral	5.91	1.10	.88	.70
SH: Emotional	5.38	1.48	.88	.71
SH: External	5.32	1.43	.87	.70
SS: Neutral	5.55	1.35	.91	.77
SS: Emotional	4.83	1.73	.89	.73
SS: External	5.09	1.53	.89	.72
SEH: Neutral	5.49	1.34	.90	.75
SEH: Emotional	4.85	1.64	.94	.84
SEH: External	5.00	1.50	.90	.74
SES: Neutral	5.34	1.58	.96	.88
SES: Emotional	4.69	1.87	.91	.76
SES: External	5.03	1.65	.93	.82
Second-order factors				
SH	5.54	1.14	.84	.64
SS	5.15	1.39	.92	.79
SEH	5.11	1.31	.88	.72
SES	5.02	1.57	.93	.82

IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation, AVE: Average Variance Extracted.

3.5.3. Measurement invariance

Measurement invariance was examined for the items that were asked in triple (across contexts) to test the assumption that each item should have a consistent performance irrespectively of the context in which it is asked. To do this, we constrained the loadings of these items to be equal across the three contexts. The decrease in fit in the constrained model was significant (˜ χ^2 (24) =102.502, $p < .001$), however, the changes in fit indices were within the acceptable criteria (ΔCFI = -.002, ΔTLI = -.001, ΔRMSEA = 0, ΔSRMR = .001) according to

Chen's recommendations for factor loading invariance (△CFI ≤ .010, △RMSEA ≤ .015, and △SRMR ≤ .030) (Chen, 2007).

Table 3.3. Change in chi square and fit indices between models testing the discriminant validity of MIRES constructs

Factors[a]	$\Delta\chi^2$ (df)[b]	*p*	ΔCFI	ΔTLI	ΔRMSEA	ΔSRMR
Sensitivity vs. Self-efficacy						
SH *vs.* SEH	130.72 (1)	< .001	-.009	-.012	.01	.005
SS *vs.* SES	116.95 (1)	< .001	-.006	-.008	.011	.005
Hunger vs. Satiation						
SH *vs.* SS	316.95 (1)	< .001	-.022	-.031	.024	.016
SEH *vs.* SES	455.77 (1)	< .001	-.024	-.034	.031	.029
Neutral context vs. Emotional context vs. External context						
SH: Neutral *vs.* SH:Emotional *vs.* SH:External	1341.51 (3)	< .001	-.235	-.47	.276	.086
SS: Neutral *vs.* SS:Emotional *vs.* SS:External	1005.99 (3)	< .001	-.139	-.278	.211	.048
SEH: Neutral *vs.* SEH:Emotional *vs.* SEH:External	1300.46 (3)	< .001	-.188	-.377	.239	.065
SES: Neutral *vs.* SES:Emotional *vs.* SES:External	1633.31 (3)	< .001	-.158	-.315	.267	.051

SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation.
[a] In the initial model, factors were distinct. In the alternative model, factors were collapsed into a single factor.
[b] Alternative model – Initial model

3.5.4. Construct validity

Since the IRE style is by nature a non-diet eating style, we used independent samples t-tests to compare scores on the MIRES subscales between individuals who said they were currently dieting for weight loss purposes (n_1 = 131) and those who said they were not (n_2 = 843), as a means of testing the scale for construct validity in a broad sense. Non-dieters scored significantly higher than dieters in all but one MIRES subscales, in line with our expectations (Appendix 3.4.). For FE, the mean difference between groups did not reach significance.

3.5.5. Temporal stability

A sub-sample of 679 participants from the UK sample filled in the MIRES for a second time after two weeks. Response rate was 43.2%, but the entire survey was completed by 261 participants. Those who failed the attention check (N = 46) and two multivariate outliers were excluded, leaving a sample of 213 responses for analysis (Table 3.1.). The sample size was adequate to get reliable estimates in models testing the stability of first-order factors, while in models testing the stability of second-order factors the sample was slightly small (4:1 participant-to-parameter-ratio).

No violations of normality were observed for the variables. We used an elaborated procedure of temporal stability assessment as suggested by Steenkamp and van Trijp (1991). Pearson's correlation coefficients, intra-class coefficients with confidence intervals, and means for the summed scores of factors were also calculated. Stability coefficients of the MIRES first- and second-order factors ranged between .63 and .90 (Table 3.4.). Imposition of constraints on factor loadings did not result in significant decreases in model fit, thus, the meaning of all subscales was stable. *S*ome subscales were further found to be stable in terms of item reliabilities (SS: Neutral and EH: External) and construct reliability (FL, SH: External, SS: Emotional, SS: External, EH: Emotional, and ES: Neutral). Finally, SH: Neutral, SEH: Neutral, and SEH manifested perfect stability as their stability coefficient was not significantly different from unity. Paired samples t-tests indicated that most factor means were stable over time; however, the means of IT, FL, SH: Emotional, and SS: External changed significantly.

Table 3.4. Stability coefficients, Pearson's correlation coefficients, intra-class correlation coefficients, and mean scores for the MIRES first- and second- order factors

	Stability coefficient	Pearson's r	ICC (CI)[a]	Mean 1	Mean 2	*p*
First-order factors						
IT	.74	.69*	.80 (.73 - .86)	18.64	20.22	< .001
FL	.79	.74*	.85 (.80 - .89)	18.39	19.37	.005
FE	.67	.65*	.79 (.72 - .84)	27.00	27.42	.29
SH: Neutral	.66	.57*	.73 (.64 - .79)	17.79	17.90	.62
SS: Neutral	.74	.69*	.81 (.75 - .86)	17.20	17.08	.56
SH: Emotional	.69	.64*	.77 (.70 - .83)	16.63	16.08	.04
SS: Emotional	.83	.77*	.87 (.83 - .90)	15.16	15.07	.70
SH: External	.70	.62*	.77 (.69 - .82)	16.21	15.82	.13
SS: External	.76	.70*	.82 (.76 - .86)	16.08	15.56	.03
SEH: Neutral	.63	.59*	.74 (.66 - .80)	16.84	16.92	.75
SES: Neutral	.76	.71*	.83 (.78 - .87)	16.84	16.87	.90
SEH: Emotional	.65	.61*	.76 (.68 - .82)	15.30	14.88	.16
SES: Emotional	.74	.71*	.83 (.78 - .87)	15.24	14.79	.13
SEH: External	.71	.65*	.78 (.71 - .83)	15.47	15.09	.15
SES: External	.72	.68*	.81 (.75 - .85)	15.96	15.62	.20
Second-order factors						
SH	.90	.75*	.85 (.81 - .89)	50.63	49.79	.10
SS	.90	.83*	.90 (.87 - .93)	48.45	47.70	.15
SEH	.83	.71*	.83 (.78 - .87)	47.62	46.89	.24
SES	.85	.78*	.88 (.84 - .91)	48.05	47.27	.22

IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation.

[a] Intra-class correlation coefficients using an absolute agreement definition.

* p < .001

3.5.6. Length optimisation

In order to further optimise the scale's length and to have the same number of items per subscale (i.e., three), we decided to drop seven items; four items from the IT subscale, one item from the FL subscale, and two items from the FE subscale. The decision on which items to drop was based on the meaning of items to retain the scale's content validity (Rossiter, 2002); items whose meaning was very similar to other items in their respective subscales were dropped. The three subscales manifested similar properties after the exclusion of items (IT: Stability coefficient = .70, r = .65, ICC = .78 (.70 - .84), Mean 1 = 14.00, Mean 2 = 15.16, p < .001; FL: Stability coefficient = .82, r = .74, ICC = .85 (.80 - .88), Mean 1 = 13.72, Mean 2 = 14.46, p = .005; FE: Stability coefficient = .66, r = .61, ICC = .76 (.69 - .82), Mean 1 = 16.01, Mean 2 = 16.33, p = .204). The final scale consisted of 45 items.

3.5.7. Confirmation of the internal structure of MIRES as a multidimensional, formative model

The 45-item MIRES was further administered to a representative sample of 1251 adults from the US (Howden & Meyer, 2011) (Table 3.1.; see also Appendix 3.5. for some additional characteristics) (recruited via a market research agency) in order to confirm the internal structure of MIRES as a multidimensional formative model and to test the scale's convergent, criterion, and incremental validity. Exclusion criteria were pregnancy and lactation, because these conditions relate to temporal irregularities in the eating patterns of women. Fifty-one multivariate outliers were excluded leaving 1200 responses for analysis. Based on the recommended 5:1 participants-to-parameter ratio, a sample of 1200 participants would be adequate to give reliable estimates for a model with maximum 240 parameters. All models that we tested had less than 240 parameters to be estimated, thus the sample size was adequate for our analyses. No significant violations of normality were observed for most variables. BMI and MWC had kurtosis values above 3 and the latter also had a skewness value above 2. However, according to Kline's more relaxed criteria for skewness and kurtosis (<3 and <10, respectively) (Kline, 2005) none of these variables were considered problematic, thus no transformations were conducted.

The MIRES model was subjected to CFA (Appendix 3.6.) with the following additional specifications. The three first-order factors—IT, FL, FE—and the four second-order factors—SH, SS, SEH, SES—loaded to the higher-order IRE style construct as formative indicators (arrows pointing to the higher-order construct). Covariances between all first- and second-order factors with the higher-order formative factor were fixed to zero, as otherwise Lavaan estimates both these covariances and the formative regression coefficients, which seem to be confounded leading to identification problems. To warrant identification, the six RI also loaded to the IRE style construct as reflective indicators (arrows pointing to the six RI).

The model had an excellent fit to the data (χ^2 (1130) = 2804.10, p < .001, CFI = .97, TLI = .97, RMSEA = .04, SRMR = .03). All observed variables served as reliable and significant indicators of their corresponding constructs and all first-order factors loaded highly and significantly to their respective second-order factors (Appendix 3.6.), as was the case in the UK sample. Regression coefficients of the seven formative indicators of the IRE style were not interpreted because their values were influenced by the presence of multi-collinearity among the seven subscales of MIRES (Variance Inflation Factors 1.52 - 7.85, cut-off <3.3), which are moderately to strongly correlated with each other (Table 3.5.). High and significant loadings were obtained for the six RI (.66-.86) and a large amount of variance in these items was accounted for by the IRE style factor (AVE = .82).

Table 3.5. Bivariate correlations of summed scores of MIRES, RI, and MIRES subscales

	1	2	3	4	5	6	7	8
1. MIRES	-							
2. RI	.80*	-						
3. IT	.71*	.60*	-					
4. FL	.63*	.64*	.61*	-				
5. FE	.60*	.46*	.49*	.38*	-			
6. SH	.89*	.66*	.53*	.43*	.52*	-		
7. SS	.95*	.73*	.61*	.55*	.49*	.81*	-	
8. SEH	.92*	.74*	.59*	.49*	.50*	.85*	.82*	-
9. SES	.93*	.75*	.60*	.55*	.45*	.74*	.91*	.81*

MIRES: Multidimensional Internally Regulated Eating Scale, RI: Reflective items, IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation.
* p < .05

3.5.8. Convergent validity

Bivariate correlations of the MIRES total score, RI, and MIRES subscales with the IES-2 and ecSI-2 total scores were substantial and significant (.32-.70) (Appendix 3.7.). High correlations were particularly observed between certain MIRES subscales and conceptually related constructs of IES-2 and ecSI-2. For example, FL and FE correlated most strongly with the EatAtt (.56) and ContSkills (.46) subscales of ecSI-2, respectively. Similarly, SEH and SES correlated most strongly with the RHSC subscale of IES-2 (.66 and .68, respectively).

3.5.9. Criterion validity

The criterion validity of MIRES, IES-2, and ecSI-2 was examined with Structural Equation Modelling (SEM) (for outcomes measured with multiple items) and with linear regression (for the single-item outcomes SISE, BMI, MWC, and WCS). Analyses with MIRES were conducted at the level of a total score (summed score of all items), at the level of the seven MIRES subscales as separate latent constructs (IT, FL, FE, SH, SS, SEH, SES), and at the level of the RI as an independent scale. Analyses for IES-2 and ecSI-2 were conducted only at the level of total scores.

MIRES, as well as its individual subscales, displayed negative associations with binge eating, restrictive eating, BMI, maximal weight change, and weight cycling severity, and positive associations with all adaptive outcomes assessed in this study (Table 3.6.). In general, MIRES, IES-2, and ecSI-2 displayed comparable predictive abilities (Appendix 3.8.) and all were better at predicting behavioural and psychological outcomes, compared to physical outcomes. MIRES accounted for a slightly larger amount of variance in RES, SR, and SE compared to the other scales, IES-2 was better at predicting BES, BMI, MWC, and WCS, and finally ecSI-2 was better at predicting PCS, BAS-2, SWLS, and SISE. The RI manifested comparable criterion validity to MIRES. Finally, certain MIRES subscales (FL, SH, SS, SES) achieved higher predictive power compared to the MIRES summed score for certain outcomes (e.g., RES, BES, SR, SE, BMI).

Table 3.6. Bivariate correlations among all constructs measured in the US sample

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. MIRES	-												
2. IES-2	.69*	-											
3. ecSI-2	.67*	.60*	-										
4. BES	-.38*	-.46*	-.16*	-									
5. RES	-.15*	-.12*	-.12*	.47*	-								
6. PCS	.38*	.35*	.44*	-.02	.14*	-							
7. SR	.23*	.19*	.15*	.002	.34*	.27*	-						
8. SE	.23*	.21*	.17*	-.14*	.16*	.21*	.39*	-					
9. BAS-2	.49*	.53*	.59*	-.26*	-.02	.52*	.26*	.24*	-				
10. SWLS	.29*	.28*	.40*	-.04	.04	.44*	.24*	.16*	.62*	-			
11. SISE	.34*	.35*	.40*	-.15*	.003	.40*	.19*	.12*	.71*	.60*	-		
12. BMI	-.15*	-.21*	-.12*	.20*	.05	-.09*	-.12*	-.07*	-.21*	-.10*	-.12*	-	
13. MWC	-.16*	-.21*	-.16*	.13*	.16*	-.08*	.002	.01	-.19*	-.13*	-.12*	.43*	-
14. WCS	-.22*	-.27*	-.09	.34*	.27*	.11*	.08	-.01	-.06	.01	-.001	.24*	.29*

MIRES: Multidimensional Internally Regulated Eating Scale, IES-2: Intuitive Eating Scale-2, ecSI-2: Eating Competence Satter Inventory 2.0, BES: Binge Eating Scale, RES: Restrictive Eating Scale, PCS: Proactive Coping Scale, SR: Satiety Responsiveness, SE: Slowness in Eating, BAS-2: Body Appreciation Scale-2, SWLS: Satisfaction With Life Scale, SISE: Single Item Self-Esteem Scale, BMI: Body Mass Index, MWC: Maximal Weight Change, WCS: Weight Cycling Severity.
* $p < .05$

3.5.10. Incremental validity

The incremental validity of MIRES in relation to IES-2 and ecSI-2 was examined with SEM (for multi-item outcomes) and hierarchical regression analysis (for single-item outcomes). Specifically, we examined whether MIRES accounted for variance in each outcome measure above and beyond the variance accounted for by IES-2 and ecSI-2, respectively. At Step 1, IES-2 was entered as a single predictor of each respective outcome and at Step 2, MIRES was added as a second predictor (in SEM analyses, MIRES was also entered as a predictor in the model at Step 1, but its regression coefficient was fixed at zero). The same procedure was followed with ecSI-2. Changes in beta coefficients were not interpreted because multi-collinearity between these conceptually similar measures was expected to interfere with these estimates. For most outcomes, a significant increase in R^2 was observed when MIRES was added in the model (Table 3.7.). Specifically, MIRES accounted for .7%-16% additional variance in outcome measures above and beyond IES-2 and ecSI-2. MIRES did not account for a significant increase in explained variance of physical outcomes (BMI [$\Delta R^2 = 0$], MWC [$\Delta R^2 = 0$], and WCS [$\Delta R^2 = .002$]) above and beyond IES-2, neither for satisfaction with life ($\Delta R^2 = 0$) and self-esteem ($\Delta R^2 = .005$) above and beyond the variance explained for by ecSI-2.

Table 3.7. Incremental variance in outcome measures accounted for by MIRES

	MIRES vs. IES-2				MIRES vs. ecSI-2			
	R^2 (IES-2)	R^2 (IES-2 + MIRES)	ΔR^2	*p*	R^2 (ecSI-2)	R^2 (ecSI-2 + MIRES)	ΔR^2	*p*
BES[a]	.25	.26	.01	<.001	.03	.19	.16	<.001
RES[a]	.02	.03	.01	.001	.02	.03	.01	<.001
PCS[a]	.15	.19	.04	<.001	.23	.24	.02	<.001
SR[a]	.05	.07	.02	<.001	.03	.07	.04	<.001
SE[a]	.05	.07	.02	<.001	.05	.07	.02	<.001
BAS-2[a]	.28	.32	.03	<.001	.35	.37	.02	<.001
SWLS[a]	.09	.10	.02	<.001	.18	.18	.00	.37
SISE[b]	.12	.14	.02	<.001	.16	.16	.01	.09
BMI[b]	.05	.05	.00	.80	.01	.04	.03	<.001
MWC[b]	.04	.04	.00	.49	.04	.04	.01	.05
WCS[bc]	.07	.07	.00	.30	.01	.06	.05	<.001

MIRES: Multidimensional Internally Regulated Eating Scale, IES-2: Intuitive Eating Scale-2, ecSI-2: Eating Competence Satter Inventory 2, BES: Binge Eating Scale, RES: Restrictive Eating Scale, PCS: Proactive Coping Scale, SR: Satiety Responsiveness, SE: Slowness in Eating, BAS-2: Body Appreciation Scale-2, SWLS: Satisfaction With Life Scale, SISE: Single Item Self-Esteem Scale, BMI: Body Mass Index, MWC: Maximal Weight Change, WCS: Weight Cycling Severity.

[a] Values obtained with SEM.

[b] Values obtained with hierarchical regression analysis.

[c] N=504

3.5.11. Testing the properties of the simplified 21-item version of MIRES

Since the 45-item MIRES manifested good psychometric properties, we wanted to examine whether the inclusion of the three contexts (neutral, emotional, external) in the sensitivity and self-efficacy subscales offers predictive advantages compared to just the neutral context. In this way we could ascertain whether a simplified version of the scale (21 items) could still be applicable. To test this empirically we performed SEM and regression analysis (depending on the outcome variable) using either the full subscales (SH, SS, SEH, and SES) including all three contexts each or the neutral counterpart of each subscale to predict each outcome measured in the US sample. The full subscales accounted for 0-8% additional variance, depending on the outcome, compared to their neutral counterparts (Appendix 3.9.). In addition, the fit of the 21-item MIRES model was still excellent (χ^2 (296) = 1258.161, p < .001, CFI = .97, TLI = .96, RMSEA = .05, SRMR = .04) (Fig. 3.2.), correlations among the MIRES subscales and with IES-2 and ecSI-2 reduced only slightly (Appendices 3.10. and 3.11.), and the incremental validity of MIRES was still upheld (Appendix 3.12.). Thus, despite the fact that the 45-item full version offers some predictive advantages, the simplified version with only 21 items generally upholds the psychometric properties of the full scale.

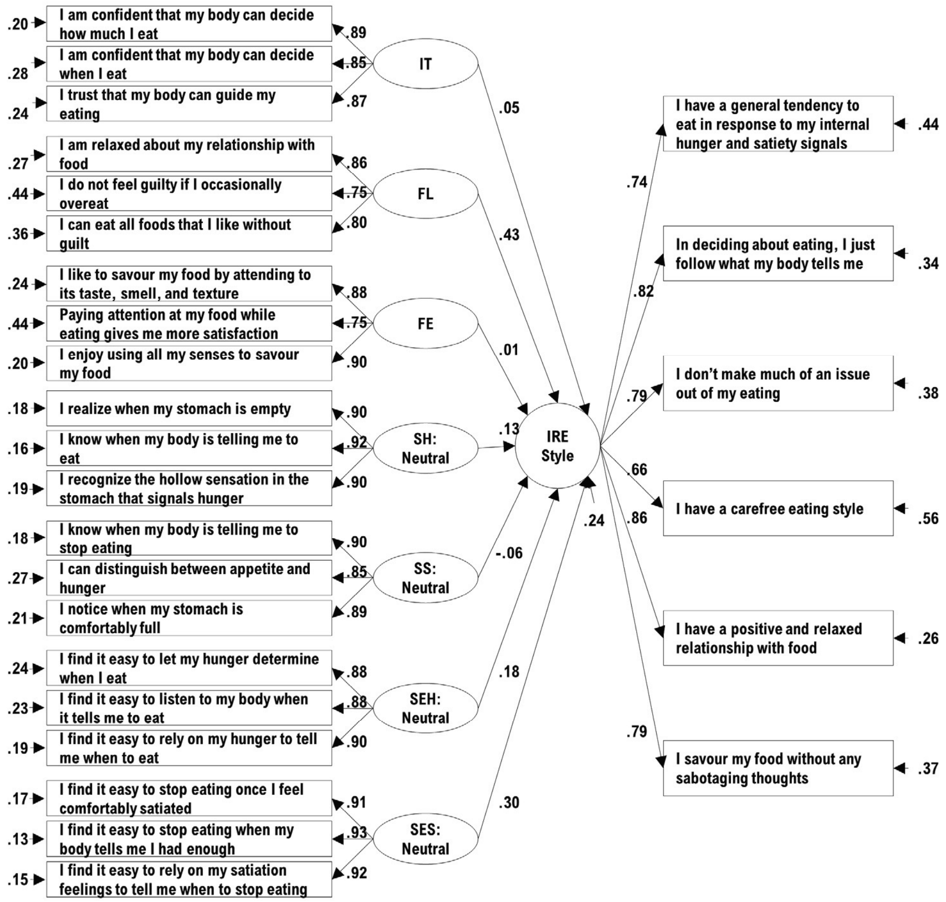


Fig 3.2. The multi-dimensional model of internally regulated eating style (simplified version). All loadings were significant at the .01 level. Covariances and disturbance terms of first-order factors are not depicted in the figure for easier readability.

3.6. Discussion

Internally regulated eating is an adaptive way of eating that leads to positive physical, psychological, behavioural, and dietary outcomes as shown by the current and previous research (Bruce & Ricciardelli, 2016; Clifford et al., 2015; Schaefer & Magnuson, 2014; Ulian et al., 2018; van Dyke & Drinkwater, 2014; Warren et al., 2017). While several attempts have been made to conceptualise and quantify this eating style, none seems to capture the full complexity of this construct. In this paper, we describe the rigorous development and validation of the MIRES, an instrument to assess the individual-difference characteristics that are necessary and jointly sufficient conditions for the manifestation of the IRE style.

Using a bottom-up approach, we showed that all first- and second-order factors of MIRES are measured reliably and a significant amount of variance in the items is accounted for by the corresponding latent factors. All first-order models and the multi-factor model that we tested had very good fit to the data. We confirmed that sensitivity to hunger, sensitivity to satiation, self-efficacy with hunger, and self-efficacy with satiation are distinct constructs, and that the three contexts within each of these subscales are also distinct from each other. Results supported the metric measurement invariance of the items asked across contexts and initial evidence on the construct validity of MIRES was obtained, as non-dieters scored higher in all but one MIRES subscales compared to dieters. Scores on FE did not differ significantly between groups, suggesting that this is perhaps the least determinative characteristic among the ones that form the IRE style. We further showed that all MIRES subscales are stable over a period of two weeks in terms of factor loadings, while even higher levels of stability (in terms of item reliabilities, construct reliabilities, or correlation of the same factor over time) were evidenced for certain subscales. Pearson's correlations underestimated the true stability of these constructs, while intra-class correlation coefficients overestimated it. Factor means remained stable for most factors except for IT, FL, SH: Emotional, and SS: External. As regards the latter two factors, however, the means of their respective second-order factors (SH and SS) were stable. The change in means in IT and FL, suggests that these subscales show variation over time across the whole sample, which could be systematic (i.e., these subscales measure less stable characteristics) or random (i.e., due to chance). Further studies are required to confirm which of the two plausible explanations is true. Evidence on the multidimensional nature of the MIRES model was also obtained in this study. The convergent validity of MIRES was supported by the moderate to strong correlations with measures of intuitive eating and eating competence.

Measures of IRE were generally better at predicting behavioural and psychological outcomes compared to physical outcomes, which is in line with existing evidence (Clifford et al., 2015; Schaefer & Magnuson, 2014; Ulian et al., 2018; van Dyke & Drinkwater, 2014). MIRES associated negatively with binge eating, restrictive eating, BMI, maximal weight change, and weight cycling severity, and positively with all adaptive outcomes assessed in this study. This confirms the adaptive nature of the constructs it assesses. The six RI had comparable predictive power to the 45-item MIRES. Furthermore, certain MIRES subscales (FL, SH, SS, and SES) accounted for a larger amount of variance in certain outcomes compared to the MIRES summed score. This further justifies their applicability as independent measures. The incremental validity of MIRES, above and beyond IES-2 and ecSI-2, was supported for most outcome variables measured in this study. Finally, we showed that the simplified 21-item version of MIRES upholds the psychometric properties of the full 45-item scale.

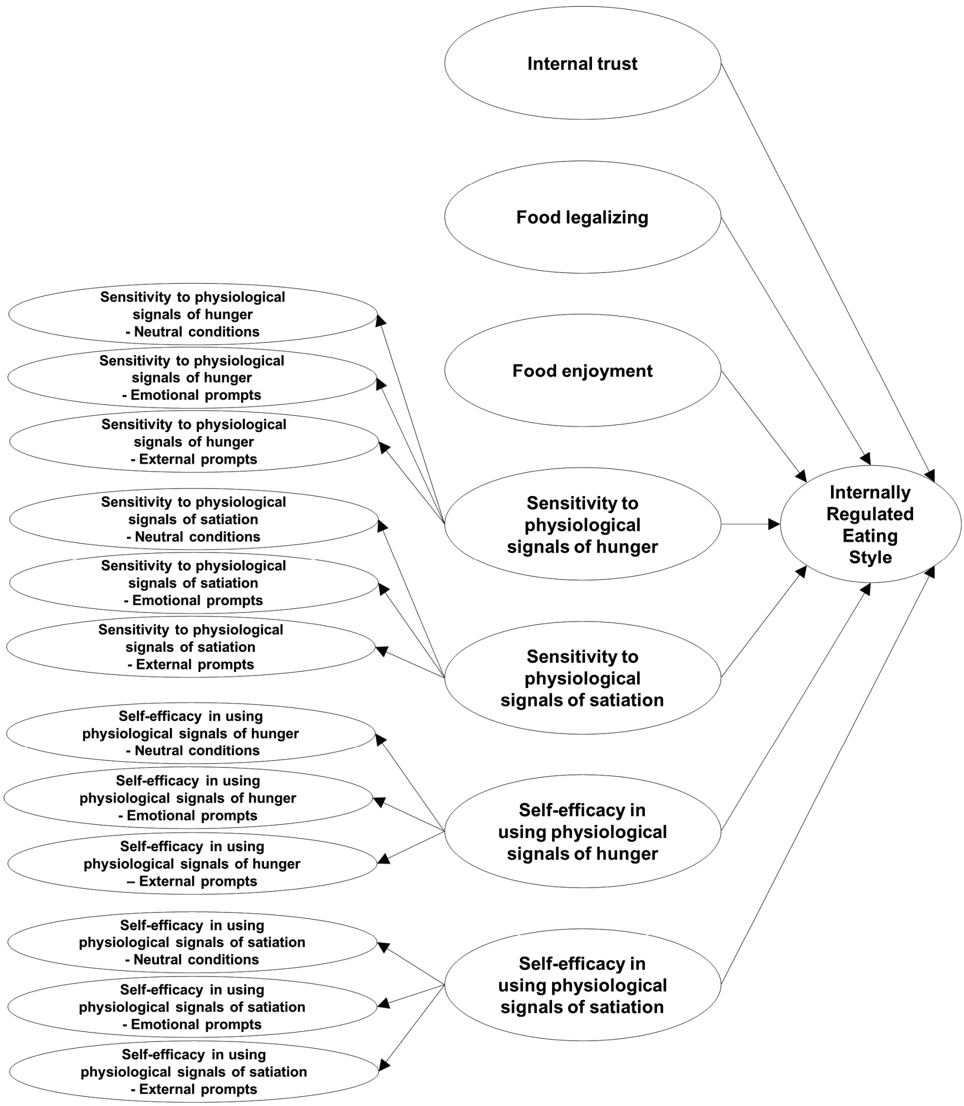
MIRES can be used by researchers and practitioners for a complete assessment of the IRE style as well as of its distinct components. MIRES can be used as an independent variable, moderator, or mediator in future scientific research investigating the role of IRE style in various processes in the eating domain. It can also be used as an outcome variable when assessing the impact of interventions aimed to strengthen IRE. Finally, MIRES can be used as a screening instrument by health practitioners who try to promote IRE among their clients or patients.

While MIRES manifested good psychometric properties, there are limitations that should be addressed. First, we should note that all data presented in this paper are solely based on self-reports. Although self-reports are practical tools for the assessment of personality constructs, they are subject to several types of response bias such as socially desirable responding, acquiescent responding, or extreme responding (McDonald, 2008). Individual responses may also be limited by the lack of sufficient self-awareness or by self-deception effects. Second, identification restrictions are inherent to formative models (Edwards, 2011), as is the one presented in this paper. Thus, researchers who are interested in conducting CFA or SEM using the complete formative MIRES model should also measure the six RI that we specifically developed to facilitate model identification. Third, the preliminary work was conducted with college students (18-35 years old) while in later steps we used community samples (18-65 years old); thus, it could be argued that it is not safe to assume the invariance of the model's internal structure across the scale development and validation process. To test the model for measurement invariance across age groups, subgroups should have at least 980 participants each to allow for reliable estimates to emerge based on the 5:1 participant to parameter ratio. The sample sizes in our study did not allow us to conduct this analysis in the typical stepwise process (Putnick & Bornstein, 2016); however, when we fitted the model in subgroups with all but seven parameters fixed to the values obtained from the full sample (only regression coefficients of the seven formative indicators were left free to be estimated) the model fit was still acceptable (18-34 years: χ^2 (1319) = 2467.93, p < .001, CFI = .95, TLI = .95, RMSEA = .05, SRMR = .03; 35-65 years: χ^2 (1319) = 2969.25, p < .001, CFI = .96, TLI = .96, RMSEA = .04, SRMR = .05) providing, thus, preliminary evidence for the invariance of the model across age groups. Finally, we acknowledge that administration of the full version of MIRES may be more complex than other self-reports because twelve of its items are repeated across three different contexts. Thus, we advise potential users to use the simplified version of the scale that consists of only 21 items.

Next to these limitations, the strengths of this newly developed measure should also be considered. In contrast to what most scale developers do, in this research we were particularly interested in the precise specification of the measurement model. Those who aim to assess the IRE style need to measure the complete set of seven MIRES subscales and calculate a total score, while those who want to focus on a particular characteristic of the IRE style can choose to measure a subscale in isolation and calculate the summed score of items of that particular subscale. The bottom-up approach that we took for the scale's development and validation (assessing the properties of lower-order factors before moving to higher levels) can give researchers and practitioners confidence on the reliability and validity of the scale's sub-parts. It should be noted here that using only a subset of subscales would allow conclusions to be drawn only on those particular constructs that are measured and not on the IRE style construct. We further observed strong convergence and comparable criterion validity between MIRES and the six RI. Given that RI is a reliable scale in itself, it could be used as the snap version of MIRES. This adds even more flexibility in the use of the new instrument. Finally, the multidimensional nature of MIRES enables the distinction of several closely related but conceptually distinct features of the IRE style. For example, the distinction between sensitivity to and self-efficacy in using physiological signals of hunger and satiation has been examined very deficiently in existing literature (see e.g., Dockendorff et al. (2012)). Therefore, MIRES can be used for a more differentiated assessment of the essentials of the IRE style.

Although we followed a rigorous process for the scale's development and validation, replication of the current findings in other populations or population segments is needed. For example, the measurement invariance of the model could be tested across sexes, age groups, and other potentially interesting population groups such individuals with overweight or obesity. Once measurement invariance of the model is evidenced, norm scores can be developed for the various subgroups. Moreover, it would be interesting to administer the simplified version of the scale without any introductory text in the sensitivity and self-efficacy subscales in order to ascertain whether this influences how individuals interpret the items. Additional studies could also be conducted to assess the temporal stability of the RI scale and to ascertain whether the change in means over time in two MIRES subscales (IT and FL) that we observed was systematic or random. Future research could also test the face validity of the final MIRES because relevance of items with the construct definitions was assessed only at the very beginning of the scale development process. This would ensure that the retained items still do a good job in reflecting the meaning of the constructs they are purported to measure. Given that a theory-based approach was used in this research, we expect that MIRES will uphold its face validity. Finally, behavioural experiments could provide convincing and invaluable evidence for the construct and predictive validity of MIRES.

Appendix 3.1. Conceptual model of internally regulated eating style. The direction of arrows indicates whether a construct is formative - arrows point to the construct - or reflective - arrows point to the dimension.



Appendix 3.2. The Multidimensional Internally Regulated Eating Scale (MIRES)

Permission and general guidelines

The MIRES is freely available and no permission is required for its use. In case modifications are made to the scale, please specify them in detail and mention that these have been made by the users. We recommend using entire subscales instead of individual items to retain the psychometric properties of the subscales. Users who want to conduct CFA or SEM using the complete formative MIRES model should also measure the six Reflective Items (RI) to warrant model identification. To use the 21-item, simplified version of MIRES, assess items 10 to 21 with the neutral context introductory text only (see below in yellow highlight).

In the research outlined in this paper we administered the full 45-item MIRES in the following way:

- Internal trust, Food legalizing, and Food enjoyment were assessed first, before participants were asked to imagine themselves in any context to avoid spill-over effects from the contexts.
- The contexts were randomized and a new context was introduced only when all items from the previous one had been rated.
- Within each context, sensitivity items were assessed before the self-efficacy items because this is a more logical order given the temporal relationship between these constructs.
- Reflective items were assessed after the MIRES using the same general instructions and response scale.

Context introductory texts for the sensitivity and self-efficacy subscales*:

Neutral context: “In order to respond to the following statements, imagine a situation where you are calm, relaxed, and without much distraction”

Emotional context: “In order to respond to the following statements, imagine a situation where you are sad, lonely, or bored”

External context: “In order to respond to the following statements, imagine a situation where you are distracted by something”

General instructions

Please indicate how true or untrue is each of the following statements for you.

Internal trust

1. I am confident that my body can decide how much I eat
2. I am confident that my body can decide when I eat
3. I trust that my body can guide my eating

Food legalizing

4. I am relaxed about my relationship with food
5. I do not feel guilty if I occasionally overeat
6. I can eat all foods that I like without guilt

Food enjoyment

7. I like to savour my food by attending to its taste, smell, and texture
8. Paying attention at my food while eating gives me more satisfaction
9. I enjoy using all my senses to savour my food

Sensitivity to physiological signals of hunger*

10. I realize when my stomach is empty
11. I know when my body is telling me to eat
12. I recognise the hollow sensation in the stomach that signals hunger

Sensitivity to physiological signals of satiation*

13. I know when my body is telling me to stop eating
14. I can distinguish between appetite and hunger
15. I notice when my stomach is comfortably full

Self-efficacy in using physiological signals of hunger*

16. I find it easy to let my hunger determine when I eat
17. I find it easy to listen to my body when it tells me to eat
18. I find it easy to rely on my hunger to tell me when to eat

Self-efficacy in using physiological signals of satiation*

19. I find it easy to stop eating once I feel comfortably satiated
20. I find it easy to stop eating when my body tells me I had enough
21. I find it easy to rely on my satiation feelings to tell me when to stop eating

Reflective items (RI) of the MIRES

1. I have a general tendency to eat in response to my internal hunger and satiety signals
2. In deciding about eating, I just follow what my body tells me
3. I don't make much of an issue out of my eating
4. I have a carefree eating style
5. I have a positive and relaxed relationship with food
6. I savour my food without any sabotaging thoughts

Suggested response format

7-point Likert-type response scale: 1 = "Completely untrue for me", 2 = "Moderately untrue for me", 3 = "Slightly untrue for me", 4 = "Neither true nor untrue for me", 5 = "Slightly true for me", 6 = "Moderately true for me", 7 = "Completely true for me".

Appendix 3.3. Factor loadings for the MIRES first- and second-order factors

Item	Standardized loading first-order factor	Standardized loading second-order factor
IT1	.92	
IT2	.87	-
IT3	.89	
IT4	.90	
FL1	.83	
FL2	.73	-
FL3	.90	
FL4	.90	
FE1	.92	
FE2	.86	
FE3	.83	-
FE4	.80	
FE5	.91	
SH: Neutral1	.83	
SH: Neutral2	.88	.80
SH: Neutral3	.81	
SH: Emotional1	.85	
SH: Emotional2	.83	.81
SH: Emotional3	.82	
SH: External1	.83	
SH: External2	.88	.81
SH: External3	.84	
SS: Neutral1	.89	
SS: Neutral2	.79	.85
SS: Neutral3	.87	
SS: Emotional1	.90	
SS: Emotional2	.83	.89
SS: Emotional3	.90	
SS: External1	.88	
SS: External2	.79	.94
SS: External3	.87	
SEH: Neutral1	.85	
SEH: Neutral2	.86	.84
SEH: Neutral3	.89	
SEH: Emotional1	.85	
SEH: Emotiona2l	.84	.84
SEH: Emotional3	.90	
SEH: External1	.85	
SEH: External2	.87	.87
SEH: External3	.90	
SES: Neutral1	.93	
SES: Neutral2	.94	.87
SES: Neutral3	.89	
SES: Emotional1	.94	
SES: Emotional2	.95	.90
SES: Emotional3	.92	
SES: External1	.92	
SES: External2	.92	.95
SES: External3	.89	

IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation.

Appendix 3.4. Mean scores on MIRES first- and second-order factors for dieters and non-dieters

	Mean Dieters (n_1 = 131)	Mean Non-dieters (n_2 = 843)	*t*	*p*	Cohen's *d*
First-order factors					
IT	3.38	4.69	-8.63	< .001	-.81
FL	3.05	4.64	-9.92	< .001	-.93
FE	5.24	5.35	-.89	.38	-.08
SH: Neutral	5.58	5.96	-3.76	< .001	-.35
SH: Emotional	5.04	5.44	-2.90	.004	-.27
SH: External	4.81	5.40	-4.46	< .001	-.42
SS: Neutral	4.85	5.66	-5.85	< .001	-.55
SS: Emotional	3.89	4.97	-6.84	< .001	-.64
SS: External	4.27	5.21	-6.67	< .001	-.63
SEH: Neutral	4.95	5.57	-5.05	< .001	-.47
SEH: Emotional	4.29	4.94	-4.30	< .001	-.40
SEH: External	4.33	5.11	-5.56	< .001	-.52
SES: Neutral	4.45	5.48	-6.37	< .001	-.60
SES: Emotional	3.59	4.86	-7.49	< .001	-.70
SES: External	4.06	5.18	-7.40	< .001	-.70
Second-order factors					
SH	5.14	5.60	-4.73	< .001	-.44
SS	4.34	5.28	-7.41	< .001	-.70
SEH	4.52	5.21	-5.64	< .001	-.53
SES	4.03	5.17	-8.01	< .001	-.75

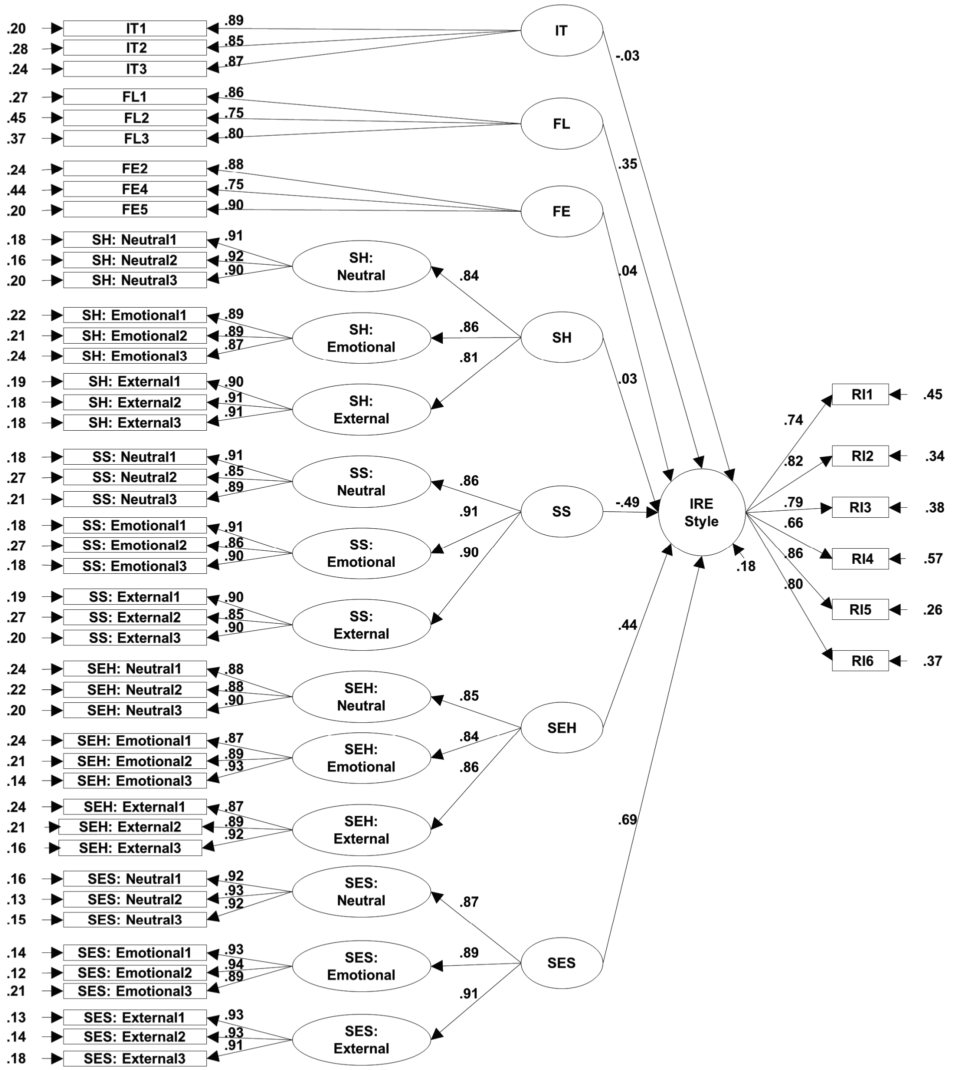
IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation.

Appendix 3.5. Additional sample characteristics of the US sample

	Male (N = 590)	Female (N = 610)	Total (N = 1200)
Household composition			
With children	219 (18.3)	287 (23.9)	506 (42.2)
Without children	371 (30.9)	323 (26.9)	694 (57.8)
BMI group (N = 1198)			
Underweight (<18.5)	29 (2.4)	30 (2.5)	59 (4.9)
Normal (18.5-24.9)	170 (14.2)	198 (16.5)	368 (30.7)
Overweight (25.0-29.9)	200 (16.7)	155 (12.9)	355 (29.6)
Obese (>30.0)	189 (15.8)	227 (19.0)	416 (34.7)
Weight trajectory (N = 1189)			
Stable weight	43 (3.6)	60 (5.0)	103 (8.7)
Weight gain	170 (14.3)	151 (12.7)	321 (27.0)
Weight loss	132 (11.1)	129 (10.9)	261 (22.0)
Weight cycling	240 (20.2)	264 (22.2)	504 (42.4)
History of eating disorders			
Yes	49 (4.1)	39 (3.3)	88 (7.3)
No	541 (45.1)	571 (47.6)	1112 (92.7)
Currently following eating rules			
Yes	216 (18.0)	232 (19.3)	448 (37.3)
No	374 (31.2)	378 (31.5)	752 (62.7)

Values are presented as counts (percentages).

Appendix 3.6. The multi-dimensional model of internally regulated eating style (full version). All loadings were significant at the .01 level. Context effects, method effects, covariances between first- and second-order factors, and disturbance terms of first- and second-order factors are not depicted in the figure for easier readability.



Appendix 3.7. Bivariate correlations of summed scores of MIRES, RI, and MIRES subscales with IES-2 and ecSI-2

	MIRES	RI	IT	FL	FE	SH	SS	SEH	SES
IES-2	.69*	.66*	.54*	.55*	.32*	.53*	.66*	.59*	.70*
UPE	.20*	.31*	.20*	.34*	.03	.17*	.14*	.17*	.15*
EPR	.46*	.38*	.35*	.38*	.16*	.32*	.49*	.36*	.52*
RHSC	.70*	.68*	.56*	.46*	.38*	.57*	.65*	.66*	.68*
BFCC	.43*	.37*	.29*	.22*	.35*	.33*	.43*	.37*	.44*
ecSI-2	.67*	.65*	.50*	.48*	.51*	.60*	.60*	.61*	.59*
EatAtt	.68*	.70*	.50*	.56*	.45*	.60*	.62*	.62*	.60*
FoodAccept	.37*	.38*	.28*	.26*	.39*	.31*	.32*	.34*	.32*
IntReg	.58*	.59*	.47*	.46*	.36*	.51*	.52*	.51*	.53*
ContSkills	.54*	.46*	.38*	.29*	.46*	.51*	.48*	.50*	.46*

MIRES: Multidimensional Internally Regulated Eating Scale, RI: Reflective items, IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation, IES-2: Intuitive Eating Scale-2, UPE: Unconditional Permission to Eat, EPR: Eating for Physical Rather Than Emotional Reasons, RHSC: Reliance on Hunger and Satiety Cues, BFCC: Body Food Choice Congruence, ecSI-2: Eating Competence Satter Inventory 2, EatAtt: Eating Attitudes, FoodAccept: Food Acceptance, IntReg: Internal Regulation, ContSkills: Contextual Skills.

* $p < .05$

Appendix 3.8. Standardized regression coefficients (and R^2) for the criterion validity of MIRES, IES-2, and ecSI-2

	MIRES[a]	IES-2[a]	ecSI-2[a]	IT[b]	FL[b]	FE[b]	SH[b]	SS[b]	SEH[b]	SES[b]	RI[b]
BES	-.42	-.50	-.18	-.30	-.31	-.15	-.33	-.48	-.34	-.51	-.36
	(.17)[c]	(.25)[c]	(.03)[c]	(.09)[c]	(.10)[c]	(.02)[c]	(.11)[c]	(.23)[c]	(.12)[c]	(.26)[c]	(.13)[c]
RES	-.17	-.14	-.14	-.10	-.11	-.13	-.23	-.16	-.15	-.14	-.14
	(.03)[c]	(.02)[c]	(.02)[c]	(.01)[c]	(.01)[c]	(.02)[c]	(.05)[c]	(.03)[c]	(.02)[c]	(.02)[c]	(.02)[c]
PCS	.41	.39	.48	.32	.27	.35	.39	.40	.39	.41	.39
	(.17)[c]	(.15)[c]	(.23)[c]	(.10)[c]	(.07)[c]	(.12)[c]	(.15)[c]	(.16)[c]	(.15)[c]	(.17)[c]	(.15)[c]
SR	.26	.22	.17	.21	.17	.13	.15	.30	.20	.34	.25
	(.07)[c]	(.05)[c]	(.03)[c]	(.04)[c]	(.03)[c]	(.02)[c]	(.02)[c]	(.09)[c]	(.04)[c]	(.12)[c]	(.06)[c]
SE	.26	.22	.23	.21	.18	.25	.18	.27	.25	.30	.25
	(.07)[c]	(.05)[c]	(.05)[c]	(.05)[c]	(.03)[c]	(.06)[c]	(.03)[c]	(.07)[c]	(.06)[c]	(.10)[c]	(.06)[c]
BAS-2	.50	.53	.59	.40	.48	.35	.40	.50	.45	.51	.51
	(.25)[c]	(.28)[c]	(.35)[c]	(.16)[c]	(.23)[c]	(.12)[c]	(.16)[c]	(.25)[c]	(.20)[c]	(.26)[c]	(.26)[c]
SWLS	.30	.29	.42	.24	.22	.24	.25	.29	.29	.30	.28
	(.09)[c]	(.09)[c]	(.18)[c]	(.06)[c]	(.05)[c]	(.06)[c]	(.06)[c]	(.08)[c]	(.08)[c]	(.09)[c]	(.08)[c]
SISE	.34	.35	.40	.28	.34	.25	.28	.33	.31	.34	.33
	(.12)[d]	(.12)[d]	(.16)[d]	(.08)[c]	(.12)[c]	(.06)[c]	(.08)[c]	(.11)[c]	(.10)[c]	(.11)[c]	(.11)[c]
BMI	-.15	-.21	-.12	-.18	-.21	-.04[e]	-.07	-.16	-.13	-.19	-.17
	(.02)[d]	(.05)[d]	(.01)[d]	(.03)[c]	(.05)[c]	(<.01)[c]	(<.01)[c]	(.02)[c]	(.02)[c]	(.04)[c]	(.03)[c]
MWC	-.16	-.21	-.16	-.15	-.14	-.07	-.14	-.14	-.16	-.17	-.17
	(.03)[d]	(.04)[d]	(.03)[d]	(.02)[c]	(.02)[c]	(<.01)[c]	(.02)[c]	(.02)[c]	(.02)[c]	(.03)[c]	(.03)[c]
WCS	-.22	-.27	-.09	-.21	-.23	-.08[e]	-.19	-.25	-.17	-.25	-.22
(N=504)	(.05)[d]	(.07)[d]	(<.01)[d]	(.04)[c]	(.06)[c]	(<.01)[c]	(.04)[c]	(.06)[c]	(.03)[c]	(.06)[c]	(.05)[c]

MIRES: Multidimensional Internally Regulated Eating Scale, IES-2: Intuitive Eating Scale-2, ecSI-2: Eating Competence Satter Inventory 2, IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation, RI: Reflective items, BES: Binge Eating Scale, RES: Restrictive Eating Scale, PCS: Proactive Coping Scale, SR: Satiety Responsiveness, SE: Slowness in Eating, BAS-2: Body Appreciation Scale-2, SWLS: Satisfaction With Life Scale, SISE: Single Item Self-Esteem Scale, BMI: Body Mass Index, MWC: Maximal Weight Change, WCS: Weight Cycling Severity.

a Summed score of all items included in the scale.

b Latent factor as measured by observed items taking into account measurement error.

c Values obtained with SEM.

d Values obtained with linear regression.

e Indicates non-significant values ($p > .05$).

Controlling for variables such as gender, age, BMI, and currently following eating rules had minor impact on the results, thus, non-corrected values are displayed.

Appendix 3.9. Standardized regression coefficients (and R^2) for the criterion validity of SH, SS, SEH, SES (full subscales including neutral, emotional, external contexts) *vs.* the neutral counterpart of each subscale

	SH[b]	SH: Neutral[b]	SS[b]	SS: Neutral[b]	SEH[b]	SEH: Neutral[b]	SES[b]	SES: Neutral[b]	MIRES (45)[a]	MIRES (21)[a]
BES	-.33	-.29	-.48	-.44	-.34	-.31	-.51	-.45	-.42	-.39
	(.11)[c]	(.08)[c]	(.23)[c]	(.19)[c]	(.12)[c]	(.10)[c]	(.26)[c]	(.21)[c]	(.17)[c]	(.15)[c]
RES	-.23	-.24	-.16	-.19	-.15	-.18	-.14	-.16	-.17	-.19
	(.05)[c]	(.06)[c]	(.03)[c]	(.04)[c]	(.02)[c]	(.03)[c]	(.02)[c]	(.03)[c]	(.03)[c]	(.04)[c]
PCS	.39	.33	.40	.40	.39	.34	.41	.39	.41	.42
	(.15)[c]	(.11)[c]	(.16)[c]	(.16)[c]	(.15)[c]	(.12)[c]	(.17)[c]	(.16)[c]	(.17)[c]	(.17)[c]
SR	.15	.12	.30	.25	.20	.17	.34	.27	.26	.23
	(.02)[c]	(.01)[c]	(.09)[c]	(.06)[c]	(.04)[c]	(.03)[c]	(.12)[c]	(.07)[c]	(.07)[c]	(.05)[c]
SE	.18	.12	.27	.21	.25	.19	.30	.24	.26	.24
	(.03)[c]	(.01)[c]	(.07)[c]	(.04)[c]	(.06)[c]	(.04)[c]	(.10)[c]	(.06)[c]	(.07)[c]	(.06)[c]
BAS-2	.40	.32	.50	.43	.45	.38	.51	.45	.50	.49
	(.16)[c]	(.10)[c]	(.25)[c]	(.18)[c]	(.20)[c]	(.15)[c]	(.26)[c]	(.20)[c]	(.25)[c]	(.24)[c]
SWLS	.25	.21	.29	.25	.29	.24	.30	.26	.30	.29
	(.06)[c]	(.04)[c]	(.08)[c]	(.06)[c]	(.08)[c]	(.06)[c]	(.09)[c]	(.07)[c]	(.09)[c]	(.08)[c]
SISE	.28	.22	.33	.28	.31	.25	.34	.29	.34	.33
	(.08)[c]	(.05)[c]	(.11)[c]	(.08)[c]	(.10)[c]	(.07)[c]	(.11)[c]	(.08)[c]	(.12)[d]	(.11)[d]
BMI	-.07	-.06	-.16	-.13	-.13	-.10	-.19	-.15	-.15	-.16
	(.005)[c]	(.004)[c]	(.02)[c]	(.02)[c]	(.02)[c]	(.01)[c]	(.04)[c]	(.02)[c]	(.02)[d]	(.02)[d]
MWC	-.14	-.07	-.14	-.14	-.16	-.15	-.17	-.15	-.16	-.16
	(.02)[c]	(.005)[c]	(.02)[c]	(.02)[c]	(.02)[c]	(.02)[c]	(.03)[c]	(.02)[c]	(.03)[d]	(.03)[d]
WCS (N=504)	-.19	-.16	-.25	-.20	-.17	-.17	-.25	-.21	-.22	-.22
	(.04)[c]	(.03)[c]	(.06)[c]	(.04)[c]	(.03)[c]	(.03)[c]	(.06)[c]	(.04)[c]	(.05)[d]	(.05)[d]

SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation, MIRES: Multidimensional Internally Regulated Eating Scale, BES: Binge Eating Scale, RES: Restrictive Eating Scale, PCS: Proactive Coping Scale, SR: Satiety Responsiveness, SE: Slowness in Eating, BAS-2: Body Appreciation Scale-2, SWLS: Satisfaction With Life Scale, SISE: Single Item Self-Esteem Scale, BMI: Body Mass Index, MWC: Maximal Weight Change, WCS: Weight Cycling Severity.

[a] Summed score of all items included in the scale.

[b] Latent factor as measured by observed items taking into account measurement error.

[c] Values obtained with SEM.

[d] Values obtained with linear regression.

Appendix 3.10. Bivariate correlations of summed scores of MIRES (21 items), RI, and MIRES subscales

	1	2	3	4	5	6	7	8
1. MIRES	-							
2. RI	.79*	-						
3. IT	.77*	.60*	-					
4. FL	.69*	.64*	.61*	-				
5. FE	.68*	.46*	.49*	.38*	-			
6. SH: Neutral	.81*	.60*	.47*	.36*	.51*	-		
7. SS: Neutral	.88*	.67*	.55*	.48*	.49*	.77*	-	
8. SEH: Neutral	.85*	.67*	.53*	.42*	.49*	.77*	.77*	-
9. SES: Neutral	.86*	.69*	.55*	.48*	.45*	.66*	.83*	.76*

MIRES: Multidimensional Internally Regulated Eating Scale, RI: Reflective items, IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation.
* $p < .05$

3

Appendix 3.11. Bivariate correlations of summed scores of MIRES (21 items), RI, and MIRES subscales with IES-2 and ecSI-2

	MIRES	RI	IT	FL	FE	SH: Neutral	SS: Neutral	SEH: Neutral	SES: Neutral
IES-2	.66*	.66*	.54*	.55*	.32*	.48*	.59*	.53*	.63*
UPE	.23*	.31*	.20*	.34*	.03	.19*	.16*	.19*	.15*
EPR	.42*	.38*	.35*	.38*	.16*	.26*	.39*	.29*	.43*
RHSC	.68*	.68*	.56*	.46*	.38*	.52*	.60*	.61*	.64*
BFCC	.41*	.37*	.29*	.22*	.35*	.30*	.38*	.33*	.41*
ecSI-2	.67*	.65*	.50*	.48*	.51*	.55*	.57*	.57*	.56*
EatAtt	.70*	.70*	.50*	.56*	.45*	.57*	.59*	.59*	.58*
FoodAccept	.39*	.38*	.28*	.26*	.39*	.30*	.31*	.32*	.31*
IntReg	.59*	.59*	.47*	.46*	.36*	.47*	.50*	.48*	.50*
ContSkills	.52*	.46*	.38*	.29*	.46*	.45*	.45*	.45*	.43*

MIRES: Multidimensional Internally Regulated Eating Scale, RI: Reflective items, IT: Internal trust, FL: Food legalising, FE: Food enjoyment, SH: Sensitivity to physiological signals of hunger, SS: Sensitivity to physiological signals of satiation, SEH: Self-efficacy in using physiological signals of hunger, SES: Self-efficacy in using physiological signals of satiation, IES-2: Intuitive Eating Scale-2, UPE: Unconditional Permission to Eat, EPR: Eating for Physical Rather Than Emotional Reasons, RHSC: Reliance on Hunger and Satiety Cues, BFCC: Body Food Choice Congruence, ecSI-2: Eating Competence Satter Inventory 2, EatAtt: Eating Attitudes, FoodAccept: Food Acceptance, IntReg: Internal Regulation, ContSkills: Contextual Skills.

* $p < .05$

Appendix 3.12. Incremental variance in outcome measures accounted for by MIRES (21 items)

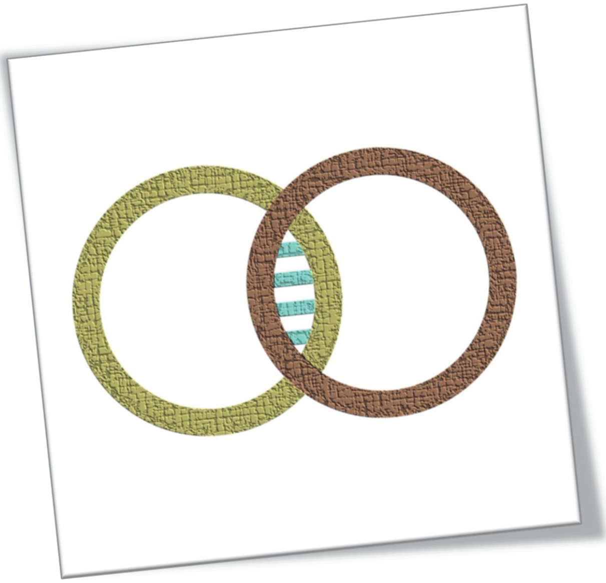
	MIRES vs. IES-2				MIRES vs. ecSI-2			
	R^2 (IES-2)	R^2 (IES-2 + MIRES)	ΔR^2	*p*	R^2 (ecSI-2)	R^2 (ecSI-2 + MIRES)	ΔR^2	*p*
BES[a]	.25	.26	.01	.002	.03	.17	.13	<.001
RES[a]	.02	.04	.02	<.001	.02	.04	.02	<.001
PCS[a]	.15	.20	.05	<.001	.23	.25	.03	<.001
SR[a]	.05	.06	.01	<.001	.03	.07	.04	<.001
SE[a]	.05	.06	.02	<.001	.05	.07	.02	<.001
BAS-2[a]	.28	.32	.03	<.001	.35	.36	.02	<.001
SWLS[a]	.09	.10	.02	<.001	.18	.18	.00	.82
SISE[b]	.12	.14	.02	<.001	.16	.17	.01	.001
BMI[b]	.05	.05	.00	.52	.01	.02	.01	<.001
MWC[b]	.04	.04	.00	.21	.03	.03	.01	.01
WCS[b] **(N=504)**	.07	.07	.00	.22	.01	.06	.05	<.001

MIRES: Multidimensional Internally Regulated Eating Scale, IES-2: Intuitive Eating Scale-2, ecSI-2: Eating Competence Satter Inventory 2, BES: Binge Eating Scale, RES: Restrictive Eating Scale, PCS: Proactive Coping Scale, SR: Satiety Responsiveness, SE: Slowness in Eating, BAS-2: Body Appreciation Scale-2, SWLS: Satisfaction With Life Scale, SISE: Single Item Self-Esteem Scale, BMI: Body Mass Index, MWC: Maximal Weight Change, WCS: Weight Cycling Severity.
[a] Values obtained with SEM.
[b] Values obtained with hierarchical regression analysis.

3

Chapter 4

Trait vs. State Sensitivity to Bodily Signals of Satiation and Hunger: a Tale of Construct Validity



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Abstract

The ability to perceive bodily signals of satiation and hunger is key for the self-regulation of food intake. Measuring this competence in large populations and/or in ecologically valid conditions requires valid self-reports. In this research, we tested the construct validity of two self-report measures of the Multidimensional Internally Regulated Eating Scale (MIRES); Sensitivity to physiological signals of satiation (SS) and Sensitivity to physiological signals of hunger (SH). In two pre-registered studies, we examined associations of SS and SH with behavioural indicators of the incidental ability to perceive the onset of satiation and hunger, respectively, but also with a generic self-report of interoceptive awareness (Multidimensional Assessment of Interoceptive Awareness - MAIA). The associations of MAIA with the behavioural indicators were also examined. In a healthy sample of 113 males/females (19-68 years), SS was not associated with satiation threshold as measured with the water load test in the laboratory (Study 1). Likewise, in a healthy sample of 107 females (18-27 years), SH was not associated with hunger threshold as measured with the preload test in a semi-controlled setting (Study 2). Neither MAIA was associated with the thresholds, but was positively associated with SS and SH, providing preliminary evidence for their construct validity.

4.1. Introduction

Bodily sensations of satiation and hunger are important determinants of the human eating behaviour. Yet, the relative contribution of such sensations in eating-related decisions varies substantially between individuals (Tuomisto et al., 1998). Some have a stronger tendency than others to rely on bodily signals to determine when and how much to eat (Palascha et al., 2020c) and this depends, among other factors, on one's own ability to perceive such signals. This ability can be seen as a domain-specific type of interoception (i.e., the ability to perceive/sense changes in the internal state of the body (Murphy et al., 2017)) and is considered adaptive since it associates positively with proactive coping, satisfaction with life, self-esteem, and body appreciation, and negatively with eating disorder symptomatology, BMI, and weight cycling (Palascha et al., 2020c).

The ability to perceive bodily signals of satiation and hunger is, thus, a plausible predictor of health outcomes; yet it is often overlooked and there is lack of valid measures to easily capture this ability in large and diverse samples of the population and/or in ecologically valid settings. Palascha et al. (2020c) have recently developed the Multidimensional Internally Regulated Eating Scale (MIRES), a self-report measure that assesses, among other individual-difference characteristics, one's sensitivity to physiological signals of satiation (SS subscale) and hunger (SH subscale), defined as the ability to sense/perceive and interpret the signals that the body generates in response to satiation and hunger (Palascha et al., 2020a). SS and SH are reliable and stable, and as mentioned previously, predict self-reported physical, psychological, and behavioural outcomes in expected ways (Palascha et al., 2020c). However, construct validity of these subscales has not been fully examined yet.

This research aimed to test the construct validity of SS (Study 1) and SH (Study 2) by examining their association with behavioural indicators of the incidental ability to perceive the onset of satiation (i.e., satiation threshold as measured with the water load test (WLT)) and hunger (i.e., hunger threshold as measured with the preload test), respectively. It is known that signals of satiation and hunger emerge in subtle forms (low intensity) and become stronger as long as we do not respond to them by ceasing or initiating a meal (Murray & Vickers, 2009). Also, individuals differ substantially in how easily they perceive such signals (Stevenson et al., 2015). For example, when stomach distention was induced in healthy individuals by a water-inflated gastric balloon, some individuals needed almost 10 times higher gastric wall pressure (four times larger volume) than others to reach the same subjective level of fullness (Stephan et al., 2003). Similarly, in the study of Sepple and Read (1989) some participants perceived the return of hunger following the ingestion of a standardized meal four times sooner than others (range 90-360min). Also, while the majority had less than 20% of the meal remaining in the stomach upon the onset of hunger, others started feeling hungry with fuller stomachs. Thus, some individuals require a stronger signal and others a weaker signal to reach the same subjective state of satiation or hunger (Fig. 4.1.). In other words, at a given level of signal intensity, individuals experience a stronger or a weaker sensation depending on how sensitive they are.

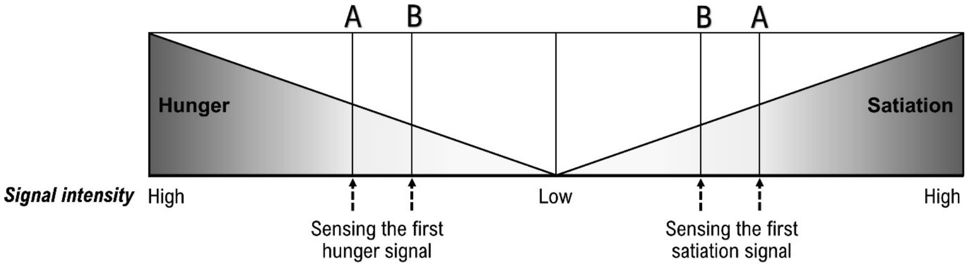

Fig. 4.1. Individual differences in perception of satiation and hunger signals. Individual B perceives the onset of satiation and hunger at lower signal intensity level than individual A (i.e., has lower satiation threshold and lower hunger threshold) because B is more sensitive than A.

We hypothesized that SS is negatively associated with satiation threshold, i.e., the higher individuals score on SS the smaller percentage of their stomach capacity they need to fill with water to perceive the onset of satiation. Similarly, SH was expected to be negatively associated with hunger threshold, i.e., the higher individuals score on SH the less time they need to perceive the onset of hunger following the consumption of a standardised preload. In line with common practice in scale validation and to provide additional evidence on the construct validity of SS and SH, we also examined associations with a generic self-report measure of interoception, the Multidimensional Assessment of Interoceptive Awareness (MAIA) (Mehling et al., 2012), which assesses body awareness, a conceptually similar but broader, non-domain-specific construct. Given this conceptual similarity, a positive association was expected between SS/SH and MAIA. More importantly, SS and SH, were expected to correlate more strongly than MAIA with their respective threshold.

This research contributes to the sparse literature that has examined the validity of self-report measures within the eating domain (but also more broadly) beyond testing for associations with other self-reports. In this way, strong evidence of construct validity can be obtained for these measures. Furthermore, it informs decisions on whether laborious procedures that assess the perception of satiation and hunger can be substituted by survey-based questionnaires, which can be applied conveniently in large population samples and in ecologically valid conditions. The studies presented in this paper were pre-registered[1] and were pre-approved by the Social Sciences Ethics Committee of Wageningen University & Research. Participants provided their written consent at the beginning of each study.

4.2. Study 1

This study examined the association of SS (and MAIA) with satiation threshold, as measured with the WLT (van Dyck et al., 2016); a non-invasive laboratory procedure that assesses how much water individuals need to ingest, starting from an empty stomach, to perceive their first signal of satiation corrected for maximum stomach capacity (referred to as *satiation threshold*). We selected this methodology because water, as opposed to caloric stimuli, restricts the process of satiation to gastric distention and rules out a series of cognitive factors that can also influence the quantities that individuals ingest to reach satiation (e.g., satiation expectations, sensory-specific satiation, cognitive restraint). Previous research has found that meal volume rather than energy content determines perception of satiation (Goetze et al., 2007; Rolls et al., 2000) and fullness ratings are related to total gastric volume for both nutrient and non-nutrient meals (Marciani et al., 2001). Thus, the WLT seemed a valuable alternative to assess the incidental ability to perceive the onset of bodily signals of satiation.

[1] The following deviations from the pre-registration took place during data collection and analysis. 1. The age range in Study 2 was adjusted from 18-25 to 18-29 to allow for the timely completion of data collection. 2. The measure of extreme response style was not used as control variable in the main analyses because there was no reason to expect this tendency to account for variance in satiation and hunger thresholds. Also, extreme response style was not significantly correlated to any of the main dependent and independent variables of this research. 3. Hunger sensations reported after the preload were not included as control variables in the main analysis in Study 2 because these could vary systematically with the DV, introducing multicollinearity issues to the model.

4.2.1. Methods

4.2.1.1. Sample size rationale

The required sample size to detect a moderate correlation between SS and satiation threshold (r = 0.3) (i.e., smallest effect size that we considered meaningful) with an alpha level of 0.05 and a power level of 0.9 in a two-tailed bivariate correlation was 112 participants (as calculated in G Power 3.1). We aimed to recruit a total of 120 participants to account for potential losses during data collection.

4.2.1.2. Participants and procedure

Participants were recruited in a Dutch city via posters, flyers, mailing lists, social media posts, as well as via a market research agency. Only Dutch people who said they understand English moderately well, very well, or extremely well (on a scale ranging from 1 = "not well at all" to 5 = "extremely well") could participate because the study was conducted in English, but one (filler) task was in Dutch. Interested individuals filled in an online questionnaire with the study's eligibility criteria and SS. Individuals with the following conditions were excluded: any type of diabetes, any type of gastrointestinal diseases (including mild conditions, e.g., heartburn, dyspepsia, bloating, irritable bowel syndrome), hypertension, cardiovascular diseases, diseases of the respiratory system, mental illnesses, eating disorders, history of bariatric surgery, use of medication that is known to affect appetite and weight, pregnant and lactating women. Data from 119 participants was collected. Six participants were excluded because they failed to comply with the instructions for preparation (described below), leaving a sample of 113 participants for analysis (29 males, 84 females). Participants' average age was 32.08 years (SD = 15.58) and average Body Mass Index (BMI) was 23.23kg/m^2 (SD = 3.48) (3.7% underweight, 70.6% normal weight, 22.0% overweight, 3.7% obese). Five participants (4.4%) reported dieting for weight loss purposes at the time of the study.

Lab sessions took place between 9:00 and 11:30. Participants were instructed to refrain from eating (including caloric drinks) for at least three hours prior to their session, from drinking (including water, coffee, or tea) for at least two hours prior to their session, from intense physical activity in the morning of their session, and from alcohol consumption the day prior to their session. In this way, participants were at the same physical state at baseline and situational factors that can influence the processes of gastric distention and emptying were controlled for

(Costa et al., 2017). Instruction compliance was checked verbally but also by calculating the time interval since participants had last eaten and drank something. First, participants were asked to imagine how they typically experience the states of comfortable satiation (Concept T1) and complete fullness (Concept T2) in a normal consumption situation and to rate those states in terms of satiation sensations. Then, they reported their baseline (T0) momentary sensations of satiation and hunger and disposition to eat (DTE). After a filler task[2], the WLT took place. Sensations of satiation and DTE were assessed after the first (T1) and after the second (T2) drinking round. In the end, participants filled in the remaining self-reports and control measures. Participants were rewarded with snacks and shopping vouchers (Fig. 4.2.) and received a debriefing email upon completion of data collection.

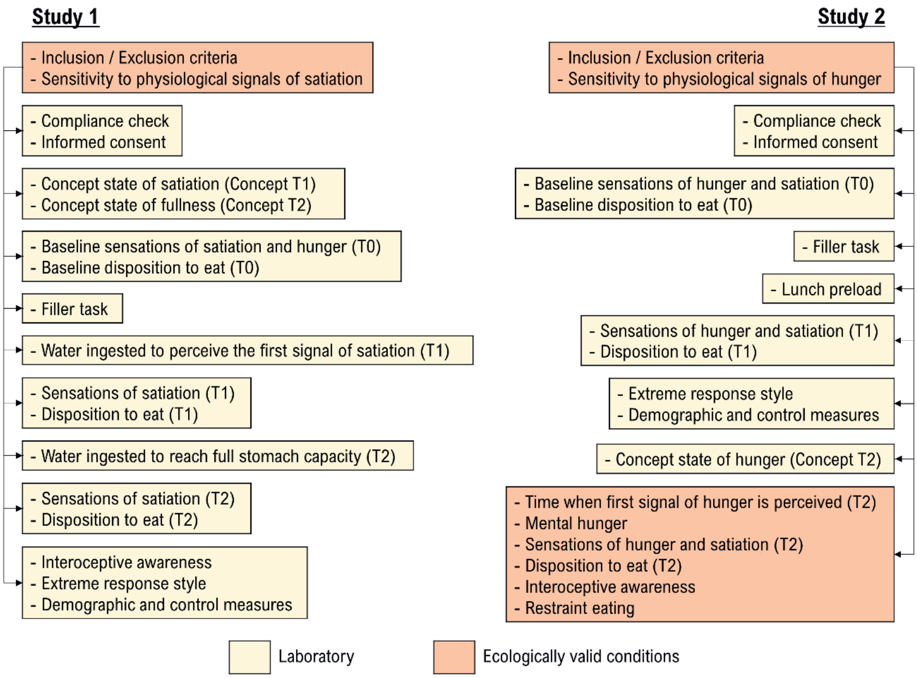

Fig. 4.2. Timeline of Studies 1 and 2

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[2] The filler task (i.e., listening and evaluating a short audio fragment) served as a neutral activity that kept participants busy for about the same amount of time as a mindfulness exercise that was conducted in a different group of participants (not described in this paper). In another manuscript, we discuss the effect of the mindfulness manipulation on satiation and hunger threshold (Palascha et al., 2021a).

4.2.1.3. Measures

Satiation threshold. Participants were given a covered 1.5L bottle of water and a straw and were asked to drink ad libitum until perceiving a first signal of satiation. The following instructions were given (slightly adapted from van Dyck et al. (2016)): 'We ask you to drink water with the straw until you perceive your first sign of satiation. By satiation we mean the comfortable sensation you perceive when you have eaten a meal and you have eaten enough, but not too much. You have 5 minutes to complete this task. Start drinking now.' Then, the bottle was replaced by a new identical bottle and participants were asked to continue drinking until reaching the point of maximum stomach fullness. The new instructions were: 'We now ask you to drink again using the straw. Please continue drinking until your stomach is completely full, that is, entirely filled with water. You have 5 minutes to complete this task. Start drinking now.' The following indices were calculated: (1) water volume (in ml) ingested to perceive the first sign of satiation (Intake_Satiation); (2) additional water volume ingested to reach full stomach capacity (Intake_Fullness); (3) total water volume ingested (Intake_Total = Intake_Satiation + Intake_Fullness); and (4) satiation threshold, calculated as the percentage of stomach capacity at which the first signal of satiation is perceived (Intake_Satiation / Intake_Total * 100). The validity of the WLT is supported by the positive association with the barostat method (Boeckxstaens et al., 2001).

Sensitivity to physiological signals of satiation. The SS subscale of MIRES (Palascha et al., 2020c) was used to assess the ability to perceive and interpret the signals that the body naturally generates in response to satiation. The nine items were administered with 7-point scales (1 = "Completely untrue for me" to 7 = "Completely true for me"). Cronbach's alpha was .88 in this study. Responses were averaged to a mean score.

Interoceptive awareness. The MAIA was used to assess interoceptive awareness defined as the 'sensory awareness that originates from the body's physiological states, processes, and actions, and functions as an interactive process that includes a person's appraisal and is shaped by attitudes, beliefs, and experience in their social and cultural context' (Mehling et al., 2012). The 32 items were administered with 6-point frequency scales (0 = "Never" to 5 = "Always"). Known-groups-testing (students vs instructors experienced with body-awareness therapies) and correlations with related constructs (e.g., body consciousness, body connection) have provided support for the scale's construct validity (Mehling et al., 2012). Cronbach's alpha was .87 in this study and responses were averaged.

Sensations of satiation and hunger. A list of 18 sensations commonly used to describe the experience of satiation and hunger was used to assess participants' subjective sensations at baseline (T0) and after each drinking round (T1 and T2) (Monello & Mayer, 1967; Murray & Vickers, 2009). Items were administered with 100mm visual analogue scales (VAS) (0 = "Not at all" to 100 = "As much as I can imagine") and were averaged using the following structure as indicated by Principal Component Analysis (PCA) (Appendix 4.1.): Hunger sensations (weakness, rumbling stomach, lack of concentration, lightheaded, irritated, nervous, tense), Early sensations of satiation (full stomach, satisfied, relaxed, happy), and Late sensations of satiation (heavy feeling, feeling bloated, discomfort, nausea, regret, disgust with yourself). A mean score was calculated for each set of items and each time point.

The satiation sensations were also used to assess how participants subjectively interpret the terms *comfortable satiation* and *complete fullness* that are relevant when performing the WLT. Specifically, participants were asked "Imagine you have just eaten a meal and you have eaten enough but not too much. How would you describe this sensation in terms of the following factors?". By averaging scores on the early and late sensations of satiation, as indicated above, we calculated two indices of participants' concept state of comfortable satiation (Concept T1). Likewise, to assess participants' concept state of complete fullness (Concept T2) participants were asked "Now imagine you have just eaten a meal until your stomach is completely full. How would you describe this sensation in terms of the following factors?" and the respective items were also averaged in two indices (early and late sensations). The four indices were used as control variables in the main analysis because we wanted to rule out any variation in satiation threshold that was caused by variation in interpretation of the WLT's instructions. Finally, participants also reported how frequently they stop eating once they reach the satiation state (Frequency_Satiation) and how frequently they reach the fullness state (Frequency_Fullness) (1 = "Never" to 5 = "Always") in their regular eating occasions.

DTE. DTE familiar foods has been shown to be a very sensitive indicator of appetite (Booth, 2009). In this study, DTE was measured to assess whether the ingestion of water impacted participant's appetite for food, which would indicate whether water is an appropriate stimulus for inducing satiation and fullness. Participants saw two images that each contained 20 items of a sweet (digestive biscuit) or a savoury (cracker with cheese) food cut into smaller pieces and were asked to click on the images to highlight how many quarters (for digestive biscuits) or halves (for crackers with cheese) they would eat if each food offered by itself at that moment. The sum of digestive biscuit quarters provided an indicator of DTE something sweet (DTE_sweet) and the sum of cracker and cheese halves indicated the DTE something savoury (DTE_savoury) at each time point.

Extreme response style. The tendency to consistently select the extremes of rating scales independently of item content was measured with the 16-item Extreme Response Scale (ERS) (Greenleaf, 1992). The scale has been found to be stable and its items exhibit low inter-item correlations as is desired in such measures (Greenleaf, 1992). ERS was used to purify SS from extreme responding bias. Therefore, the items were administered with the same 7-point scale as the SS measure (1 = "Completely true for me" to 7 = "Completely true for me"). Participants who selected the extremes of the rating scale in both ERS and SS 80% of the time or more were identified as extreme responders and were excluded from the analysis.

Demographic and control variables. Participants reported their gender, age (years), weight (kg), height (cm), whether they were dieting for weight loss (Yes/No), whether they were smokers (Yes/No), how many hours they slept the previous night, how physically active they had been the last days (1 = "Not active at all" to 5 = "Extremely active"), how frequently they consume breakfast (1 = "Never" to 5 = "Always"), what was the last time they ate and drank something, and whether they had any reason that prevented them from eating digestive biscuits and crackers with cheese (Yes/No). These variables were measured to characterize the sample, to check participant's compliance with the instruction for preparation, and/or to be used as control variables in the main analyses.

4.2.2. Analysis

Analysis was conducted with SPSS 26. No participant was identified as extreme respondent; thus, all were included in the analyses. To address the main hypothesis, we conducted multiple linear regression analysis with satiation threshold as dependent variable (DV) and SS as independent variable (IV) with and without control variables. The same analysis was conducted with MAIA as the main IV. Bootstrapping (10000 samples) was used to accurately estimate the 95% Confidence Intervals (CI). The assumptions of normality and homoscedasticity were met in both analyses, thus, results are generalizable beyond the study sample. Independent variables were standardised to prevent multi-collinearity issues. Variance Inflation Factors (VIF) and condition indices were inspected for presence of multi-collinearity (desired values below 10) and the Durbin-Watson test was inspected for presence of auto-correlation (desired values around 2). Four repeated-measures ANOVA were conducted to understand how the various stages of the WLT impacted participants' early and late sensations of satiation as well as DTE_sweet and DTE_savoury. To determine whether participants adequately simulated their concept states of satiation and fullness by ingesting water, we used pairwise tests (Bonferroni adjustment) comparing the satiation sensations reported for the concept states (Concept T1 and Concept T2) with those experienced during the WLT (T1 and T2) ($\alpha = .005$). Likewise, we assessed changes in DTE (T1 vs. T0 and T2 vs. T1) ($\alpha = .017$).

4.2.3. Results

Large individual differences were observed in satiation thresholds. Some participants perceived the first signal of satiation at 15.43% of their stomach capacity, while others had to ingest almost 5 times larger volumes (74.61% of stomach capacity). SS did not significantly predict satiation threshold, neither in the absence ($B = 1.28$, $SE = 1.24$, $t = 1.04$, $p = .30$) nor presence of control variables ($B = 1.54$, $SE = 1.43$, $t = 1.08$, $p = .29$) (Table 4.1.). VIF values ranged between 1.00 and 1.14, condition indices between 1.01 and 4.52, and the Durbin-Watson test had a value of 2.02. Neither MAIA predicted satiation threshold significantly (Table 4.2.). Multi-collinearity (VIF between 1.00 and 1.07 and condition indices between 1.00 and 4.49) and auto-correlation (Durbin-Watson test was 2.03) were not present in this model either. A significant positive correlation was observed between SS and MAIA ($r = .27$, $p = .004$) (Table 4.3.). Positive correlations were observed between the various volumes ingested during the WLT and with satiation threshold. Moreover, sensations of satiation at T1 and T2 were not significantly correlated with satiation threshold (neither with the individual volumes ingested at each drinking round), while early sensations of satiation correlated positively with SS (Table 4.4.).

Table 4.1. Crude and adjusted linear regression models predicting satiation threshold by SS

	B	SE	*t*	*p*	Bootstrap 95% CI	R^2
Crude model						
SS	1.28	1.24	1.04	.30	-1.18, 3.70	.01
Adjusted model						
SS	1.54	1.43	1.08	.29	-1.22, 4.49	.06
Age	-1.92	1.66	-1.15	.25	-5.32, 1.56	
Gender	2.45	3.29	.75	.46	-4.44, 10.27	
BMI	1.59	1.50	1.06	.29	-1.29, 5.25	
Dieting	-1.80	6.56	-.27	.79	-18.88, 14.36	
Satiation early sensations_Concept T1	2.23	1.53	1.46	.15	-.75, 6.02	
Satiation late sensations_Concept T1	1.12	1.63	.69	.49	-1.59, 4.19	
Satiation early sensations_Concept T2	-.80	1.61	-.50	.62	-4.21, 2.39	
Satiation late sensations_Concept T2	-1.16	1.80	-.64	.52	-5.28, 2.25	

SS: Sensitivity to physiological signals of satiation, BMI: Body Mass Index

Table 4.2. Crude and adjusted linear regression models predicting satiation threshold by MAIA

	B	SE	*t*	*p*	Bootstrap 95% CI	R^2
Crude model						
MAIA	-.09	1.24	-.07	.94	-3.23, 3.10	<.001
Adjusted model						
MAIA	.20	1.33	.15	.88	-2.99, 3.52	.05
Age	-1.29	1.60	-.81	.42	-4.26, 1.93	
Gender	2.63	3.30	.80	.43	-4.08, 10.75	
BMI	1.34	1.49	.90	.37	-1.62, 4.71	
Dieting	-.80	6.57	-.12	.90	-19.32, 15.42	
Satiation early sensations_Concept T1	2.65	1.48	1.79	.08	-.32, 6.27	
Satiation late sensations_Concept T1	1.26	1.65	.76	.45	-1.57, 4.72	
Satiation early sensations_Concept T2	-1.09	1.61	-.68	.50	-4.54, 2.05	
Satiation late sensations_Concept T2	-1.56	1.80	-.87	.39	-5.93, 1.78	

MAIA: Multidimensional Assessment of Interoceptive Awareness, BMI: Body Mass Index

Table 4.3. Descriptive statistics and correlations for the main variables of Study 1

	M	SD	1	2	3	4	5	6	7	8	9	10
1. Intake_Satiation	339.07	147.74	-									
2. Intake_Fullness	412.96	191.72	.20*	-								
3. Intake_Total	752.04	263.83	.70*	.84*	-							
4. Satiation threshold	45.95	12.85	.52*	-.66*	-.19*	-						
5. SS	5.51	.91	-.04	-.17	-.15	.10	-					
6. MAIA	3.68	.53	.03	.02	.03	-.004	.27*	-				
7. Age	32.08	15.58	-.16	-.11	-.17	-.05	.34*	.25*	-			
8. BMI	23.23	3.48	-.05	-.15	-.14	.03	.06	.09	.47*	-		
9. Physical activity	3.04	.81	-.07	.17	.08	-.18	-.06	.26*	-.02	-.13	-	
10. Frequency_Satiation	3.42	.87	-.10	-.25*	-.24*	.17	.15	.07	-.05	-.03	.06	-
11. Frequency_Fullness	2.30	.76	.01	.14	.11	-.16	-.03	.01	.01	-.09	.007	-.19*

SS: Sensitivity to physiological signals of satiation, MAIA: Multidimensional Assessment of Interoceptive Awareness, BMI: Body Mass Index

* $p < .05$

Table 4.4. Descriptive statistics and correlations for measures of sensation and disposition to eat in Study 1

	M	SD	Range	Satiation threshold	Intake_ Satiation	Intake_ Fullness	Intake_ Total	SS	MAIA
Hunger sensations_T0	22.68	18.09	0-95	-.01	-.001	-.01	-.01	-.24*	-.23*
Satiation early sensations_T0	37.76	17.58	0-79	-.09	.004	.15	.11	.18	.23*
Satiation late sensations_T0	10.27	12.22	0-90	-.02	.04	.06	.06	-.15	-.08
Satiation early sensations_Concept T1	67.52	17.95	6-100	.16	.08	-.11	-.03	.19*	.08
Satiation late sensations_Concept T1	15.00	14.15	0-77	-.01	.06	.15	.14	-.10	-.09
Satiation early sensations_Concept T2	60.05	19.25	4-100	-.004	.06	.07	.08	-.04	.04
Satiation late sensations_Concept T2	51.28	23.07	4-99	-.02	-.01	.05	.03	-.12	.02
Satiation early sensations_T1	57.17	16.10	12-89	.04	.12	.08	.12	.21*	.29*
Satiation late sensations_T1	15.34	14.76	0-98	.09	.06	.02	.05	-.17	-.08
Satiation early sensations_T2	55.37	19.28	2-99	-.10	-.03	.08	.04	.17	.20*
Satiation late sensations_T2	43.56	18.79	0-99	.12	.09	-.01	.04	-.13	-.01
DTE sweet_T0	13.19	9.82	0-54	-.00	.11	.07	.11	-.20*	-.00
DTE savoury_T0	4.31	3.08	0-18	.20*	.28*	-.04	.13	-.01	-.08
DTE sweet_T1	7.24	5.69	0-28	-.01	.11	.06	.10	-.19*	-.04
DTE savoury_T1	2.85	2.23	0-12	.11	.19*	-.03	.09	-.06	-.11
DTE sweet_T2	3.28	4.14	0-20	-.03	.08	.08	.11	-.15	-.05
DTE savoury_T2	1.28	1.58	0-8	-.01	.05	.04	.06	-.07	-.09

SS: Sensitivity to physiological signals of satiation, MAIA: Multidimensional Assessment of Interoceptive Awareness, DTE: Disposition to eat

* $p < .05$

Early and late sensations of satiation varied significantly during the study (Early: F (4,109) = 65.33, $p < .001$, $\eta^2 = .71$; Late: F (4,109) = 144.79, $p < .001$, $\eta^2 = .84$) (Fig. 4.3.). Pairwise comparisons indicated that early sensations were significantly lower at T1 compared with Concept T1 (Mdiff = 10.35, SDdiff = 1.88, $p < .001$). No significant difference in early sensations was observed between T2 and Concept T2 (Mdiff = 4.69, SDdiff = 1.93, p = .17), neither in late sensations between T1 and Concept T1 (Mdiff = -.34, SDdiff = 1.03, p = 1.00). Late sensations were significantly lower at T2 compared with Concept T2 (Mdiff = 7.72, SDdiff = 1.90, p = .001).

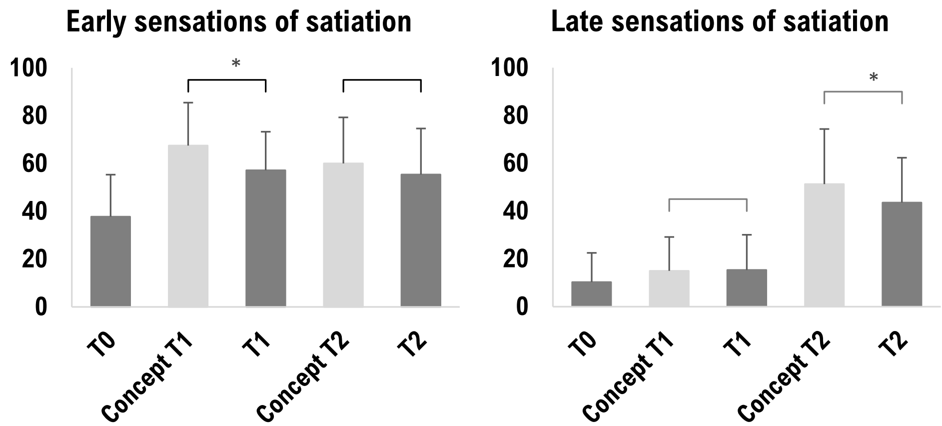


Fig. 4.3. Means and standard deviations for early and late sensations of satiation in Study 1

Finally, DTE_sweet and DTE_savoury also varied significantly during the study (DTE_sweet: F (2,110) = 97.89, $p < .001$, $\eta^2 = .64$; DTE_savoury: F (2,104) = 72.90, $p < .001$, $\eta^2 = .58$) (Fig. 4.4.). DTE_sweet reduced significantly at T1 compared with T0 (Mdiff = -5.97, SDdiff = .66, $p < .001$) and at T2 compared with T1 (Mdiff = -3.97, SDdiff = .31, $p < .001$). Similarly, DTE_savoury decreased significantly both at T1 (Mdiff = -1.46, SDdiff = .18, $p < .001$) and at T2 (Mdiff = -1.63, SDdiff = .16, $p < .001$).

Fig. 4.4. Means (plus 95% CI) for disposition to eat something sweet (digestive biscuit quarters) and something savoury (cracker with cheese halves) in Study 1

4.2.4. Discussion

Contrary to our expectations, neither SS, as a domain-specific self-report, nor MAIA, as a generic self-report, predicted satiation threshold; yet the two self-reports were positively associated. Exploratory analysis of the data showed that the higher people scored in SS, the more intense early sensations they reported at T1, suggesting that sensitivity associates with stronger perception of early sensations of satiation, irrespectively of satiation threshold.

The significant reductions in DTE after each round of the WLT, indicate that the ingestion of water is an effective means for inducing satiation and fullness. Nevertheless, we also found that early sensations of satiation at T1 and late sensations of satiation at T2 were significantly lower compared with the respective concept states, which indicates that water (as compared with food) has a reduced capacity to elicit sensations of satiation. This discrepancy might have impacted satiation threshold in an unbalanced way. Participants who are able to perceive early sensations of satiation might have needed to ingest larger volumes (than the ones they would have ingested if a caloric stimulus had been used) to perceive the onset of satiation. In the contrary, those who perceive the onset of satiation only by means of late sensations of satiation likely ingested their usual volumes (late sensations at T1 did not differ from those reported for Concept T1). As a result, the satiation thresholds of sensitive individuals might have inflated, obscuring, thus, the true association between SS and satiation threshold.

Furthermore, it was evident that the more water participants ingested at T1 (Intake_Satiation) the more they ingested at T2 (Intake_Fullness), suggesting that the greater one's stomach capacity, the more one had to drink to perceive the onset of satiation. This underscores the importance of controlling for one's stomach capacity when using the WLT methodology. Yet, this can also mean that the harder it is for one to perceive the onset of satiation, the harder it is to perceive complete fullness or the less aversive one is to stomach stretch. Thus, the ability to perceive sensations of gastric distention may be a generalized individual trait. Finally, we found that sensations of satiation reported at T1 and T2 were not associated with satiation threshold (neither with individual volumes), suggesting that ingesting more water did not cause participants to experience more intense sensations. Thus, our assumption that people need to ingest different volumes to experience the same subjective states of satiation or fullness was at least not rejected by the data.

Overall, the findings of this study indicate that trait sensitivity to bodily signals of satiation does not predict the incidental ability to perceive the onset of satiation but is positively related to trait interoceptive awareness as well as to self-reported early sensations of satiation at the onset of satiation. Some of our findings suggest that the use of water to assess satiation threshold may be accountable for the lack of association with SS.

4.3. Study 2

In this study we examined the association of SH with hunger threshold, assessed with the preload test in a semi-controlled setting. The preload test (Blundell et al., 2010), assesses how much time individuals need after the ingestion of a standardized preload to perceive their first signal of hunger (referred to as *hunger threshold,* for correspondence with Study 1). Participants consumed in the laboratory a precisely prepared meal (preload) and continued their day as normal with the task of not eating or drinking anything until the moment they would perceive their first signal of hunger. Because it was not possible in this study to rule out by design confounding effects of cognitive factors that could influence the perception of hunger, we measured and controlled for the mental component of hunger (i.e., thinking about food despite not being physically hungry) in the analysis.

4.3.1. Methods

4.3.1.1. Participants and procedure

The same sample size rationale, recruitment means, and eligibility criteria as in Study 1 were used. In addition, we excluded males and individuals who had medical (e.g., allergy, intolerance), ethical, religious, or other personal reasons that prevented them from eating any of the foods offered in this study. We recruited a rather homogeneous sample of females between 18-29 years old to reduce variability in the satiating effect of the preload. Data from 120 participants was collected. Two participants who had incomplete data and seven participants who failed to comply with the instructions for preparation were excluded. Participants' average age was 22.21 years (SD = 2.05) and average BMI was 21.77kg/m^2 (SD = 2.29) (6.5% underweight, 89.7% normal weight, 2.8% overweight, 1.0% obese). One participant reported dieting at the time of the study.

Eligibility criteria and SH were assessed via an online questionnaire. Lab sessions took place between 13:00 and 15:30. Participants were instructed to refrain from eating (including caloric drinks) for at least four hours prior to their session, from intense physical activity in the morning of their session, and from consuming alcohol the day prior to their session. Instruction compliance was checked verbally but also computationally, by calculating the time interval since participants had last eaten and drank something. First, participants reported their baseline (T0) sensations of hunger and satiation and DTE and conducted a filler task (same as Study 1). Then, they were offered the lunch preload and reported the exact time when they finished it (T1). Then, they reported sensations of satiation and hunger and DTE, followed by the ERS and the remaining control measures. At the end of their lab session, participants described their concept state of hunger (Concept T2) (as in Study 1) and were given a sealed questionnaire that they had to fill in by the time they would notice their first signal of hunger (T2). In this questionnaire, they reported the time when they perceived the hunger signal, hunger as a mental state, hunger and satiation sensations, DTE, interoceptive awareness, and restraint eating. Participants returned this questionnaire to the researcher in person or by post and received a shopping voucher as a reward. Participants received a debriefing email upon completion of data collection.

4.3.1.2. Measures

Hunger threshold. Participants consumed a standardized lunch preload consisted of a hummus and cucumber sandwich, a raisin bun, 200ml orange juice, and a cup of water (125ml). The mean caloric content of the preload was 562.87kcals (SD =12.93). Participants filled in the exact time when they finished the preload and were traced in terms of what time they would perceive their first signal of hunger under ecologically valid conditions. They were instructed to not eat or drink anything until they reach this state. The instructions were as follows: “The researcher will now give you a sealed envelope that includes a questionnaire. We ask you to open this envelope the moment you perceive a first sign of hunger. By hunger we mean the sensation you perceive when you haven’t eaten for some time and your stomach is ready to receive food. We request that you don't eat or drink anything (except for water) before you reach this state”. Hunger threshold (in minutes) was calculated by computing the time between finishing the preload and opening the envelope.

Sensitivity to physiological signals of hunger. The SH subscale of MIRES (Palascha et al., 2020c) was used to assess the ability to perceive and interpret the signals that the body naturally generates in response to hunger. The nine items were administered with 7-point scales (1 = “Completely untrue for me” to 7 = “Completely true for me”). Cronbach’s alpha was .88 and items were averaged.

Interoceptive awareness. MAIA was used to measure interoceptive awareness as Study 1. Cronbach’s alpha was .90 in this study.

Sensations of hunger and satiation. Like in Study 1, participants reported their hunger and satiation sensations at baseline (T0), after the preload (T1), and upon the onset of hunger (T2). Items were averaged using the following structure that emerged from PCA (Appendix 4.1.): Hunger early sensations (empty stomach, rumbling stomach), Hunger late sensations (weakness, lack of concentration, lightheaded, tense, nervous, irritated), Satiation early sensations (satisfied, relaxed, happy), and Satiation late sensations (heavy feeling, feeling bloated, nausea, discomfort, regret, disgust with yourself). A mean score was calculated for each set of items and each time point. The hunger sensations were also used to assess participants’ concept state of hunger (Concept T2). The following question was asked “Imagine that you haven’t eaten for some time and your stomach is ready to receive food. How would you describe this sensation in terms of the following factors?”. Participants also reported how frequently they start eating the moment they reach this state (Frequency_Hunger) (1 = “Never” to 5 = “Always”) in normal consumption situations.

DTE. DTE_sweet (chocolate chip cookies in quarters) and DTE_savoury (salty crackers in halves) was measured as in Study 1.

Mental hunger. Hunger as a mental state was assessed with one item (Since you left the lab, to what extent did you think about eating despite not being physically hungry?) administered with a 100mm VAS (0 = “I did not think about eating at all” and 100 = “I was constantly thinking about eating”). Mental hunger was used as control variable because thinking about food can create an attention bias towards food in the environment (Higgs et al., 2015) and could possibly rash the perception of physical hunger.

Extreme response style. As in Study 1, ERS was used to measure extreme response style.

Restraint eating (RE). The RE scale of the Dutch Eating Behaviour Questionnaire (DEBQ) (van Strien et al., 1986) was used to measure one’s intention to restrict food intake in order to control body weight. The 10 items were administered with a 5-point frequency scale (1 = “Never” and 5 = “Very often”). Positive associations with other self-report measures of restraint eating have provided evidence on the scale’s convergent validity (Cebolla et al., 2014). Cronbach’s alpha was .89 in this study and a mean score was calculated, which was used as control variable in the main analyses.

Demographic and control variables. The same demographic and control variables as in Study 1 were measured.

4.3.2. Analysis

Same as Study 1. No participant was identified as extreme respondent. Four outliers were excluded for the assumptions of normality and homoscedasticity to be met; thus, analysis was conducted with 107 participants.

4.3.3. Results

Hunger thresholds ranged between 19 and 330 min for the study participants. SH did not significantly predict hunger threshold, neither in the absence ($B = 3.04$, $SE = 6.01$, $t = .51$, $p = .61$) nor presence of control variables ($B = 1.74$, $SE = 6.37$, $t = .27$, $p = .79$) (Table 4.5.). There was no evidence of multi-collinearity (VIF values: 1.00 - 1.04, Condition indices: 1.15 - 2.05) or auto-correlation (Durbin-Watson: 2.24). Neither MAIA predicted hunger threshold significantly (Table 4.6.). VIF values for this model ranged between 1.00 and 1.02, condition indices between 1.15 and 2.10, and the Durbin-Watson test had a value of 2.23. A significant positive correlation was observed between SH and MAIA ($r = .36$, $p < .001$) (Table 4.7.). Hunger threshold was correlated with measures of sensation and DTE reported at T1, but also with early sensations of hunger at T2, while significant correlations were also observed between SH and several measures of late sensations of hunger and satiation (Table 4.8.).[3]

Table 4.5. Crude and adjusted linear regression models predicting hunger threshold by SH

	B	SE	*t*	*p*	Bootstrap 95% CI	R^2
Crude model						
SH	3.04	6.01	.51	.61	-8.30, 14.48	.002
Adjusted model						
SH	1.74	3.37	.27	.79	-9.69, 14.17	.05
Age	1.44	6.66	.22	.83	-12.81, 14.52	
BMI	2.94	6.62	.44	.66	-11.22, 15.37	
Mental hunger	-9.70	6.27	-1.55	.13	-22.45, 3.69	
RE	6.90	6.52	1.06	.29	-6.85, 21.82	
Dieting	-60.39	67.62	-.89	.37	-113.18, -8.69	
Hunger early sensations_Concept T2	2.56	7.26	.35	.73	-11.99, 15.85	
Hunger late sensations_Concept T2	-3.48	7.35	-.47	.64	-17.42, 12.46	

SH: Sensitivity to physiological signals of hunger, BMI: Body Mass Index, RE: Restrained Eating

[3] MAIA also manifested significant correlations with measures of sensation and DTE. However, we do not interpret these results because these might have occurred by the fact that MAIA was assessed at the end of the study and responses might have been influenced by participants performance in the previous tasks.

Table 4.6. Crude and adjusted linear regression models predicting hunger threshold by MAIA

	B	SE	*t*	*p*	Bootstrap 95% CI	R^2
Crude model						
MAIA	2.50	6.01	.42	.68	-9.67, 14.90	.002
Adjusted model						
MAIA	2.51	6.39	.39	.70	-10.95, 16.61	.05
Age	1.37	6.65	.21	.84	-12.98, 14.79	
BMI	3.06	6.61	.46	.64	-11.18, 15.19	
Mental hunger	-9.96	6.28	-1.59	.12	-23.15, 3.39	
RE	6.93	6.52	1.06	.29	-7.12, 21.90	
Dieting	-62.10	67.86	-.92	.36	-120.87, -3.04	
Hunger early sensations_Concept T2	2.25	7.34	.31	.76	-13.94, 16.47	
Hunger late sensations_Concept T2	-3.24	7.36	-.44	.66	-17.01, 12.32	

MAIA: Multidimensional Assessment of Interoceptive Awareness, BMI: Body Mass Index, RE: Restrained Eating

Table 4.7. Descriptive statistics and correlations for the main variables of Study 2

	M	SD	1	2	3	4	5	6	7	8
1. Hunger threshold	173.01	61.66	-							
2. SH	5.77	.82	.05	-						
3. MAIA	2.89	.55	.04	.36*	-					
4. Mental hunger	4.57	2.42	-.14	-.08	.04	-				
5. RE	1.55	.76	.09	-.03	-.02	.05	-			
6. Age	22.21	2.05	.03	.09	.09	.05	-.11	-		
7. BMI	21.77	2.28	.07	.11	.06	.05	.22*	.20*	-	
8. Physical activity	3.01	.72	-.09	.05	.08	.15	.20*	.07	.02	-
9. Frequency_Hunger	3.94	.70	.04	-.11	-.04	.17	-.01	.16	-.03	-.04

SH: Sensitivity to physiological signals of hunger, MAIA: Multidimensional Assessment of Interoceptive Awareness, RE: Restrained eating, BMI: Body Mass Index

* $p < .05$

Table 4.8. Descriptive statistics and correlations for measures of sensation and disposition to eat in Study 2

	M	SD	Range	Hunger threshold	SH	MAIA
Hunger early sensations_T0	57.98	23.12	3-100	.02	.07	.001
Hunger late sensations_T0	24.83	17.89	0-78	-.11	-.20*	-.18
Satiation early sensations_T0	44.60	18.98	2-91	.11	.13	.22*
Satiation late sensations_T0	12.75	12.68	0-62	-.12	-.17	-.15
Hunger early sensations_T1	6.83	13.48	0-83	-.20*	.03	-.15
Hunger late sensations_T1	9.25	9.24	0-58	-.15	-.18	-.29*
Satiation early sensations_T1	64.19	18.19	13-100	.11	-.06	.21*
Satiation late sensations_T1	28.02	15.86	0-74	.28*	.01	-.01
Hunger early sensations_Concept T2	68.70	20.89	16-99	.03	.06	.11
Hunger late sensations_Concept T2	32.47	20.86	1-89	-.05	-.19*	-.15
Hunger early sensations_T2	46.19	19.38	3-86	.20*	.06	.17
Hunger late sensations_T2	22.75	15.79	1-71	.01	-.30*	-.20*
Satiation early sensations_T2	49.09	16.76	5-80	-.11	.10	.25*
Satiation late sensations_T2	12.56	10.56	0-60	.12	-.23*	-.18
DTE sweet_T0	12.77	9.27	0-60	-.03	-.14	-.16
DTE savoury_T0	11.63	7.71	0-40	-.03	-.09	-.11
DTE sweet_T1	3.66	3.58	0-20	-.20*	-.10	-.21*
DTE savoury_T1	2.91	3.47	0-22	-.25*	-.01	-.14
DTE sweet_T2	10.31	6.33	0-40	.14	-.09	-21*
DTE savoury_T2	9.13	5.85	0-30	.16	-.01	-.22*

SH: Sensitivity to physiological signals of hunger, MAIA: Multidimensional Assessment of Interoceptive Awareness, DTE: Disposition to eat
* $p < .05$

Both early ($F(3,104) = 260.15$, $p < .001$, $\eta^2 = .88$) and late sensations of hunger ($F(3,104) = 67.74$, $p < .001$, $\eta^2 = .66$) changed significantly during the study (Fig. 4.5.). Pairwise comparisons indicated that both early (Mdiff = 22.50, SDdiff = 2.16, $p < .001$) and late (Mdiff = 9.72, SDdiff = 1.27, $p < .001$) sensations were significantly lower at T2 compared with Concept T2.

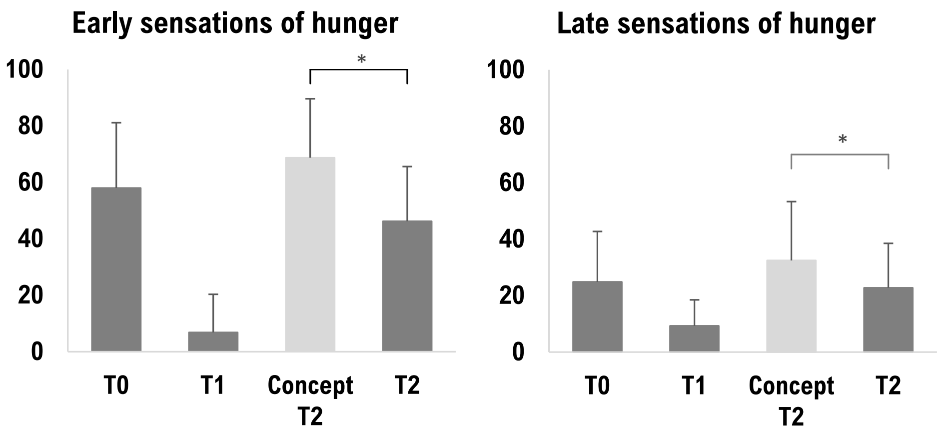


Fig. 4.5. Means and standard deviations for early and late sensations of hunger in Study 2

Finally, DTE_sweet ($F(2,104) = 115.82$, $p < .001$, $\eta^2 = .69$) and DTE_savoury ($F(2,103) = 111.42$, $p < .001$, $\eta^2 = .68$) also changed significantly during the study (Fig. 4.6.). DTE_sweet decreased significantly at T1 compared with T0 (Mdiff = -9.11, SDdiff = .75, $p < .001$) and increased significantly at T2 compared with T1 (Mdiff = 6.67, SDdiff = .50, $p < .001$). Likewise, DTE_savoury decreased significantly at T1 (Mdiff = -8.84, SDdiff = .65, $p < .001$) and increased significantly at T2 (Mdiff = 6.30, SDdiff = .54, $p < .001$).

Fig. 4.6. Means (plus 95% CI) for disposition to eat something sweet (chocolate chip cookie quarters) and something savoury (salty cracker halves) in Study 2

4.3.4. Discussion

This study failed to confirm the hypothesis that SH and MAIA would predict hunger threshold. However, the two self-reports were positively correlated. Exploratory analysis of the data showed that SH was also negatively associated with late sensations of hunger at T2, thus, the more sensitive participants said they are, the less intense late sensations of hunger they experienced upon the onset of hunger. It is possible, therefore, that sensitive individuals did not need to experience late hunger sensations to perceive the onset of hunger because they were able to sense and respond to early sensations, irrespectively of hunger threshold.

Furthermore, we found that hunger threshold was associated with several measures of sensation and DTE at T1, which indicates that hunger threshold was influenced by how satiated participants felt after the preload. Thus, our efforts to limit variation in the satiating effect of the preload by recruiting a relatively homogeneous sample of young females were not completely successful. Moreover, in this study, hunger threshold was positively correlated with early hunger sensations at T2, which means that early hunger sensations became stronger the more time one needed to perceive the onset of hunger. This is contradictory to what was observed in Study 1, where satiation threshold was not associated with sensations reported after each drinking round, and disconfirms our assumption that people need different amounts of time to reach the same subjective state of hunger after consuming a standardized preload. This inconsistency could be explained by the fact that satiation threshold was controlled for stomach capacity, while hunger threshold was not controlled for the rate of gastric emptying or the hormonal response to the preload, two important confounders in this research.

Finally, we found that participants experienced less intense hunger sensations (early and late) upon the onset of hunger (T2) compared with their concept state of hunger (Concept T2), indicating a heightened ability to perceive the onset of hunger. There are two likely explanations for this finding; either participants perceived the signal sooner than normal because they actively attended to their bodily sensations or a demand effect occurred (i.e., participants exaggerated their competence deliberately).

The findings of this research converge with those of Study 1 and together suggest that trait and state sensitivity to bodily signals do not necessarily go hand in hand. Plausible explanations for this lack of convergence are discussed below.

4.4. General discussion

In this research we conducted a stringent test of construct validity for two self-report measures of sensitivity to physiological signals of satiation and hunger (SS and SH subscales of MIRES), by examining their association with behavioural indicators of the incidental ability to perceive the onset of satiation and hunger, respectively. In addition, we examined the associations of SS and SH with a generic self-report measure of interoceptive awareness (MAIA) and we aimed to compare the ability of the domain-specific and generic self-reports to predict the behavioural indicators. Contrary to our expectations, none of the self-reports predicted the behavioural indicators. Yet, SS and SH were positively associated with MAIA.

There are several plausible explanations for these findings. First, it is likely that either the self-reports or the behavioural indicators (or both) do not really capture the theoretical constructs they are assumed to be capturing. Unfortunately, our data do not allow us to ascertain which measure is (more) problematic. Alternatively, the different measures may be capturing different parts of the same construct. The behavioural indicators we employed in this research perhaps focused too heavily on visceral sensations, while SS and SH may in fact be capturing sensitivity to a broader range of bodily sensations of satiation (e.g., a general feeling of being re-energized) and hunger (e.g., general weakness). Second, our data suggest that the experimental stimuli (Study 1) or the experimental procedure itself (Study 2) may have introduced bias to the behavioural indicators. For example, in Study 1 the use of water perhaps backfired, leading highly sensitive individuals to ingest larger volumes than they would normally need to perceive the onset of satiation. In contrast, in Study 2 both early and late hunger sensations reported at the onset of hunger were lower compared with the concept state of hunger, indicating a general deflation of hunger thresholds, caused either by the active attendance to bodily sensations or by a demand effect. It is also possible that the true associations between self-reports and behavioural indicators were of smaller magnitude than the ones our studies were powered to detect. Finally, several types of self-report bias (e.g., socially desirable responding, acquiescent responding), the lack of sufficient self-awareness, or self-deception, might have also influenced our results (McDonald, 2008). These biases concern both the self-reports and the behavioural indicators of this research since the latter too involve subtle elements of self-reporting.

A useful theory to interpret these result is the signal detection theory (Green & Swets, 1966). This theory holds that the detection of a signal is a decision-making process that takes place under conditions of uncertainty and depends on the intensity of the signal, the sensitivity of the individual to the signal, as well as on cognitive factors (e.g., attention, perceived consequences of signal misattribution). In our research, signal intensity was gradually increased until participants could reach their detection threshold and trait sensitivity was assumed to be reflected on this threshold. However, cognitive factors were not controlled for. It is likely, therefore, that a large amount of unexplained variance in thresholds is accounted for by variability in attention paid during the tasks. This is particularly relevant in Study 2, where hunger threshold was likely reported amidst a multitude of environmental distractions. Furthermore, in Study 1, some participants might have been more aversive than others to thirst, and, therefore, more strongly inclined to report the onset of satiation with delay because this would allow them to drink more water. In turn, in Study 2, some participants might have been more strongly inclined to rush the reporting of hunger onset because this would give them quicker access to food.

The lack of association between self-reported traits and incidental indicators of behaviour did not specifically concern SS and SH, but also escalated to the generic self-report of interoceptive awareness (MAIA). This phenomenon has also been observed in other studies. For example, gastric sensitivity, as measured with the WLT, was not associated neither with self-reported body awareness (Ferentzi et al., 2019) nor with self-reported private body consciousness (van Dyck et al., 2016) in studies employing healthy subjects. Similar results have been documented with measures of eating behaviour. For example, self-reported external eating was found to be positively associated with self-reported food reactivity but not associated with food intake after food cue exposure (Jansen et al., 2011). Similarly, Stice et al. (2010) found that four self-report measures of restrained eating were not correlated with an objective measure of caloric intake over a 2-week period. It is possible, therefore, that our results tap into a broader phenomenon. According to the principle of correspondence, general dispositions/traits are not always associated with specific behaviours but are more likely to associate with aggregate measures of behaviour (multi-act indices) (Ajzen, 1987). Our results confirm and further extend this assertion, as we have shown that neither competences manifest themselves in momentary challenge tasks.

Although the present studies failed to confirm the main hypotheses, several findings in this research comprise preliminary evidence for the construct validity of SS and SH. First, it was evident that trait sensitivity to bodily signals of satiation or hunger was positively associated with trait interoceptive awareness, which indicates that SS and SH tap into the broader theoretical construct they are intended to measure. Additionally, SS was associated with stronger perception of early sensations of satiation at the onset of satiation and SH was associated with weaker perception of late sensations of hunger at the onset of hunger, indicating a trend towards subtle signal perception at higher sensitivity levels. Yet, these pieces of evidence should be treated with caution because they are based on exploratory analysis of the data.

The following limitations should be acknowledged for the present research. As discussed earlier, in this research we did not control for a series of cognitive factors that could influence the satiation and hunger thresholds. Furthermore, as explained earlier, the use of water in Study 1 might have introduced bias in the satiation threshold of individuals who were particularly sensitive to early signals of satiation. In turn, in Study 2 hunger threshold was reported under ecologically valid conditions and might have been influenced by several uncontrolled factors (e.g., physical activity, environmental distractions). More importantly, in this study we did not control for rate of gastric emptying or the hormonal response to the preload. These factors could potentially explain a large amount of variation in hunger threshold.

Despite these limitations, the following theoretical and practical implications can be drawn from this research. One issue that emerges is that, with regard to eating-related interoceptive abilities, there should be caution when using self-reports to predict incidental behaviours and vice versa. In relation to that, researchers should be careful when reviewing evidence from studies that employ different methodologies of assessing interoceptive processes in the eating domain. On a more practical note, it became evident that the WLT is perhaps less ideal for studying perception of early signals of satiation because these are elicited to a lesser extent with water than with food.

More research is needed to assess the validity of SS and SH. Future studies could measure satiation threshold using a caloric load test, thereby allowing the full spectrum of physical sensations of satiation to emerge. If the caloric preload is ingested orally, cognitive factors (e.g., satiation expectations) should be controlled for. Alternatively, infusion of the caloric load directly in the stomach would surpass oral exposure and the accompanying cognitive effects. Ideally, several measurements of satiation or hunger threshold should be taken to calculate aggregate and more representative indicators of competence. Furthermore, neuroimaging studies could be employed to assess the association of trait sensitivity to bodily signals of satiation and hunger with patterns of neural activation in the brain during behavioural tasks. For example, Beaver et al. (2006) showed that trait reward sensitivity (as measured with the Behavioural Activation Scale - BAS) was highly correlated with activation in relevant brain regions as a response to images of palatable food. This finding supports the construct validity of the BAS scale and elucidates a possible explanation for individual differences in reward sensitivity. Sensitivity to bodily signals of satiation and hunger may be mapped in the brain in a similar way. Finally, future studies could try to disentangle the visceral processes that generate peripheral signals of satiation and hunger (i.e., neural or hormonal signals that are transmitted to the brain) from the corresponding neural activation processes that take place in the brain. This might help understand the relative contribution of the various signalling processes in determining one's level of sensitivity and to explain more accurately individual differences in this domain. To study these associations, measures of brain activity should be complemented with physiological measures of gastric wall tension, gastric emptying rate, and hormonal response to nutrients.

4.5. Conclusions

Self-reports of trait sensitivity to physiological signals of satiation (SS) and hunger (SH) were positively associated with a generic self-report of trait interoceptive awareness (MAIA) but not with behavioural indicators of the incidental (state) ability to perceive the onset of satiation and hunger, thereby showing only preliminary evidence of construct validity. This research contributes to the scarce literature that has examined the convergence between self-reported (trait) and behavioural (state) responses in the eating domain.

Appendix 4.1. Results of the Principal Component Analyses (PCA)

Study 1

We conducted separate analyses for satiation sensations at Concept T1 (first time that participants responded to these items) and for hunger sensations at T0. One component emerged in the PCA with hunger sensations (Table S1) and two in the analysis with satiation sensations (Table S2) by inspection of the scree plots. The items that were asked at later time points were grouped according to the structure that emerged from these analyses. The results of the reliability analysis of the emerged components is shown in Table S3.

Table S1. Summary of PCA results for hunger sensations at T0

	Component 1
Item 1: Lack of concentration	**.86**
Item 2: Irritated	**.84**
Item 3: Weakness	**.81**
Item 4: Tense	**.80**
Item 5: Lightheaded	**.76**
Item 6: Nervous	**.71**
Item 7: Rumbling stomach	**.63**
Eigenvalues	4.22
% of variance	60.28
KMO	.87
Bartlett's Test of Sphericity (p value)	< .001

Table S2. Summary of PCA results for satiation sensations at Concept T1

	Component 1 (Late sensations)	Component 2 (Early sensations)
Item 1: Disgust with yourself	**.82**	-.19
Item 2: Discomfort	**.81**	-.25
Item 3: Feeling bloated	**.78**	.23
Item 4: Nausea	**.77**	-.13
Item 5: Regret	**.77**	-.19
Item 6: Heavy feeling	**.72**	.45
Item 7: Satisfied	-.10	**.86**
Item 8: Happy	-.23	**.79**
Item 9: Full stomach	.28	**.73**
Item 10: Relaxed	-.29	**.71**
Eigenvalues	4.32	2.44
% of variance	43.19	24.41
KMO	.80	
Bartlett's Test of Sphericity (p value)	< .001	

Table S3. Reliability analysis for the resulting components

Component	Cronbach's alpha
Hunger sensations_T0	.88
Satiation early sensations_T0	.73
Satiation late sensations_T0	.82
Satiation early sensations_Concept T1	.82
Satiation late sensations_Concept T1	.86
Satiation early sensations_Concept T2	.75
Satiation late sensations_Concept T2	.88
Satiation early sensations_T1	.76
Satiation late sensations_T1	.87
Satiation early sensations_T2	.75
Satiation late sensations_T2	.80

Study 2

Two PCAs were conducted, one for hunger sensations at T0 and one for satiation sensations at T0 (first time that participants responded to these items). Two components emerged in each analysis by inspection of the scree plots (Tables S4 and S5). The items that were asked at later time points were grouped according to the structure that emerged from these analyses. The results of the reliability analysis of the emerged components is shown in Table S6.

Table S4. Summary of PCA results for hunger sensations at T0

	Component 1 (Late sensations)	Component 2 (Early sensations)
Item 1: Tense	**.91**	-.18
Item 2: Nervous	**.82**	-.22
Item 3: Irritated	**.80**	.06
Item 4: Weakness	**.67**	.29
Item 5: Lack of concentration	**.63**	.35
Item 6: Lightheaded	**.54**	.41
Item 7: Rumbling stomach	-.06	**.89**
Item 8: Empty stomach	.03	**.88**
Eigenvalues	3.93	1.53
% of variance	49.15	19.08
KMO	.80	
Bartlett's Test of Sphericity (p value)	< .001	

Table S5. Summary of PCA results for satiation sensations at T0

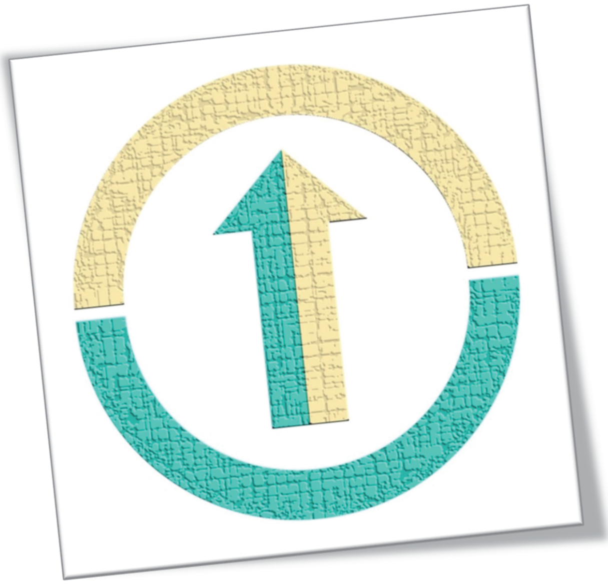
	Component 1 (Late sensations)	Component 2 (Early sensations)
Item 1: Feeling bloated	**.80**	.19
Item 2: Heavy feeling	**.79**	-.04
Item 3: Disgust with yourself	**.73**	.12
Item 4: Nausea	**.73**	-.16
Item 5: Regret	**.72**	.09
Item 6: Discomfort	**.63**	-.35
Item 7: Happy	-.06	**.82**
Item 8: Relaxed	-.06	**.77**
Item 9: Satisfied	.17	**.75**
Eigenvalues	3.30	2.02
% of variance	36.63	22.41
KMO	.71	
Bartlett's Test of Sphericity (p value)	< .001	

Table S6. Reliability analysis for the resulting components

Component	Cronbach’s alpha
Hunger early sensations_T0	.81
Hunger late sensations_T0	.86
Satiation early sensations_T0	.71
Satiation late sensations_T0	.81
Hunger early sensations_T1	.82
Hunger late sensations_T1	.78
Satiation early sensations_T1	.84
Satiation late sensations_T1	.84
Hunger early sensations_Concept T2	.83
Hunger late sensations_Concept T2	.88
Hunger early sensations_T2	.81
Hunger late sensations_T2	.86
Satiation early sensations_T2	.81
Satiation late sensations_T2	.80

Chapter 5

Unveiling the Effect of Mindfulness on Perception of Bodily Signals of Satiation and Hunger



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Abstract

An increasing number of studies investigate the effects of mindfulness on food intake and weight outcomes, while the underlying mechanisms by which mindfulness exerts its effects have received less attention. We conducted two pre-registered studies to shed light on the frequently proposed yet largely understudied hypothesis that mindfulness improves awareness of bodily signals of satiation and hunger. We assessed the ability to perceive the onset of bodily signals of satiation with the two-step water load test (Study 1) and the ability to perceive the onset of bodily signals of hunger with the preload test (Study 2). A brief mindfulness exercise (body scan) did not impact the perception of satiation but improved the ability to perceive bodily signals of hunger. After the consumption of a standardised preload, participants in the two experimental conditions felt equally satiated; nevertheless, those in the mindfulness condition perceived the onset of hunger 18min earlier than those in the control condition and this effect persisted also in the presence of control variables. These findings together suggest that even a single and short mindfulness exercise can improve perception of hunger signals substantially, while more intensive mindfulness training may be needed to impact perception of satiation signals.

5.1. Introduction

Mindfulness has received increasing attention in the domain of eating regulation and weight management over the last decades. Mindfulness-based interventions have been found to reduce dysfunctional eating behaviours (e.g., binge eating, emotional eating, and external eating) (Carrière et al., 2018; O'Reilly et al., 2014), food intake (Tapper, 2017), and weight (Olson & Emery, 2015). Strikingly, even brief mindfulness exercises seem to have positive effects on physical, psychological, and behavioural outcomes (Heppner & Shirk, 2018; Howarth et al., 2019). Considerably less attention has been paid, however, to the underlying mechanisms by which mindfulness exerts these effects. Several mechanisms have been proposed such as enhancement of episodic memory of the eating episode, reduction in eating automaticity, enhancement of sensory-specific satiation, increased awareness of emotional and external cues of eating, and increased awareness of bodily sensations of hunger and satiation (Tapper, 2017; Vanzhula & Levinson, 2020; Warren et al., 2017). Yet only few studies have tested these mechanisms (see Tapper (2017) for an overview).

In particular, there is scarce evidence on the effect of mindfulness on awareness of bodily sensations or hunger and satiation (Vanzhula & Levinson, 2020). Mindfulness-based interventions have been found to improve awareness of internal hunger and satiety cues, as measured with self-reports that are administered before and after the intervention (Warren et al., 2017). Nevertheless, it is possible that this improvement is mainly due to a demand effect because cultivation of awareness and responsiveness to such cues is a core intervention component in these studies. Additional insights come from experimental research in the field of interoception. Interoception refers to the perception of the physiological condition of the body (Craig, 2003) and can be seen as a broad domain that includes, among other systems, awareness of eating-related bodily sensations. Evidence from fMRI studies indicate that mindfulness impacts areas of the brain that are related to interoception, thereby increasing awareness of the internal state of the body (Farb et al., 2013; Ives-Deliperi et al., 2011). Similar results have been reported by studies that use self-report measures of interoceptive awareness (e.g., the Multidimensional Assessment of Interoceptive Awareness - MAIA) (de Jong et al., 2016; Fissler et al., 2016) or behavioural measures of interoceptive accuracy (e.g., heartbeat detection task) (Fischer et al., 2017), although evidence is less consistent for the latter (Ma-Kellams, 2014). To our knowledge no study has investigated the effect of mindfulness on abdominal visceral interoception (or gastric interoception as is commonly referred to), which is the most relevant interoceptive modality for eating-related sensations among the interoceptive modalities known for the various body systems (cardiac, respiratory, skin, etc.). This is an important gap given that different body systems tap into distinct neural processes (Baranauskas et al., 2017) and different measures of interoceptive accuracy do not necessarily correlate with each other (Ferentzi et al., 2018).

While this body of evidence provides preliminary support for the idea that mindfulness improves perception of bodily signals of hunger and satiation, to our knowledge only one study has examined the effect of mindful attention to the body on satiety perception, i.e., feelings of fullness at the post-meal interval. van de Veer et al. (2016) found that participants who ate a low-caloric preload felt less full than those who ate a high-caloric preload only after having performed a brief body scan exercise, while no difference was observed in reported sensations by participants who focussed their attention to an object in the environment or those who conducted a filler task (control group). These results suggest that mindful attention to the body can improve the perception of satiety during the post-meal interval. Yet, the effect of mindfulness on perception of satiation and hunger remains unknown.

In this paper, we present two experimental studies that we conducted to assess the effect of mindfulness, specifically a brief body scan exercise, on the ability to perceive bodily signals of satiation and hunger. In Study 1, we used the two-step Water Load Test (WLT) to measure the ability to perceive the onset of bodily signals of satiation, operationalised as the percentage of stomach capacity that one needs to fill with water to perceive the first signal of satiation (referred to as satiation threshold) (van Dyck et al., 2016). In Study 2 we conducted a standard preload test (Blundell et al., 2010) to measure how much time it takes one to perceive the onset of bodily signals of hunger after ingestion of a standardised preload (referred to as hunger threshold for correspondence with Study 1). Because we were particularly interested in the perception of bodily signals, we made several efforts to distinguish the physical component of satiation and hunger from cognitive components that also underlie these processes. By using water in Study 1 we bypassed the effects of cognitive factors that accompany the ingestion of food (e.g., sensory-specific satiation, satiation expectations, restrained eating tendencies) and restricted the process of satiation to gastric distention, or more accurately, gastro-intestinal distention since water empties quickly from the stomach to the intestine (Murray et al., 1994). After all, it has been shown that volume rather than energy content determines feelings of satiation (Goetze et al., 2007; Rolls et al., 2000). In Study 2 it was not possible to rule out the cognitive (mental) component of hunger (i.e., the tendency to think about food and eating despite not being physically hungry) by the design. Therefore, we measured and controlled for this in the analysis because cognitive elaboration with food can induce an attention bias towards food (Higgs et al., 2015), which might accelerate the perception of hunger. Furthermore, in this research we controlled for individual differences in trait sensitivity to physiological signals of satiation and hunger (Palascha et al., 2020a; 2020c), an important factor that has been overlooked in previous studies (Tapper, 2017).

We hypothesised that individuals who conduct a short body scan exercise (mindfulness condition) achieve a lower mean satiation threshold (i.e., they need to fill a smaller percentage of their stomach capacity with water to perceive their first signal of satiation) (Study 1) and a lower mean hunger threshold (i.e., they need less time to perceive their first signal of hunger after consumption of a standardised preload) (Study 2) compared with individuals who conduct a filler task (control condition). The studies were pre-registered (Study 1: https://osf.io/har5x; Study 2: https://osf.io/2px4a)[1] and were pre-approved by the Social Sciences Ethics Committee of Wageningen University & Research. A written consent was obtained from all participants at the beginning of each study. The data of this research can be found in the Supplementary material. The data of each study's control group were also used to address a different research question (i.e., construct validity of self-report measures of trait sensitivity to satiation and hunger) that is discussed in Palascha et al. (2021b).

5.2. Study 1

5.2.1. Methods

5.2.1.1. Participants

Posters, flyers, emailing lists, social media, and a research agency were used to recruit participants in Wageningen, the Netherlands. Exclusion criteria included any type of diabetes,

[1] During data collection and analysis, we deviated from the pre-registration on the following points. 1. Study's 2 eligibility criterion for age was adjusted from 18-25 to 18-29 to allow for the timely completion of data collection. 2. We did not control the main analyses for extreme response style because there was no theoretical reason to believe that this measure would account for variance in satiation and hunger thresholds. 3. Sensations reported after the preload were not included as control variables in the main analysis in Study 2 to prevent multicollinearity problems since those sensations could vary systematically with hunger threshold.

any type of gastrointestinal diseases (including mild conditions, e.g., heartburn, dyspepsia, bloating, irritable bowel syndrome), hypertension, cardiovascular diseases, diseases of the respiratory system, mental illnesses, eating disorders, history of bariatric surgery, use of medication that is known to affect appetite and weight, pregnant and lactating women. Only Dutch people who said they adequately understand English (i.e., scored three or higher on a scale ranging from 1 = “not well at all” to 5 = “extremely well”) were eligible because the study’s main language was English but the experimental manipulation was conducted in Dutch. We aimed to recruit at least 240 participants in total. The sample size was decided in an auxiliary manner. First, we calculated the required sample size for the control group (n = 120), which would be used to address a research question that is addressed in Palascha et al. (2021b). This sample size was doubled so that a second arm (mindfulness group) of equal size could be recruited. After exclusion of 11 participants who failed to comply with the instructions for preparation (mentioned below) and one participant who had been subjected to the same experimental manipulation in the past, data from 226 participants remained for analysis (57 males, 169 females). Average age was 31.9 years (SD = 15.6) and average Body Mass Index (BMI) was 23.3kg/m^2 (SD = 3.4) (3% underweight, 71% normal weight, 21% overweight, 3% obese, 2% missing). Ten participants (4%) were dieting for weight-loss at the time of the study.

5.2.1.2. Experimental design and manipulation

A quasi experimental design was used in this study. Participants were assigned to one of two experimental conditions such that the following criteria were met in order: 1. no participant had been previously exposed to the same experimental condition (participants could join both Studies 1 and 2, which were conducted in parallel and used the same experimental manipulation) and 2. experimental conditions had the same ratio of males/females during the course of the study. In the mindfulness condition, participants listened to an audio fragment that instructed them to perform a body scan exercise (4.19min). This manipulation aimed to direct participants’ attention to various parts of their body and make them aware of their bodily sensations. In the control condition, participants listened to a neutral audio fragment about tourism (3.49min). The audio fragments were pre-existing material developed by van de Veer et al. (2016). Participants evaluated the audio fragment they listened to in terms of liking (1 = “Dislike a lot” to 5 = “Like a lot”), length (1 = “Too short” to 5 = “Too long”), pace of narrator

(1 = "Extremely slow" to 5 = "Extremely fast"), and interestingness (1 = "It did not catch my interest at all" to 5 = "It caught my interest a lot").

5.2.1.3. Measures

Satiation threshold. Satiation threshold was measured with the two-step WLT (van Dyck et al., 2016). Participants were given a non-transparent 1.5L bottle of water and a straw and were asked to drink ad libitum until they could perceive their first sign of satiation (T1). The instructions were slightly adapted from van Dyck et al. (2016) as follows, to make it explicit that participants should report their *first* signal of satiation (not *a* signal): 'We ask you to drink water with the straw until you perceive your *first* sign of satiation. By satiation we mean the comfortable sensation you perceive when you have eaten a meal and you have eaten enough, but not too much. You have 5 minutes to complete this task. Start drinking now.' Upon completion of the first drinking round, the bottle was replaced by a new identical bottle and participants were asked to continue drinking until reaching their maximum stomach capacity (T2). The instructions were: 'We now ask you to drink again using the straw. Please continue drinking until your stomach is completely full, that is, entirely filled with water. You have 5 minutes to complete this task. Start drinking now.' The following measures were calculated: 1. water volume (in ml) required to perceive the first sign of satiation (Intake Satiation), 2. additional water volume required to produce maximum fullness (Intake Fullness), 3. total water volume ingested (Intake Total), and 4. percentage of Intake Satiation to Intake Total (Satiation threshold).

Trait sensitivity to physiological signals of satiation. The sensitivity to physiological signals of satiation subscale (SS) of the Multidimensional Internally Regulated Eating Scale (MIRES) was used to measure the ability to perceive and interpret the signals that the body naturally generates in response to satiation (Palascha et al., 2020c). The scale consists of nine items administered with 7-point scales (1 = "Completely untrue for me" to 7 = "Completely true for me"). Cronbach's alpha was .89 and items ratings were averaged to an overall score that was used as control variable in the main analysis.

Sensations of satiation and hunger. Participants reported their subjective sensations of hunger and satiation using a list of commonly reported terms identified from prior research (Guss et al., 2000; Monello & Mayer, 1967; Murray & Vickers, 2009). Responses were provided on 100mm visual analogue scales (VAS) (0 = "Not at all" to 100 = "As much as I can imagine").

Hunger sensations were assessed at baseline (T0) and satiation sensations were assessed at baseline and after each drinking round of the WLT (T1 and T2). The items were grouped using the following structure, as indicated by Principal component Analysis (PCA) (see Supplementary material): Hunger sensations (weakness, rumbling stomach, lack of concentration, lightheaded, irritated, nervous, tense), Early sensations of satiation (full stomach, satisfied, relaxed, happy), Late sensations of satiation (heavy feeling, feeling bloated, discomfort, nausea, regret, disgust with yourself). We calculated a mean score for each group of items and each time point and used those scores to compare how the two experimental groups experienced the WLT. Furthermore, we used the satiation sensations to assess participants' concept states of comfortable satiation and complete fullness to control for differences in interpretation of the WLT instructions in the main analysis. Specifically, participants were asked "Imagine you have just eaten a meal and you have eaten enough but not too much. How would you describe this sensation in terms of the following factors?" (Concept T1) and "Now imagine you have just eaten a meal until your stomach is completely full. How would you describe this sensation in terms of the following factors?" (Concept T2). Participants also indicated how frequently they stop eating once they reach comfortable satiation (Frequency Satiation) and how frequently they reach complete fullness (Frequency Fullness) (1 = "Never" to 5 = "Always") under natural circumstances.

Disposition to eat. Participants were presented with two images that each contained 20 items of a food product: digestive biscuits and crackers with cheese, respectively. They were asked to click on the images to highlight how many quarters (for digestive biscuits) and how many halves (for crackers with cheese) they would eat if each food offered by itself at that moment (Booth, 2009). Disposition to eat (DTE) was measured to assess the impact of the WLT on appetite for food. For each time point (T0, T1, T2), we calculated an indicator of DTE something sweet (DTE sweet) by adding the quarters of digestive biscuit and an indicator of DTE something savoury (DTE savoury) by adding the halves of crackers with cheese.

Demographic and control variables. Gender, age (years), weight (kg), height (cm), dieting for weight loss (Yes/No), smoking (Yes/No), last night's sleep duration (hours), physical activity (1 = "Not active at all" to 5 = "Extremely active"), and frequency of breakfast consumption (1 = "Never" to 5 = "Always") were also reported. In addition, participants indicated what time they last ate and drank something and whether there was any medical, ethical, religious, or other personal reason that prevented them from eating digestive biscuits and crackers with cheese (Yes/No). These measures were used to characterise the sample, to compare the experimental groups, to check participants' compliance with the instruction for preparation, and/or to be used as control variables in the main analysis.

Other measures. Extreme response style (Greenleaf, 1992) and interoceptive awareness (Mehling et al., 2012) were also measured to address a research question that is discussed in Palascha et al. (2021b) and are not mentioned further in this paper.

5.2.1.4. Procedure

Interested individuals filled in an online eligibility questionnaire that also assessed trait sensitivity to physiological signals of satiation. Eligible participants arrived at the laboratory between 9:00 and 11:30, having remained abstinent from eating (including caloric drinks) for at least three hours prior to their session, from drinking (including water, coffee, or tea) for at least two hours prior to their session, from intense physical activity in the morning of their session, and from alcohol consumption the day prior to their session. Thus, participants arrived at the same physical state and a series of situational factors that influence the processes of gastric accommodation and gastric emptying were controlled for (Costa et al., 2017; Hellmig et al., 2006). To check participants' compliance with the instructions we asked them verbally upon arrival but also calculated how much time had passed since they had last eaten and drank something. First, we assessed how participants interpret the instructions of the WLT by asking them to imagine a typical consumption situation in which they feel comfortably satiated (Concept T1) or completely full (Concept T2) and to rate how they would feel in each case using a list of satiation sensations. Then, we assessed their baseline (T0) hunger and satiation sensations and disposition to eat, followed by the experimental manipulation. Participants then conducted the WLT and reported their satiation sensations and disposition to eat after the first (T1) and after the second (T2) drinking round. The remaining self-reports and control measures were assessed at the end of the study. Participants were rewarded with snacks and shopping vouchers and received a debriefing email upon completion of data collection.

5.2.2. Analysis

Statistical analysis was performed in SPSS 26. Multiple linear regression analysis was conducted with satiation threshold as dependent variable and experimental condition as independent variable with and without control variables. The assumptions of normality and homoscedasticity were met; thus, the results of this study can be assumed to be generalisable beyond the study's sample (Field, 2009). Furthermore, repeated measures ANOVA was used to assess changes in reported sensations of satiation and disposition to eat during the study. Experimental condition was entered as a between-subjects factor in these analyses and pairwise comparisons with Bonferroni adjustment were used to assess differences between the various time points (alpha was set at $\alpha = .02$). Differences in baseline characteristics and control variables between experimental conditions were assessed with independent samples t-tests. Because we expected to not reject the null hypothesis in these analyses, we also conducted equivalence tests in R to confirm that differences between experimental conditions were significantly small ($-0.5 < D < 0.5$), or in other words, significantly equivalent to zero. Finally, Pearson's chi square tests indicated whether the experimental conditions were comparable in terms of distribution of nominal variables (e.g., males/females).

5.2.3. Results

5.2.3.1. Randomisation check

No significant differences were observed between experimental conditions in age, BMI, SS, sleep duration, physical activity, baseline sensations of hunger and satiation, baseline disposition to eat, concept states of satiation and fullness, and frequency of reaching the concept state of fullness (Table 5.1.). Equivalence tests further showed that these differences were significantly equivalent to zero. The distributions of males/females ($\chi^2(1) = .02$, $p = 1.00$), dieters/non-dieters ($\chi^2(1) < .001$, $p = 1.00$), and smokers/non-smokers ($\chi^2(1) = .35$, $p = .77$) also did not differ significantly between experimental conditions. The control group reported significantly lower frequency of breakfast consumption ($t(224) = -2.50$, $p = .01$) and lower frequency of stopping eating upon experience of comfortable satiation ($t(224) = -2.04$, $p = .04$) compared with the mindfulness group. Finally, the control audio fragment was liked significantly less than the mindfulness audio fragment ($t(224) = -2.56$, $p = .01$) and was also found to be significantly less interesting ($t(224) = -3.46$, $p = .001$), lengthier ($t(224) = 5.75$, $p < .001$), and slower in terms of pace of narration ($t(224) = -4.65$, $p < .001$). Inclusion of these variables in the multiple linear regression model did not impact the results.

Table 5.1. Characteristics of participants in the control and mindfulness group (Study 1)

	t	*p*	M (SD)	
			Control condition	Mindfulness condition
Age (years)	.19	.85	32.1 (15.6)	31.7 (15.6)
BMI (kg/m^2)	-.09	.93	23.2 (3.5)	23.3 (3.2)
SS (scales 1-7)	-.69	.49	6 (1)	6 (1)
Sleep duration (hours)	.19	.85	8 (1)	8 (1)
Physical activity (scale 1-5)	-.57	.57	3 (1)	3 (1)
Frequency of breakfast consumption (scale 1-5)	-2.50	.01	5 (1)	5 (1)
Hunger sensations T0 (scales 1-100)	.55	.59	23 (18)	21 (16)
Satiation early sensations T0 (scales 1-100)	.20	.84	38 (18)	37 (18)
Satiation late sensations T0 (scales 1-100)	-.43	.67	10 (12)	11 (13)
DTE sweet T0 (# of quarters)	-.03	.98	13 (10)	13 (9)
DTE savoury T0 (# of halves)	-1.54	.13	4 (3)	5 (4)
Satiation early sensations Concept T1 (scales 1-100)	-1.83	.07	68 (18)	72 (18)
Satiation late sensations Concept T1 (scales 1-100)	-.37	.71	15 (14)	16 (15)
Satiation early sensations Concept T2 (scales 1-100)	-.43	.67	60 (19)	61 (19)
Satiation late sensations Concept T2 (scales 1-100)	1.46	.15	51 (23)	47 (21)
Frequency Satiation (scale 1-5)	-2.04	.04	3 (1)	4 (1)
Frequency Fullness (scale 1-5)	-.47	.64	2 (1)	2 (1)
Audio fragment: Liking (scale 1-5)	-2.56	.01	3 (1)	4 (1)
Audio fragment: Length (scale 1-5)	5.75	<.001	4 (1)	3 (1)
Audio fragment: Pace of narrator (scale 1-5)	-4.65	<.001	3 (1)	3 (1)
Audio fragment: Interesting (scale 1-5)	-3.46	.001	3 (1)	4 (1)

SS: Sensitivity to physiological signals of satiation, BMI: Body Mass Index, DTE: Disposition to eat

5.2.3.2. Hypothesis testing

Multiple linear regression analysis yielded a non-significant effect of Condition on satiation threshold both in the absence (B = -.16, SE = 1.81, p = .93) and presence of control variables (B = -.67, SE = 1.82, p = .72) (Table 5.2.). The interaction between SS and Condition was non-significant and was not included in the final model because we had not formulated an a priori hypothesis for this term. The volumes ingested at each drinking round of the WLT are shown in (Table 5.3.).

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Table 5.2. Multiple linear regression analysis predicting satiation threshold

	B	*SE*	*t*	*p*	R^2
Crude model					
Condition	-.16	1.81	-.09	.93	<.001
Adjusted model					
Condition	-.67	1.82	-.37	.72	.06
Age	-.14	.08	-1.80	.07	
Gender	4.13	2.22	1.86	.07	
BMI	.13	.32	.41	.68	
SS	1.37	1.11	1.23	.22	
Dieting	-1.61	4.49	-.36	.72	
Satiation early sensations Concept T1	-.01	.06	-.08	.94	
Satiation late sensations Concept T1	.09	.07	1.23	.22	
Satiation early sensations Concept T2	.05	.06	.92	.36	
Satiation late sensations Concept T2	-.05	.05	-.85	.40	

SS: Sensitivity to physiological signals of satiation, BMI: Body Mass Index

Table 5.3. Descriptive statistics for the WLT data

	Control condition (n_1 = 113)		Mindfulness condition (n_2 = 113)		Total sample (N = 226)		
	M	SD	M	SD	M	SD	Range
Intake to satiation (ml)	339	148	353	179	346	164	41-959
Intake to fullness (ml)	413	192	410	212	412	202	46-1211
Total intake (ml)	752	264	763	313	758	289	141-1760
Satiation threshold (%)	46.0	12.9	46.2	14.0	46.1	13.4	11.4-79.7

5.2.3.3. Changes in sensations and disposition to eat

Repeated measures ANOVA with early sensations of satiation yielded a non-significant Time x Condition interaction effect (F (2,223) = .69, p = .50, η^2 = .01) and a significant Time effect (F (2,223) = 138.36, p < .001, η^2 = .55). Pairwise comparisons indicated that early sensations increased significantly at T1 (Mdiff = 18, SDdiff = 1, p < .001) but did not differ significantly between T1 and T2 (Mdiff = -2, SDdiff = 1, p = .12) (Fig. 5.1.). In turn, a non-significant Time x Condition interaction effect (F (2,223) = .28, p = .76, η^2 = .002) and a significant Time effect (F (2,223) = 316.39, p < .001, η^2 = .74) were evident for late sensations of satiation. Late sensations increased significantly both at T1 (Mdiff = 5, SDdiff = 1, p < .001) and at T2 (Mdiff = 28, SDdiff = 1, p < .001). Furthermore, a non-significant Time x Condition interaction (F (2,220) = 1.89, p = .15, η^2 = .02) and a significant Time effect (F (2,220) = 221.47, p < .001, η^2 = .67) were observed for DTE sweet. DTE sweet reduced significantly at T1 (Mdiff

= -6, SDdiff = 1, p < .001) and at T2 (Mdiff = -4, SDdiff = .2, p < .001). Similar results were obtained for DTE savoury [Time x Condition: F (2,207) = 2.09, p = .13, η^2 = .02; Time effect: F (2,207) = 279.22, p < .001, η^2 = .64]. DTE savoury decreased significantly at T1 (Mdiff = -2, SDdiff = .1, p < .001) and at T2 (Mdiff = -2, SDdiff = .1, p < .001).

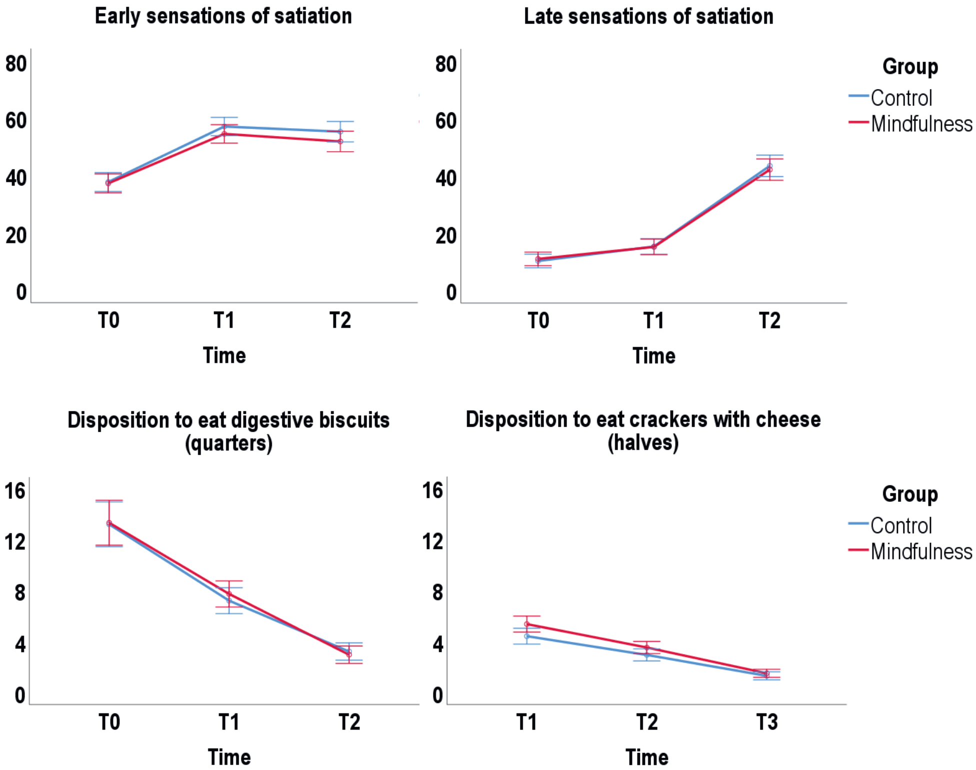

Fig. 5.1. Sensations of satiation and disposition to eat reported in Study 1. Error bars represent 95% CI.

5.2.4. Discussion

In this study, a brief mindfulness exercise was not effective in making individuals more perceptive of their bodily signals of satiation. Participants in the two experimental conditions manifested similar satiation thresholds and experienced similar patterns of satiation sensations and disposition to eat over the course of the study. The increase in satiation sensations and decrease in disposition to eat that were documented after the two drinking rounds of the WLT indicate that water was effective in inducing satiation and fullness.

5.3. Study 2

5.3.1. Methods

5.3.1.1. Participants

A relatively homogeneous sample of Dutch females between 18-29 years old was recruited in this study to minimise variability in the satiating effect of the preload. The same recruitment means, eligibility criteria, and rationale for sample size calculations as in Study 1 were used. In addition, individuals who had medical (e.g., allergy, intolerance), ethical, religious, or other personal reasons that prevented them from eating any of the study foods were excluded. After excluding three participants who had incomplete data, two who did not finish the preload, and 14 who failed to comply with the instructions for preparation, data from 217 participants remained for analysis. Participants' average age was 22.0 years (SD = 2.1) and average BMI was 22.0kg/m^2 (SD = 2.4) (4% underweight, 89% normal weight, 7% overweight, 1% obese). Six participants (3%) were dieting for weight-loss at the time of the study.

5.3.1.2. Experimental design and manipulation

Same as Study 1.

5.3.1.3. Measures

Hunger threshold. Hunger threshold was measured with the preload test (Blundell et al., 2010). Participants were offered a standardised lunch preload (M = 563kcals, SD = 13kcals) and were asked to consume it entirely. The preload consisted of a sandwich with hummus and cucumber, a raisin bun, a small carton of orange juice (200ml), and a cup of water (125ml). Participants noted 1. the exact time of finishing the preload in the laboratory (T1) and, 2. the exact time of perceiving their first signal of hunger under natural circumstances (T2). By subtracting the two times, we calculated the hunger threshold in minutes. Participants were instructed to not eat or drink anything between the two time points. The instructions were as follows: “The researcher will now give you a sealed envelope that includes a questionnaire. We ask you to open this envelope the moment you perceive a first sign of hunger. By hunger we mean the sensation you perceive when you haven’t eaten for some time and your stomach is ready to receive food. We request that you don't eat or drink anything (except for water[2]) before you reach this state".

Trait sensitivity to physiological signals of hunger. We assessed the ability to perceive and interpret the signals that the body naturally generates in response to hunger with the sensitivity to physiological signals of hunger (SH) subscale of MIRES (Palascha et al., 2020c), which is consisted of nine items administered with 7-point scales (1 = "Completely untrue for me" to 7 = "Completely true for me"). Cronbach's alpha was .85 in this study and the average score was used as control variable in the main analysis.

Sensations of hunger and satiation. Like in Study 1, participants provided repeated ratings of their hunger and satiation sensations at baseline (T0), T1, and T2. The hunger sensations were also used to rate participants' concept state of hunger (Concept T2) as a means of controlling the main analysis for individual differences in interpretation of the instructions used to report hunger threshold. Specifically, participants were asked "Imagine that you haven't eaten for some time and your stomach is ready to receive food. How would you describe this sensation in terms of the following factors?". Participants also indicated how frequently they initiate eating as soon as they reach this state under natural circumstances (Frequency Hunger) (1 = "Never" to 5 = "Always"). In this study the items were grouped as follows as indicated by PCA (see Supplementary material): Early sensations of hunger (empty stomach, rumbling stomach), Late sensations of hunger (weakness, lack of concentration, lightheaded, irritated, tense, nervous), Early sensations of satiation (satisfied, happy, relaxed), and Late sensations of satiation (heavy feeling, feeling bloated, nausea, discomfort, regret, disgust with yourself). A mean score was calculated for each group of items and each time point.

Disposition to eat. The same procedure as in Study 1 was used. Chocolate chip cookies (in quarters) and salty crackers (in halves) were used to measure DTE sweet and DTE savoury, respectively.

Hunger as a mental state. A single item ("Since you left the lab, to what extent did you think about eating despite not being physically hungry?") administered on a 100mm VAS (0 =

[2] Water can have a temporary satiating effect as shown in Study 1; nevertheless, small amounts of water are unlikely to impact satiety since water empties quickly to the intestines (Murray et al., 1994). Therefore, in this study participants were allowed to drink water in anticipation of the hunger signal.

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“I did not think about eating at all” and 100 = “I was constantly thinking about eating”) was used to measure hunger as a mental state and was added as control variable in the main analysis.

Restrained eating. To measure one’s intention to restrict food intake in order to control body weight we used the restrained eating (RE) scale of the Dutch Eating Behaviour Questionnaire (DEBQ) (van Strien et al., 1986), consisted of 10 items administered with 5-point frequency scales (1 = “Never” and 5 = “Very often”). Cronbach’s alpha was .89 in this study and responses were averaged. RE was used as a control variable in the main analyses because the chronic tendency to restrict food intake could influence the ability to perceive physical sensations of hunger (Herman & Polivy, 1983; Murray & Vickers, 2009).

Demographic, control, and other measures. Same as Study 1.

5.3.1.3. Procedure

An online questionnaire included the study’s eligibility criteria and the measure of trait sensitivity to physiological signals of hunger. Eligible participants joined a laboratory session between 13:00 and 15:30, after having refrained from eating (including caloric drinks) for at least four hours prior to their session, from intense physical activity the morning of their session, and from alcohol consumption the day prior to their session. Instruction compliance was checked verbally but also computationally as in Study 1. First, participants reported their hunger and satiation sensations and disposition to eat at baseline (T0) and then performed the experimental manipulation. Then, they consumed the lunch preload and noted the exact time of ending the meal. Sensations of hunger and satiation and disposition to eat were reported after the preload (T1), followed by the control measures. Before leaving the laboratory, participants used the list of hunger sensations to rate their concept state of hunger (Concept T2) (in line with Study 1) and received a sealed questionnaire that they had to open and fill in by the moment they would perceive their first signal of hunger (T2). This questionnaire was used to report the time of hunger onset as well as hunger as a mental state, sensations of hunger and satiation, disposition to eat, and restrained eating. This questionnaire was returned by participants in person or by post and participants received a shopping voucher as a reward for their participation as well as a debriefing email upon completion of data collection.

5.3.2. Analysis

Same as Study 1. Four outliers were excluded for the assumptions of normality and homoscedasticity to be met. Thus, analysis was conducted with 213 participants. We only report results excluding the outliers, as otherwise the model is not appropriate for parametric analysis.

5.3.3. Results

5.3.3.1. Randomisation checks

With the exception of SH, which was significantly higher in the control group (t (211) = 2.20, p = .03), non-significant differences were observed between the experimental conditions in terms of background characteristics (Table 5.4.). Equivalence tests further indicated that all differences were significantly equivalent to zero. Likewise, the distribution of dieters/non-dieters (χ^2 (1) = 2.78, p = .12), and smokers/non-smokers (χ^2 (1) < .001, p = 1.00) did not differ significantly between experimental conditions. Finally, the control audio fragment was liked significantly less than the mindfulness audio fragment (t (211) = -5.58, p < .001) and was also found to be significantly less interesting (t (211) = -4.74, p < .001), lengthier (t (211) = 6.84, p < .001), and slower in terms of pace of narration (t (211) = -3.41, p = .001). Inclusion of these variables in the regression model did not impact the results.

5.3.3.2. Hypothesis testing

The mean hunger threshold for the study participants was 176min (SD = 112). The effect of Condition on hunger threshold was significant (B = -18.32, SE = 8.22, p = .03) (Table 5.5.). Participants in the mindfulness condition perceived the onset of hunger 18min earlier (on average) than participants in the control condition and this effect persisted also in the presence of control variables (B = -17.14, SE = 8.43, p = .04). Mental hunger was also a significant predictor of hunger threshold (B = -4.80, SE = 1.65, p = .004). The interaction between SH and Condition was non-significant and was not included in the final regression model because no a priori hypothesis had been formulated for this term.

Table 5.4. Characteristics of participants in the control and mindfulness group (Study 2)

	t	*p*	M (SD) Control condition (n1 = 107)	M (SD) Mindfulness condition (n2 = 106)
Age (years)	1.74	.08	22.2 (2.1)	21.7 (2.1)
BMI (kg/m²)	-1.22	.22	21.8 (2.3)	22.2 (2.5)
SH (scales 1-7)	2.20	.03	6 (1)	6 (1)
RE (scales 1-5)	-1.12	.26	2 (1)	2 (1)
Sleep duration (hours)	.69	.49	8 (1)	8 (1)
Physical activity (scale 1-5)	-.18	.86	3 (1)	3 (1)
Hunger early sensations T0 (scales 1-100)	.27	.79	58 (23)	57 (22)
Hunger late sensations T0 (scales 1-100)	-.80	.42	25 (18)	27 (17)
Satiation early sensations T0 (scales 1-100)	1.27	.21	45 (19)	42 (17)
Satiation late sensations T0 (scales 1-100)	.01	.99	13 (13)	13 (11)
DTE sweet T0 (# of quarters)	-1.16	.25	13 (9)	14 (9)
DTE savoury T0 (# of halves)	-.96	.34	12 (8)	13 (8)
Hunger early sensations Concept T2 (scales 1-100)	.15	.88	69 (21)	68 (19)
Hunger late sensations Concept T2 (scales 1-100)	-.99	.32	33 (21)	35 (20)
Frequency Hunger (scale 1-5)	-.18	.85	4 (1)	4 (1)
Audio fragment: Liking (scale 1-5)	-5.58	< .001	3 (1)	4 (1)
Audio fragment: Length (scale 1-5)	6.84	< .001	4 (1)	4 (1)
Audio fragment: Pace of narrator (scale 1-5)	-3.41	.001	2 (1)	3 (1)
Audio fragment: Interesting (scale 1-5)	-4.74	< .001	3 (1)	3 (1)

SH: Sensitivity to physiological signals of hunger, BMI: Body Mass Index, RE: Restrained eating, DTE: Disposition to eat

Table 5.5. Multiple linear regression analysis predicting hunger threshold

	B	*SE*	*t*	*p*	R^2
Crude model					
Condition	-18.32	8.22	-2.23	.03	.02
Adjusted model					
Condition	-17.14	8.43	-2.03	.04	.07
Age	.13	2.16	.06	.95	
BMI	1.09	1.87	.58	.56	
SH	.84	5.25	.16	.87	
Mental hunger	-4.80	1.65	-2.91	.004	
RE	4.02	5.70	.71	.48	
Dieting	-33.89	28.32	-1.20	.23	
Hunger early sensations Concept T2	.04	.24	.18	.86	
Hunger late sensations Concept T2	-.05	.23	-.22	.82	

SH: Sensitivity to physiological signals of hunger, BMI: Body Mass Index, RE: Restrained eating

5.3.3.3. Changes in sensations and disposition to eat

Repeated measures ANOVA with early sensations of hunger yielded a non-significant Time x Condition interaction effect (F (2,210) = .80, p = .45, η^2 = .01) and a significant Time effect (F (2,210) = 658.83, p < .001, η^2 = .86). Pairwise comparisons indicated that early sensations of hunger reduced significantly at T1 (Mdiff = -51, SDdiff = 2, p < .001) and increased significantly at T2 (Mdiff = 38, SDdiff = 1, p < .001) (Fig. 5.2.). Likewise, a non-significant Time x Condition interaction effect (F (2,210) = .08, p = .93, η^2 = .001) and a significant Time effect (F (2,210) = 164.87, p < .001, η^2 = .61) were evident for late sensations of hunger, which reduced significantly at T1 (Mdiff = -15, SDdiff = 1, p < .001) and increased significantly at T2 (Mdiff = 13, SDdiff = 1, p < .001).

Analysis with early sensations of satiation yielded a non-significant Time x Condition interaction effect (F (2,210) = .01, p = .99, η^2 < .001) and a significant Time effect (F (2,210) = 111.29, p < .001, η^2 = .52). Early sensations of satiation increased significantly at T1 (Mdiff = 20, SDdiff = 1, p < .001) and decreased significantly at T2 (Mdiff = -15, SDdiff = 1, p < .001). Finally, a marginally significant Time x Condition interaction effect (F (2,210) = 3.12, p = .05, η^2 = .03) and a significant Time effect (F (2,210) = 20.35, p < .001, η^2 = .16) were evident for late sensations of satiation. Analysis by time point showed no significant differences between experimental conditions (T0: F (1,212) < .001, p = .99, η^2 < .001; T1: F (1,212) = 1.25, p = .27, η^2 = .01; T2: F (1,212) = 1.80, p = .18, η^2 = .01) and sub-group analysis showed that in the Control condition late sensations of satiation increased significantly at T1 (Mdiff = 8, SDdiff = 2, p < .001) and decreased significantly at T2 (Mdiff = -8, SDdiff = 1, p < .001), while in the Mindfulness condition they increased significantly at T1 (Mdiff = 5, SDdiff = 1, p < .001) but did not decrease significantly at T2 (Mdiff = -4, SDdiff = 1, p = .03).

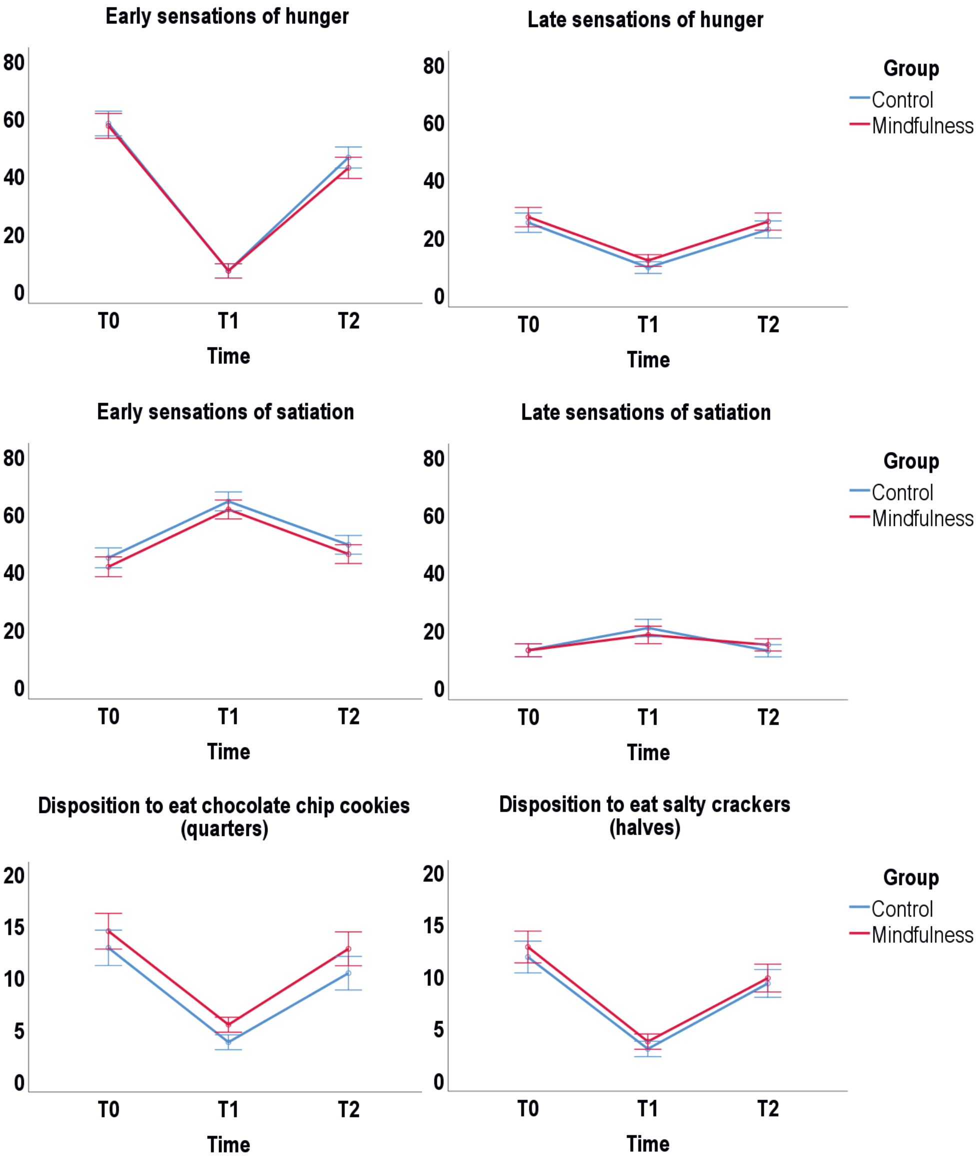

Fig. 5.2. Sensations of hunger and satiation and disposition to eat reported in Study 2. Error bars represent 95% CI.

A non-significant Time x Condition interaction effect ($F(2,207) = .32$, $p = .73$, $\eta^2 = .003$) and a significant Time effect ($F(2,207) = 187.05$, $p < .001$, $\eta^2 = .64$) were observed for DTE sweet. DTE sweet reduced significantly at T1 (Mdiff = -9, SDdiff = 1, $p < .001$) and increased significantly at T2 (Mdiff = 7, SDdiff = 1, $p < .001$). Similarly, there was a non-significant Time x Condition interaction ($F(2,207) = .11$, $p = .89$, $\eta^2 = .001$) and a significant Time effect ($F(2,207) = 226.36$, $p < .001$, $\eta^2 = .69$) for DTE savoury. DTE savoury decreased significantly at T1 (Mdiff = -9, SDdiff = 1, $p < .001$) and increased significantly at T2 (Mdiff = 6, SDdiff = .4, $p < .001$).

5.3.4. Discussion

The results of this study show that mindfulness improves the ability to perceive bodily signals of hunger. Participants who conducted a brief body scan exercise prior to eating the preload perceived the onset of physical hunger 18min earlier than participants in the control condition. The general pattern of experienced sensations of hunger and satiation and disposition to eat was similar between experimental conditions, which suggests that participants in the mindfulness condition simply perceived the signal faster. In turn, the control group experienced a steeper decline in late sensations of satiation upon the onset of hunger, which means that a larger shift in experienced sensation had to take place for the control group to perceive the onset of hunger. Finally, reported sensations and disposition to eat changed in predictable ways over the course of the study in both experimental conditions, providing evidence that the preload was adequate to induce satiation at T1 but also that participants had indeed started feeling hungry when they reported the onset of hunger at T2.

5.4. General discussion

In this research we investigated the effect of mindfulness on the ability to perceive bodily signals of satiation and hunger, a largely understudied mechanism that might explain how mindfulness influences food intake and weight. We showed that a brief mindfulness exercise (body scan) did not have an impact on the ability to perceive bodily signals of satiation (Study 1), but it improved the ability to perceive bodily signals of hunger substantially (Study 2). These findings are in line with those observed by van de Veer et al. (2016), who showed that the difference in fullness feelings after a small versus a large preload in participants who performed the body scan exercise was attributed to the reduction in fullness after the small preload and not to an increase in fullness after the large preload. These pieces of evidence together suggest that focusing attention on the body has a more pronounced effect in increasing awareness of hunger cues compared with satiation cues.

This contrast can be understood from the evolutionary perspective that suggests that humans are hardwired towards overeating as a means of storing energy reserves in anticipation of famine, a state frequently encountered by our early ancestors (Pinel et al., 2000). In this light, it should be easier for humans to perceive hunger signals driving meal initiation than to perceive satiation signals driving meal termination. Therefore, more intensive practice with mindfulness may be required to improve the ability to perceive bodily signals of satiation than just a single and brief body scan exercise. In support to this, it has been found that time spent on meditation practice predicts reductions in binge eating episodes (Kristeller & Hallett, 1999) and correlates negatively with BMI and weight (Kristeller et al., 2014).

Another explanation for the present findings is that mindfulness requires some time to take effect. This is supported by the fact that in Study 2, sensations of hunger and satiation after consumption of the preload did not differ between experimental conditions, and it was only at a later stage (anticipation of the hunger signal) that mindfulness exerted its effect. Evidence from prior literature supports this idea, since mindfulness has more pronounced effects on subsequent food intake (later in the day) than on immediate food intake (while mindfulness takes place or right after) (see Tapper (2017) for a review).

Finally, it is also likely that mindfulness did not have a consistent effect on perception of satiation and hunger because a different setting was used in the two studies. In Study 1, participants' ability to perceive the onset of satiation was assessed in the laboratory, while in Study 2, perception of hunger onset was assessed under ecologically valid conditions. Therefore, it is possible that a ceiling effect occurred in the quiet environment of the laboratory where participants had ideal conditions for attending to their bodily sensations. Instead, in Study 2, environmental distractions likely made the task of attending to bodily sensations more challenging, thereby unveiling the effect of mindfulness.

The present work contributes to the existing literature in several important ways. First, this research provides the first comprehensive assessment of the effects of mindfulness on perception of bodily signals of satiation and hunger, while ruling out a series of cognitive confounders. Second, in this research we took into account individual differences in sensitivity to physiological signals of satiation and hunger, a factor that has been overlooked in prior research. Third, this is the first research that looked at the effect of mindfulness on abdominal visceral interoception (as measured with the WLT), thereby contributing to the growing body of evidence on the various interoceptive modalities.

The following limitations should be acknowledged for the present research. Trait mindfulness or prior experience with mindfulness practice were not taken into account in this research. Also, in Study 2 participants reported their hunger threshold in ecologically valid conditions, thus, several uncontrolled factors such as the level of physical exercise or environmental distractions might have influenced hunger threshold. The allocation to experimental conditions likely neutralised the effects of these confounders. However, it should be noted that the limitation of this study is at the same time its strength because the ecologically valid setting generates findings that are more directly generalisable (higher external validity). Also, as we discussed previously, this setting might have played a role in the manifestation of the mindfulness effect. Finally, this research is also limited by the fact that it did not assess potential underlying mechanisms by which mindfulness impacts the perception of bodily signals of satiation and hunger. For example, the effect of mindfulness could be explained by top-down processes (i.e., increased active attendance to bodily sensations), bottom-up processes (i.e., the sensation itself enters awareness more vividly), both, or other processes (e.g. related to memory).

More studies are certainly needed to establish whether and how mindfulness impacts the perception of bodily signals of satiation and hunger and, in turn, whether this translates to lower food intake and weight. In this research we paid attention only to the direct effect of mindfulness on perception, thus, future studies could assess perception and outcome measures within the same investigation in order to shed light on the full mediation model. In particular, it would be interesting to investigate whether the improved ability to perceive early signals of hunger and satiation helps individuals achieve a narrower control of their eating by initiating meals at early levels of hunger and ceasing meals at early levels of satiation. Evidence from self-reports support this assertion since sensitivity to physiological signals of hunger and satiation associates positively with self-efficacy in using those signals to determine when and how much to eat (Palascha et al., 2020c). Assuming this holds true, the results of the present research imply that mindfulness may trigger early meal initiation but not necessarily early meal termination, which could ultimately lead to increased food intake if meals become more frequent but not smaller. Therefore, mindfulness interventions should prioritise the perception of satiation signals before attempting to improve the perception of hunger signals. Preferably, a more intensive type of mindfulness training should be employed than just a single and brief body scan exercise and could possibly be combined with training individuals to stop eating before reaching complete satiation, which is associated with lower food intake (Fukkoshi et al., 2015). Finally, in this research (particularly in Study 1) we sacrificed external validity in order to isolate and assess the effects of interest. Future studies could employ more ecologically valid settings to assess how mindfulness impacts perception of satiation and hunger signals in real consumption situations.

Appendix 5.1. Result of the Principal Component Analyses (PCA)

Study 1

Satiation and hunger sensations were analysed separately. We conducted one PCA with satiation sensations at Concept T1 (first time that participants responded to these items) and another one with hunger sensations at T0. One component emerged in the PCA with hunger sensations (Table S1) and two in the analysis with satiation sensations (Table S2) by inspection of the scree plots. The satiation sensations that were reported at later time points were grouped according to the structure that emerged from this analysis. The results of the reliability analysis of the emerged components is shown in Table S3.

Table S1. Summary of PCA results for hunger sensations at T0

	Component 1
Item 1: Lack of concentration	**.87**
Item 2: Tense	**.79**
Item 3: Weakness	**.78**
Item 4: Irritated	**.77**
Item 5: Lightheaded	**.76**
Item 6: Nervous	**.65**
Item 7: Rumbling stomach	**.58**
Eigenvalues	3.90
% of variance	55.78
KMO	.85
Bartlett's Test of Sphericity (p value)	< .001

Table S2. Summary of PCA results for satiation sensations at Concept T1

	Component 1 (Late sensations)	Component 2 (Early sensations)
Item 1: Feeling bloated	**.80**	.21
Item 2: Nausea	**.80**	-.11
Item 3: Heavy feeling	**.77**	.37
Item 4: Discomfort	**.72**	-.33
Item 5: Disgust with yourself	**.70**	-.20
Item 6: Regret	**.68**	-.22
Item 7: Satisfied	-.06	**.86**
Item 8: Happy	-.20	**.81**
Item 9: Relaxed	-.21	**.79**
Item 10: Full stomach	.24	**.76**
Eigenvalues	4.19	2.39
% of variance	41.93	23.91
KMO	.82	
Bartlett's Test of Sphericity (p value)	< .001	

Table S3. Reliability analysis for the resulting components

Component	Cronbach's alpha
Hunger sensations_T0	.86
Satiation early sensations_T0	.69
Satiation late sensations_T0	.82
Satiation early sensations_Concept T1	.85
Satiation late sensations_Concept T1	.85
Satiation early sensations_Concept T2	.74
Satiation late sensations_Concept T2	.85
Satiation early sensations_T1	.74
Satiation late sensations_T1	.83
Satiation early sensations_T2	.76
Satiation late sensations_T2	.82

Study 2

Like in Study 1, two PCAs were conducted: one for hunger sensations and one for satiation sensations at T0 (first time that participants responded to these items). Two components emerged in each analysis by inspection of the scree plots (Tables S4 and S5). The hunger and satiation sensations that were reported at late time points were grouped according to the structure that emerged from these analyses. The results of the reliability analysis of the emerged components is shown in Table S6.

Table S4. Summary of PCA results for hunger sensations at T0

	Component 1 (Late sensations)	Component 2 (Early sensations)
Item 1: Tense	**.90**	-.19
Item 2: Nervous	**.83**	-.20
Item 3: Irritated	**.77**	.08
Item 4: Lack of concentration	**.60**	.36
Item 5: Weakness	**.57**	.42
Item 6: Lightheaded	**.56**	.39
Item 7: Empty stomach	-.02	**.89**
Item 8: Rumbling stomach	-.06	**.88**
Eigenvalues	3.86	1.53
% of variance	48.23	19.11
KMO	.81	
Bartlett's Test of Sphericity (p value)	< .001	

Table S5. Summary of PCA results for satiation sensations at T0

	Component 1 (Late sensations)	Component 2 (Early sensations)
Item 1: Feeling bloated	**.78**	.24
Item 2: Heavy feeling	**.75**	-.05
Item 3: Disgust with yourself	**.68**	.02
Item 4: Nausea	**.68**	-.10
Item 5: Regret	**.63**	.05
Item 6: Discomfort	**.60**	-.27
Item 7: Relaxed	-.11	**.79**
Item 8: Happy	-.12	**.79**
Item 9: Satisfied	.20	**.77**
Eigenvalues	3.03	1.89
% of variance	33.65	21.00
KMO	.72	
Bartlett's Test of Sphericity (p value)	< .001	

Table S6. Reliability analysis for the resulting components

Component	Cronbach's alpha
Hunger early sensations_T0	.79
Hunger late sensations_T0	.85
Satiation early sensations_T0	.70
Satiation late sensations_T0	.77
Hunger early sensations_T1	.84
Hunger late sensations_T1	.84
Satiation early sensations_T1	.81
Satiation late sensations_T1	.83
Hunger early sensations_Concept T2	.82
Hunger late sensations_Concept T2	.86
Hunger early sensations_T2	.78
Hunger late sensations_T2	.86
Satiation early sensations_T2	.80
Satiation late sensations_T2	.80

Chapter 6

General Discussion

Eating is a complex process and there is not a one-size-fits-all path to effective eating regulation. This thesis has dealt specifically with internally regulated eating, a relatively new and understudied concept in the domain of eating regulation. The central aim of this thesis was to reflect on the literature on internally regulated eating from a panoramic perspective and to synthesize existing knowledge into a comprehensive theoretical framework based on which measurement and application of internally regulated eating could also be advanced. More specifically, this thesis aimed to address which individual-difference characteristics underpin the internally regulated eating style, which are the hypothesized relationships between them, and which mechanisms may explain how they lead to effective regulation of food intake (Chapter 2). Another aim was to investigate how these characteristics can be quantified in the population (Chapter 3) and whether the measures that quantify them are valid (Chapters 3 and 4). Stringent validity testing was also conducted for some characteristics (sensitivity to bodily signals of satiation and hunger) (Chapter 4). The purpose was to examine to what extent sensitivity to bodily signals of satiation and hunger (trait) manifests itself in behavioural tasks (state). Finally, a last aim was to address if and to what extent a brief mindfulness intervention (i.e., focussed attention to the body) impacts the ability to perceive bodily signals of satiation and hunger (Chapter 5).

This chapter provides an overview of main findings, reflects upon these findings from a theoretical and methodological point of view, and discusses implications for research and practice.

6.1. Overview of main findings

Chapter 2 provided a unique and comprehensive conceptualisation of internally regulated eating style. This was achieved by synthesising constructs from a fragmented literature into an integrated framework. Five[1] individual-difference characteristics were found to underpin the internally regulated eating style: 1. the ability to perceive bodily signals of hunger and satiation (sensitivity), 2. the ease of using bodily signals of hunger and satiation to

[1] Originally, the sensitivity and self-efficacy constructs were assumed to be unidimensional. However, as became evident in Chapter 3, Sensitivity to bodily signals of hunger, Sensitivity to bodily signals of satiation, Self-efficacy in using bodily signals of hunger, and Self-efficacy to bodily signals of satiation are distinct constructs. This distinction was not reflected in the conceptual definitions presented in Chapter 2 and this was done to aid brevity and avoid repetitive writing. In line with Chapter 2, we refer here to five (instead of seven) characteristics.

determine when and how much to eat (self-efficacy), 3. a self-trusting attitude for the regulation of eating (internal trust), 4. a relaxed and non-restrictive relationship with food (food legalising), and 5. a tendency to savour the food while eating (food enjoyment). These characteristics were hypothesised to associate positively with each other and to synergistically form a general tendency to eat in response to bodily signals of hunger and satiation.

The conceptual synthesis in Chapter 2 brought to surface a methodological gap. It was evident that none of the existing self-report measures could adequately capture the full complexity and theoretical structure of the internally regulated eating style. Filling this gap, Chapter 3 presented the systematic development and initial validation of the MIRES. The seven subscales of MIRES were found to be reliable and stable, and initial evidence of construct, convergent, discriminant, incremental, and criterion validity was obtained for the scale in a cross-sectional study with a large sample from the US.

Following the development of MIRES, this thesis also initiated an endeavour of stringent validation testing of the MIRES subscales via behavioural experiments. Chapter 4 dealt specifically with the construct validation of the sensitivity subscales; sensitivity to bodily signals of satiation (SS) and sensitivity to bodily signals of hunger (SH). Contrary to our expectations, trait sensitivity, both at the domain-specific level (SS and SH) and at a more generic level (interoceptive awareness), did not manifest itself in behavioural tasks such as the water load test and the preload test. The evidenced link of SS and SH to the broader domain of interoceptive awareness provided, thus, only preliminary evidence of construct validity for these subscales.

Finally, the first experimental investigation of the effect of mindfulness on perception of bodily signals of satiation and hunger was presented in Chapter 5. It was found that a brief mindfulness intervention (i.e., focussed attention to the body) did not impact the ability to perceive the onset of bodily signals of satiation but resulted in a substantial improvement in the ability to perceive the onset of bodily signals of hunger. These findings indicate that even brief practices that can be easily applied in everyday life can help individuals perceive their hunger signals sooner, while more intensive practice may be needed to improve the perception of satiation signals.

6.2. Theoretical reflection

Taking a more distant perspective, we hereby discuss how the various findings of this thesis integrate and how they inform existing knowledge.

6.2.1. Internally regulated eating style and well-being

Modern societies are characterized not only by obesogenic environments that promote overeating and sedentary behaviour (Lake & Townshend, 2006), but also by a widespread concern around weight and the diet-health links (de Ridder et al., 2014). The combination of these elements is likely to create unfavourable conditions for the regulation of food intake, in some individuals more than in others. Under such circumstances, eating healthily and in moderation can become a difficult task and this may have implications for physical and psychological health.

Embedded within a broader movement that emphasises health irrespectively of weight status (Avalos & Tylka, 2006; Bacon & Aphramor, 2011), internally regulated eating aims to address these challenges, in particular the anxiety that surrounds eating and the susceptibility to overeating in response to environmental triggers (Schaefer & Magnuson, 2014; Warren et al., 2017). Evidence from prior literature on the correlates and outcomes of earlier versions of internally regulated eating style, as reviewed in Chapter 2, provide support for the adaptive nature of this eating style. Chapter 3 further corroborates these findings, as it features a favourable pattern of associations between internally regulated eating style (as conceptualised and operationalised in this thesis) and physical, psychological, and behavioural outcomes. Specifically, it was found that all internally regulated eating style characteristics, and their composite, are positively associated with adaptive outcomes such as satiety responsiveness, slowness in eating, body appreciation, proactive coping, self-esteem, and satisfaction with life. In addition, negative associations were documented with eating disorder symptomatology, BMI, and weight cycling.

Although the present evidence is preliminary and solely based on self-reported and cross-sectional data, it seems to suggest that this body-based and flexible approach to eating may indeed be adaptive. Thus, holding relaxed attitudes towards food and overeating, emphasising the eating pleasure, and being guided by bodily signals for eating regulation may be an effective means to physical and psychological health and overall wellbeing. It is also possible, however, that internally regulated eating style does not lead to health and wellbeing by itself. For example, there can be confounding factors (e.g., biological, developmental, psychological, and societal factors) that pre-dispose individuals towards regulating eating internally and, at the same time, lead to improved health. More research is needed to shed light on the relationships of the present conceptualisation of internally regulated eating style with a broader range of health indicators and to examine the direction and causality of these relationships. In addition, it is important to gather evidence on how this eating style relates to food consumption in terms of both quantity and quality, as very limited evidence is currently available in this respect.

6.2.2. Network of associations between the internally regulated eating style characteristics

A novel element of the theoretical framework presented in Chapter 2 is that it elaborates on the hypothesized associations between the defining features of internally regulated eating style. A central proposition it makes is that internally regulated eating style is a formative construct, meaning that none of its individual-difference characteristics is an adequate reflection of this eating style in isolation and that all of them are needed to fully define the construct. While this may hold true also for other conceptually similar constructs in the eating domain (e.g., intuitive eating, mindful eating, eating competence), these constructs have been (mis)specified as reflective. This issue is important, as model mis-specification results in biased estimates of model parameters both within the construct (item loadings) but also in how the construct associates with other constructs (regression coefficients) (Diamantopoulos et al., 2008). Also, treating a formative construct as reflective can lead to inappropriate item purification strategies (e.g., dropping items based on low item-total correlations rather than based on meaning), which can restrict the breadth of the construct's domain (Diamantopoulos et al., 2008). This thesis is, therefore, the first to provide a theoretically justified conceptualisation of internally regulated eating style and the first to pay attention to the implications of this specification for measurement of this construct. In this way, it does justice to formative measurement modelling, which has not been sufficiently utilized in this field (but also more generally) despite its apparent applicability.

Furthermore, the theoretical framework of Chapter 2 proposed that each defining characteristic has its specific role in this eating style and that the different elements work synergistically in forming the inclination to regulate eating internally. Specifically, sensitivity, self-efficacy, and internal trust were hypothesised to feed each other via positive learning mechanisms. Food legalizing was assumed to facilitate sensitivity and self-efficacy by providing a permissive environment where cognitive resources are available for attending and responding to bodily signals. Finally, food enjoyment was also assumed to facilitate sensitivity and self-efficacy by aiding individuals stay in tune with the sensory experience of eating, which is important for the perception of eating-related sensations. The positive associations that were observed among these individual-difference characteristics in Chapter 3 provide initial support for our hypothesised network of associations. Yet, it is still to be investigated whether the mechanisms we have proposed to explain these associations are valid.

6.2.3. The distinction of hunger and satiation in internally regulated eating style

During the scale development process (Chapter 3) it became evident that, although highly related, sensitivity to bodily signals of hunger and sensitivity to bodily signals of satiation are distinct constructs. The same was the case for self-efficacy in using bodily signals of hunger and self-efficacy in using bodily signals of satiation. Furthermore, a difference between hunger and satiation also became apparent in Chapter 5, where it was shown that a body scan exercise before eating a meal was adequate to improve the perception of the onset of physical hunger following meal consumption, while it did not have an impact on perception of physical satiation. Although there are several plausible explanations for this discrepancy (discussed in Chapter 5), the explanation that perception of satiation is more challenging than perception of hunger is consistent with earlier findings (van de Veer et al., 2016) as well as with evolutionary perspectives on appetite regulation (Pinel et al., 2000). Therefore, according to this explanation, it can be concluded that, both as traits and as states, perception of hunger and perception of satiation are not interchangeable and should not be treated as such. Likely, the same holds true for self-efficacy in using those signals, although self-efficacy was not assessed as a state in this thesis.

These findings contribute to an ongoing debate on whether interoceptive awareness is a generalized individual competence. Some studies have shown that interoceptive modalities of various body systems (e.g., heart, stomach) converge, thereby representing a generalised sensitivity for interoceptive processes (Herbert et al., 2012). However, other studies have failed to find such generalized effect, and instead propose that only modalities of the same body system are related (Ferentzi et al., 2018). The present thesis suggests that even within the same body system (e.g., stomach) modalities can be distinct. This highlights the importance of differentially assessing hunger and satiation and proves the unique advantage of MIRES over conceptually similar measures (e.g., intuitive eating, mindful eating) (Tylka & Kroon Van Diest, 2013; Winkens et al., 2018), which rather seem to conflate these constructs.

Furthermore, considering the inconsistent results of the two studies in Chapter 5, it was suggested that a heightened ability to perceive hunger signals, if not accompanied by a heightened ability to perceive satiation signals, could lead to increased intake. This would be a result of meals becoming more frequent but not smaller. Contrary to this intuitive assumption, in Chapter 3 it was found that both sensitivity to hunger and sensitivity to satiation are negatively associated with BMI, weight cycling, and maximal weight change. Although food intake was not assessed in this research, the negative associations that were observed with weight outcomes imply that a positive link between sensitivity to hunger and food intake is not self-evident. More research is definitely needed to shed light on these associations.

6.3. Methodological reflection

Despite the clear conceptual coherence between different paradigms of internally regulated eating, these had not been sufficiently integrated that far. In fact, efforts to integrate these streams of literature had focused either on operationalizations (Kerin et al., 2019; Winkens et al., 2018) or outcomes (Clifford et al., 2015; van Dyke & Drinkwater, 2014; Warren et al., 2017) of these paradigms. Taking a theory-driven approach, this thesis presented the first conceptual integration of this fragmented literature and introduced a common language to the field. However, it should be acknowledged that the narrative review presented in Chapter 2 was not a systematic review. Although it included the most prominent research lines as well as a wide range of independent interventions on internally regulated eating there may be relevant literature that has been missed. In addition, the synthesis of identified concepts was not done using a systematic methodology (e.g., thematic analysis) but rather in an intuitive way as we were gradually becoming familiar with the various concepts. It is, therefore, to be found if the same repertoire of overarching concepts emerges when more systematic approaches are employed.

Furthermore, this thesis made an important step in advancing the assessment of internally regulated eating style by developing a practical and psychometrically sound self-report instrument that can be used in large and diverse populations and/or under ecologically valid conditions. MIRES offers the advantage of capturing the full spectrum of characteristics that define the internally regulated eating style (as identified in this thesis) and at the same time preserving the distinctiveness between highly related, conceptually distinct constructs. Thus, it can be used for a thorough and differentiated assessment of the essentials of the internally regulated eating style. Yet it is important to recognise that this thesis has provided only initial evidence on the psychometric properties of MIRES. This evidence was based on self-reported, cross-sectional data. The employment of behavioural tasks for construct validity testing, in combination with pre-registration, strengthened our methodology and provided an exemplar for further research in this field. Yet, this thesis failed to obtain strong evidence of validity based on behavioural data. It is apparent, therefore, that the properties and validity of MIRES need to be re-tested in new samples and by means of additional methodologies. Only then we can be confident for the performance of the scale.

A last methodological issue that deserves attention pertains to the use of the water load test to measure satiation threshold. In Chapter 4, it was argued that this test offers the advantage of assessing perception of bodily signals of satiation in isolation by ruling out a series of cognitive (e.g., restrained eating tendencies) and physiological factors (e.g., hormonal response to nutrients) that are difficult to measure and control for. Yet it became evident that the very virtue of this task, the use of water as a distention stimulus, may also be its vice, as water was found to be less effective in eliciting early sensations of satiation compared with food. As discussed in Chapter 4, this methodological issue perhaps played a role in the non-significant association that was observed between self-reported sensitivity to bodily signals of satiation and satiation threshold. We also speculate that the use of water might have mitigated the effect of mindfulness on satiation threshold in Chapter 5. This might be the case if water forced the satiation threshold of all participants to increase to such high level at which the reduction caused by mindfulness would no longer be noticeable. However, this assertion remains speculative given the available evidence. Be it as it may, it seems reasonable to suggest that the water load test is less appropriate to study perception of subtle satiation signals but may be a valuable method to study satiation in its upper limits, where the differences in elicited sensations between water and food seem to be less apparent.

6.4. Implications for research

This thesis aimed to provide a solid theoretical and methodological foundation that would define the future research agenda within this important research field. An important step has been made. Yet, there is still a lot more to be learnt. We have already pinpointed several elements that deserve attention in future research both in the individual chapters and in this general discussion. Below we elaborate on some broader issues that are to be addressed in future investigations.

While this thesis has delineated the defining characteristics of the internally regulated eating style, it has not paid attention to the antecedents of these characteristics or potential moderators (barriers and facilitators) that play a role in their maintenance. For example, early experiences and child feeding practices seem to be of major importance for the development of an eating style that is based on responsiveness to internal signals of hunger and satiation (Birch & Fisher, 1997; 2000; Birch et al., 1987; 2003; Harshaw, 2008). However, there are also other factors that play a role therein. For example, it has been shown that heritability can partially account for individual differences in premeal levels of hunger and fullness, in how responsive people are to these states, and in the ability to perceive visceral signals and changes in visceral states (Stevenson et al., 2015). In addition, a positive attitude towards the body (or more generally towards the self) is considered an important element for the adoption of internally regulated eating (Andrew et al., 2016; Avalos & Tylka, 2006). Future research should try to fully elucidate which biological, developmental, psychological, and environmental factors play a role in the development and maintenance of the individual-difference characteristics that were identified in this thesis. Longitudinal designs would be most appropriate to study these associations.

Another important topic that has not been discussed in this thesis is food selection from the perspective of internally regulated eating. Different approaches to food selection have been proposed in the literature in this domain, such as selecting foods according to body cravings (Carrier et al., 1994; Higgins & Gray, 1998; Tylka, 2006), selecting foods according to learned food preferences (Satter, 2007), or selecting foods that taste good but at the same time promote health and body functionality (Kristeller & Wolever, 2010; Tylka & Kroon van Diest, 2013). Another, more pragmatic, approach that seems to be more consistent with the fundamental principles of internally regulated eating might be to select foods that have enhanced satiating capacity, i.e., they induce satiation in smaller quantities and stave off hunger for longer periods. Examples are foods whose sensory characteristics (e.g., texture, taste) communicate their nutrient content (flavour-nutrient match) (“honest” foods) (Chambers et al., 2013; Yeomans, 2015; Yeomans & Chambers, 2011), foods that require high oral processing (mastication) (e.g., solids) (de Graaf, 2011, 2012), foods high in protein and fibre (Chambers et al., 2015), or foods with low energy density (e.g., fruits and vegetables) (Rolls, 2009). Future research could examine which of the above-mentioned approaches is more compatible with the internally regulated eating style and how these approaches impact dietary quantity and quality.

Furthermore, this thesis has examined the construct validity of only two of the seven MIRES subscales. The remaining subscales are still to be tested for validity. Some ideas are provided hereby in this respect. Ecological momentary assessment (EMA) methodology could be used to test the validity of the self-efficacy subscales of MIRES. EMA involves repeated sampling of subjects' current behaviours and experiences in real time and in natural environments (Shiffman et al., 2008). This methodology could be used to assess when individuals perceive bodily sensations of hunger and satiation during the day, how easy they find it to respond to these sensations (perhaps considering barriers or facilitators), and whether they eventually respond to them by initiating or ending a meal. The internal trust subscale could be validated with behavioural experiments assessing the extent to which individuals trust the information they get from their body versus information they get from external sources to determine satiation expectations and food intake. The manipulation proposed by Brunstrom et al. (2011) (i.e., providing true or false information about the ingredients used to make a preload) could be used to test these effects. The validity of the food legalizing subscale could be tested with an implicit association test or a primed lexical decision task. For example, participants could be primed with tempting food words and then conduct a lexical decision task with neutral words or words suggesting food pre-occupation (e.g., guilt, regret, unhealthy, caloric, fat, avoid, bad). Based on response times to the various words it could be assessed to what extent individuals have pre-occupied thoughts about tempting food or indulgent consumption. Finally, the food enjoyment subscale could be validated with observation of eating behaviour in ecologically valid circumstances or in the laboratory. Participants could be videotaped while eating to assess to what extent they look, touch, smell, and chew their food. Self-reports could be used to assess how much enjoyment they derive from the eating episode.

Once convincing evidence from longitudinal research has been collected regarding the associations of internally regulated eating style with food consumption and health outcomes, intervention studies can be designed to promote this eating style in the population. This thesis can be used as a basis to design new theory-based interventions (or to adapt existing ones) in order to assess the effects of this eating style on important outcomes preferably over long periods. The following insights may be useful in this respect. First, this thesis designates the elements that need to be addressed in internally regulated eating interventions. Existing interventions can be supplemented with specific elements they may be lacking. Second, this thesis emphasises that all elements need to receive adequate attention as each of them has its specific role in this eating style. The MIRES can be used as an indicator of effective change of the individual-difference characteristics of internally regulated eating style during the course of the intervention. Finally, this thesis has shown that some of these elements (e.g., sensitivity to satiation signals) may be more resistant to change than others. Therefore, it designates elements that may have to be prioritized or receive extra attention during the intervention.

The integrative approach that this thesis takes with respect to the various internally regulated eating paradigms can also generate inspiration regarding potential strategies that can be used to boost the characteristics of the internally regulated eating style. For example, hunger and satiation diaries (Craighead & Allen, 1995), mindfulness exercises (Kristeller & Wolever, 2010), body awareness and interoceptive training (Khoury et al., 2018; Smith et al., 2021), or biofeedback training (Ciampolini et al., 2013; Jospe et al., 2017b) are all strategies that could be used to enhance sensitivity to bodily signals of hunger and satiation. Identification of personal barriers and facilitators with regard to responding to internal signals of hunger and satiation and formulation of implementation intentions could be used to enhance self-efficacy (Rothman et al., 2009). Cognitive behavioural therapy could be used to enhance both internal trust (fostering self-reliance and taking agency in eating, valuing the body and its signals) and food legalizing (tackling rigid or dichotomous thoughts about food, building a relaxed and positive relationship with food) (Dicker & Craighead, 2004; Lam & Cheng, 2001; Tanco et al., 1998). Implicit attitude change techniques could also be used to foster positive attitudes towards food, thereby boosting the food legalizing component (Rothman et al., 2009). Finally, mindfulness exercises (Alberts et al., 2012; Kristeller et al., 2014), sensory-based training, (Gravel et al., 2014), or savouring interventions (Smith et al., 2019) could be used to enhance food enjoyment. Addressing all elements of internally regulated eating style is expected to lead to stronger effects because the characteristics are hypothesized to support each other. Thus, a comprehensive intervention that addresses all elements may also benefit from synergistic effects. Finally, internally regulated eating interventions may fit well within holistic systems approaches to healthy eating. By cultivating adaptive individual competences that facilitate eating in moderation, such interventions can work complementarily with interventions that steer individuals towards healthy eating through changes in the food and eating environment or interventions that increase motivation to adopt healthy lifestyles.

6.5. Implications for practice

From a practical point of view, this thesis has made available a freely accessible self-report instrument that can be used also by health practitioners. Potential users may choose to use the 21-item MIRES scale, individual subscales, or even the 6-item scale (reflective items) that were developed for the purpose of model identification. It is important to bear in mind, however, that the 6-item scale has not been developed and validated as thoroughly as the 21-item scale, thus its properties should be further examined. Finally, for a more comprehensive assessment of internally regulated eating style, which assesses sensitivity and self-efficacy in context, the complete 45-item scale can be used. Such thorough assessment may be useful when practitioners have indications that a client's sensitivity and self-efficacy may be compromised in the presence of emotional or environmental cues.

Furthermore, two important implications about mindfulness practice in the eating context can be drawn from the present thesis. The first is concerned with the order and the second with the intensity of performing mindfulness exercises that tap into awareness of hunger and satiation sensations. First, individuals who use mindfulness to become aware of eating-related sensations should prioritize exercises that increase awareness of satiation signals before attempting to increase awareness of hunger signals. Second, it is important to recognise that one may need to follow more intensive mindfulness training (higher frequency and duration) to improve their ability to perceive early bodily signals of satiation as compared with early signals of hunger. These considerations may be useful both for individuals and health practitioners who employ mindfulness techniques with their clients.

6.6. Conclusion

Compatible with general trends in positive psychology and positive health, this thesis has investigated the concept of internally regulated eating style from various angles, including theory, measurement, and application. Building on existing knowledge, this thesis delineated the defining features of internally regulated eating style, developed practical tools for the assessment of these features, initiated the validation of these assessment tools, and examined the effects of existing interventions on some of the internally regulated eating features.

Internally regulated eating style is a function of five individual-difference characteristics that can be reliably measured with the newly developed Multidimensional Internally Regulated Eating Scale (MIRES). Initial evidence on the scale's validity was provided in this thesis. Yet more behavioural research is needed to fully substantiate the validity of MIRES subscales. Finally, this thesis shed light on a largely unexplored mechanism by which mindfulness has been hypothesized to impact food intake. It was found that focussed attention to the body can have a substantial effect on the ability to perceive bodily signals of hunger, while perception of bodily signals of satiation was not influenced by this type of attention. This thesis has laid the groundwork in the study of internally regulated eating style as a unified concept. Scientists may take this as a starting point to further advance research on this domain and health practitioners may draw from this research to supplement or adapt their strategies.

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Summary

Food intake regulation has become a difficult task nowadays. In modern societies, where the societal pressure for thinness is widespread and the environmental triggers of overeating abundant this task becomes even more challenging. Yet, even under these circumstances, some individuals manage to regulate their eating effectively as they achieve to eat healthily and in moderation. This thesis argues that one effective approach to eating regulation is internally regulated eating. Internally regulated eating is a non-restrictive form of eating regulation that is grounded on responsiveness to bodily signals of hunger and satiation. Previous research has shown that internally regulated eating is not only associated with improved health outcomes but also leads to them. However, the literature on internally regulated eating is highly fragmented and built upon limited theoretical accounts.

This thesis embraces the multiformity in this field and uses it to build an integrated theoretical framework of internally regulated eating style. This framework is then used as a basis to advance measurement and applications in this field. Specifically, the following research questions are addressed in the chapters of this thesis: 1. Which are the individual-difference characteristics that underpin the internally regulated eating style, how do they associate with each other, and how do they lead to effective regulation of food intake?; 2. How can we quantify these individual-difference characteristics in the population?; 3. To what extent does sensitivity to bodily signals of hunger and satiation (trait) manifest itself in behavioural tasks (state)?; 4. To what extent is perception of bodily signals of hunger and satiation (state) affected by focused attention to the body?

To address the different elements of the first research question, a narrative review of the literature on various paradigms of internally regulated eating was conducted (Chapter 2). The term internally regulated eating style was coined, defined as the general tendency to eat in response to physiological signals of hunger and satiation, which is underpinned by a specific set of individual-difference characteristics, namely, 1. sensitivity to physiological signals of hunger and satiation, 2. self-efficacy in using physiological signals of hunger and satiation to determine when and how much to eat, 3. trust on the body's physiological processes for the regulation of eating (internal trust), 4. a relaxed relationship with food (food legalising), and 5. a tendency to savour the food while eating (food enjoyment). These characteristics were theorised to not be interchangeable, as each of them captures a unique aspect of the internally regulated eating style. Furthermore, a classical theoretical model of eating behaviour, the boundary model of eating, was used to explain how the internally regulated eating style leads

to effective regulation of food intake. It was argued that the individual-difference characteristics of internally regulated eating enable individuals to maintain narrow control of their eating, as they form an inclination to initiate meals in response to moderate signals of hunger and to cease meals in response to moderate signals of satiation. It is assumed that, in this narrow control, there is less room for non-physiological factors to exert their influences on food intake.

The comprehensive conceptualisation of internally regulated eating style was used as a basis to drive research in the remaining chapters of this thesis. Since none of the available self-report measures could adequately capture the full complexity and theoretical structure of the internally regulated eating style, a new measure was developed for this purpose (Chapter 3), thereby addressing the second research question of this thesis. A stepwise, theory-based, and empirically driven process was used to develop the Multidimensional Internally Regulated Eating Scale (MIRES) and to provide initial evidence for its validity. A preliminary item pool was generated with items assessing each of the individual-difference characteristics of the internally regulated eating style. This item pool was revised according to feedback from nutrition researchers and experts and was further subjected to two rounds of preliminary testing with college samples. Starting from the structure that emerged from this preliminary work, the scale's psychometric properties were tested and confirmed in broad samples of consumers from the UK and US. Specifically, evidence on the scale's internal structure and consistency, measurement invariance, and two-week temporal stability was obtained. In addition, the construct, discriminant, convergent, criterion, and incremental validity of the scale were upheld in this cross-sectional research.

Following the development and initial validation of the MIRES, this thesis took the validity testing of MIRES subscales one step forward (Chapter 4). Two pre-registered behavioural experiments were conducted to assess the construct validity of two MIRES subscales: sensitivity to bodily signals of satiation (SS) and sensitivity to bodily signals of hunger (SH). In these experiments, associations of SS and SH with behavioural indicators of the incidental ability to perceive the onset of satiation and hunger (respectively) were examined, thereby addressing the third research question of this thesis. Two standardised methodologies were employed to assess the behavioural indicators. Specifically, the water load test was used to assess satiation threshold in the laboratory (i.e., the percentage of stomach capacity that needs to be filled with water for the person to perceive the first bodily signal of satiation) and the preload test was used to assess hunger threshold in a semi-controlled setting (i.e., the amount of time that needs to pass after consumption of a standardised preload for the person to perceive the first bodily signal of hunger). In addition, participants filled in a self-report measure that taps into the broader domain of awareness of bodily sensations (Multidimensional Assessment of Interoceptive Awareness - MAIA). It was found that in a healthy sample of males and females (19-68 years), SS was not associated with satiation threshold (Study 1). Likewise, in a healthy sample of young females (18-27 years), SH was not associated with hunger threshold (Study 2). MAIA was not associated with the satiation and hunger thresholds either, but it was positively associated with SS and SH. It was concluded that this research failed to obtain strong evidence on the construct validity of the MIRES subscales; however, the finding that these subscales tap into the broader theoretical construct they are intended to measure (i.e., interoceptive awareness) provides preliminary support for their construct validity.

Finally, this thesis also paid attention to potential applications in the field of internally regulated eating. Specifically, it investigated the effect of a brief mindfulness intervention (i.e., focussed attention to the body) on perception of bodily signals of satiation and hunger (Chapter 5), thereby addressing the last research question of this thesis. Mindfulness is an increasingly studied concept in the domain of eating regulation and several studies have documented its positive effects on food intake and weight. Yet, little is known about the underlying mechanisms by which mindfulness exerts these effects. This thesis examined one such potential mechanism that has not received adequate attention in prior research. By adding a second experimental group (i.e., mindfulness group) to each of the studies presented in Chapter 4, the studies were turned into quasi experiments, allowing thus, the effects of mindfulness on perception of bodily signals of satiation and hunger to be studied in a controlled experimental setting. It was found that a brief mindfulness exercise (body scan) did not influence the perception of satiation (Study 1) but improved the ability to perceive bodily signals of hunger (Study 2). After consuming a standardized preload, participants in the mindfulness group perceived the onset of hunger 18min earlier than those in the control group and this effect persisted also in the presence of control variables. Hence, it was concluded that even a single mindfulness exercise can improve the perception of hunger signals substantially, while more intensive mindfulness training may be required to impact the perception of satiation signals.

Overall, this thesis provides a solid theoretical foundation for the study of internally regulated eating style, a reliable instrument that can be used for its measurement, as well as inspiration for potential applications in research and practice in this field. It provides a starting point for a unified understanding of existing non-dieting approaches to eating, supplements (with cross-sectional data) existing evidence on the adaptive nature of the internally regulated eating style, and generates insights that are relevant to various streams of literature, including those on measurement, construct validation, mindfulness, and interoception.

Σύνοψη

Η ρύθμιση της διατροφικής πρόσληψης έχει γίνει δύσκολο έργο στις μέρες μας. Στις σύγχρονες κοινωνίες, όπου η κοινωνική πίεση για λεπτότητα είναι ευρέως διαδεδομένη και τα περιβαλλοντικά ερεθίσματα για υπερκατανάλωση φαγητού άφθονα, το έργο αυτό γίνεται ακόμη πιο απαιτητικό. Ωστόσο, ακόμα και κάτω από αυτές τις συνθήκες, ορισμένα άτομα καταφέρνουν να ρυθμίζουν αποτελεσματικά την κατανάλωση τους καθώς επιτυγχάνουν να τρώνε υγιεινά και με μέτρο. Αυτή η διατριβή υποστηρίζει ότι μια αποτελεσματική προσέγγιση στη ρύθμιση της κατανάλωσης τροφής είναι η εσωτερικά ρύθμιζόμενη διατροφή. Η εσωτερικά ρυθμιζόμενη διατροφή είναι μια μή περιοριστική μορφή ρύθμισης της κατανάλωσης τροφής που βασίζεται στην ανταπόκριση στα σωματικά σημάδια πείνας και κορεσμού. Προηγούμενη έρευνα έχει δείξει ότι η εσωτερικά ρυθμιζόμενη διατροφή όχι μόνο συσχετίζεται με βελτίωση δεικτών υγείας αλλά οδηγεί σε αυτήν. Ωστόσο, η βιβλιογραφία πάνω στην εσωτερικά ρυθμιζόμενη διατροφή είναι πολύ κατακερματισμένη και βασισμένη πάνω σε περιορισμένα θεωρητικά μοντέλα.

Αυτή η διατριβή αγκαλιάζει την πολυμορφία σε αυτό το πεδίο και τη χρησιμοποιεί για να χτίσει ένα ολοκληρωμένο θεωρητικό πλαίσιο για τον εσωτερικά ρυθμιζόμενο τρόπο διατροφής. Αυτό το πλαίσιο χρησιμοποιείται στη συνέχεια ως βάση για την προαγωγή της μέτρησης και των εφαρμογών σε αυτόν τον τομέα. Συγκεκριμένα, τα ακόλουθα ερευνητικά ερωτήματα εξετάζονται στα κεφάλαια αυτής της διατριβής: 1. Ποια χαρακτηριστικά ατομικής διαφοράς υποστηρίζουν τον εσωτερικό ρυθμιζόμενο τρόπο διατροφής, πώς συνδέονται μεταξύ τους και πώς οδηγούν σε αποτελεσματική ρύθμιση της διατροφικής πρόσληψης; 2. Πώς μπορούμε να ποσοτικοποιήσουμε αυτά τα χαρακτηριστικά ατομικής διαφοράς στον πληθυσμό; 3. Σε τί βαθμό εκδηλώνεται η ευαισθησία στα σωματικά σημάδια πείνας και κορεσμού (ως χαρακτηριστικό) σε συμπεριφορικές δοκιμασίες (ως κατάσταση); 4. Σε τί βαθμό επηρεάζεται η αντίληψη των σωματικών σημαδιών πείνας και κορεσμού (ως κατάσταση) από την εστίαση της προσοχής στο σώμα;

Για την εξέταση των διαφόρων στοιχείων του πρώτου ερευνητικού ερωτήματος, πραγματοποιήθηκε μια αφηγηματική ανασκόπηση της βιβλιογραφίας σχετικά με τα διάφορα πρότυπα εσωτερικά ρυθμιζόμενης διατροφής (Κεφάλαιο 2). Ο όρος εσωτερικά ρυθμιζόμενος τρόπος διατροφής επινοήθηκε, ο οποίος ορίσθηκε ως η γενική τάση να τρεφόμαστε ως απάντηση στα σωματικά σημάδια πείνας και κορεσμού η οποία υποστηρίζεται από ένα συγκεκριμένο σύνολο χαρακτηριστικών ατομικής διαφοράς, ονομαστικά: 1. ευαισθησία στα σωματικά σημάδια πείνας και κορεσμού, 2. αυτο-αποτελεσματικότητα στη χρήση σωματικών

σημαδιών πείνας και κορεσμού για τον προσδιορισμό του πότε και πόσο τρώμε, 3. εμπιστοσύνη στις φυσιολογικές διαδικασίες του σώματος για τη ρύθμιση της κατανάλωσης τροφής (εσωτερική εμπιστοσύνη) , 4. μια χαλαρή σχέση με το φαγητό (νομιμοποίηση φαγητού) και 5. μια τάση να απολαμβάνουμε το φαγητό κατά τη διάρκεια της σίτισης (απόλαυση φαγητού). Αυτά τα χαρακτηριστικά θεωρήθηκαν ως μή εναλλάξιμα, καθώς καθένα από αυτά συλλαμβάνει μια μοναδική πτυχή του εσωτερικά ρυθμιζόμενου τρόπου διατροφής. Επιπλέον, χρησιμοποιήθηκε ένα κλασικό θεωρητικό μοντέλο διατροφικής συμπεριφοράς, το περιοριστικό μοντέλο διατροφής, για να εξηγήσει πώς ο εσωτερικά ρυθμιζόμενος τρόπος διατροφής οδηγεί σε αποτελεσματική ρύθμιση της διατροφικής πρόσληψης. Υποστηρίχθηκε ότι τα χαρακτηριστικά ατομικής διαφοράς της εσωτερικά ρυθμιζόμενης διατροφής επιτρέπουν στα άτομα να διατηρούν στενό έλεγχο της κατανάλωσης τροφής, καθώς σχηματίζουν μια τάση να ξεκινάμε γεύματα ως απάντηση σε μέτρια σημάδια πείνας και να σταματάμε τα γεύματα ως απάντηση σε μέτρια σημάδια κορεσμού. Υποτίθεται ότι, σε αυτόν τον στενό έλεγχο, υπάρχει λιγότερο περιθώριο για παράγοντες έκτος της φυσιολογίας του σώματος να ασκήσουν τις επιρροές τους στην διατροφική πρόσληψη.

Η ολοκληρωμένη εννοιολογική σύλληψη του εσωτερικά ρυθμιζόμενου τρόπου διατροφής χρησιμοποιήθηκε ως βάση για να οδηγήσει την έρευνα στα υπόλοιπα κεφάλαια αυτής της διατριβής. Δεδομένου ότι καμία από τις διαθέσιμες κλίμακες αυτοαναφοράς δεν θα μπορούσε να συλλάβει επαρκώς την πλήρη πολυπλοκότητα και θεωρητική δομή του εσωτερικά ρυθμιζόμενου τρόπου διατροφής, μία νέα κλίμακα αναπτύχθηκε για το σκοπό αυτό (Κεφάλαιο 3), εξετάζοντας έτσι το δεύτερο ερευνητικό ερώτημα αυτής της διατριβής. Χρησιμοποιήθηκε μια διαδικασία σταδιακή, βασισμένη στη θεωρία και καθοδηγούμενη από ερευνητικά ευρήματα για την ανάπτυξη της Πολυδιάστατης Κλίμακας Εσωτερικά Ρυθμιζόμενης Διατροφής (MIRES) και για την παροχή αρχικών στοιχείων για την εγκυρότητά της. Δημιουργήθηκε ένα προκαταρκτικό σύνολο ερωτήσεων που αξιολογούν κάθε ένα από τα χαρακτηριστικά ατομικής διαφοράς του εσωτερικά ρυθμιζόμενου τρόπου διατροφής. Αυτό το σύνολο ερωτήσεων τροποποιήθηκε σύμφωνα με σχόλια ερευνητών διατροφής και εμπειρογνωμόνων και υποβλήθηκε περαιτέρω σε δύο γύρους προκαταρκτικών δοκιμών σε δείγματα φοιτητών. Ξεκινώντας από τη δομή που προέκυψε από αυτό το προκαταρκτικό έργο, οι ψυχομετρικές ιδιότητες της κλίμακας δοκιμάστηκαν και επιβεβαιώθηκαν σε ευρεία δείγματα καταναλωτών από το Ηνωμένο Βασίλειο και τις ΗΠΑ. Συγκεκριμένα, ελήφθησαν στοιχεία σχετικά με την εσωτερική δομή και συνοχή της κλίμακας, την σταθερότητα μέτρησης και τη χρονική σταθερότητα δύο εβδομάδων. Επιπλέον, η εγκυρότητα της εννοιολογικής κατασκευής της κλίμακας, καθώς επίσης και η αποκλίνουσα, συγκλίνουσα, συντρέχουσα και επαυξητική της εγκυρότητα επιβεβαιώθηκαν σε αυτήν την συγχρονική έρευνα.

Μετά την ανάπτυξη και αρχική επικύρωση του MIRES, αυτή η διατριβή μετέφερε τον έλεγχο εγκυρότητας υποκατηγοριών του MIRES ένα βήμα πιο πέρα (Κεφάλαιο 4). Διεξήχθησαν δύο προ-εγγεγραμένα πειράματα συμπεριφοράς για να εκτιμηθεί η εγκυρότητα της εννοιολογικής κατασκευής δύο υποκατηγοριών του MIRES: ευαισθησία στα σωματικά σημάδια κορεσμού (SS) και ευαισθησία στα σωματικά σημάδια πείνας (SH). Σε αυτά τα πειράματα, εξετάστηκαν οι συσχετίσεις των SS και SH με συμπεριφορικούς δείκτες της τυχαίας ικανότητας των ατόμων να αντιληφθούν την έναρξη του κορεσμού και της πείνας (αντίστοιχα), εξετάζοντας έτσι το τρίτο ερευνητικό ερώτημα αυτής της διατριβής. Δύο τυποποιημένες μεθοδολογίες χρησιμοποιήθηκαν για την αξιολόγηση των δεικτών συμπεριφοράς. Συγκεκριμένα, η δοκιμασία φόρτισης νερού χρησιμοποιήθηκε για την εκτίμηση του κατωφλίου κορεσμού στο εργαστήριο (δηλ., το ποσοστό της χωρητικότητας του στομάχου που πρέπει να γεμίσει με νερό για να αντιληψθεί το άτομο το πρώτο σωματικό σημάδι κορεσμού) και η δοκιμασία προ-φόρτισης χρησιμοποιήθηκε για την εκτίμηση του κατωφλίου πείνας υπό ημι-ελεγχόμενες συνθήκες (δηλ., το χρονικό διάστημα που πρέπει να περάσει μετά την κατανάλωση ενός τυποποιημένου προ-φορτίου για να αντιληφθεί το άτομο το πρώτο σωματικό σημάδι πείνας). Επιπλέον, οι συμμετέχοντες συμπλήρωσαν ένα ερωτηματολόγιο αυτοαναφοράς που εμπίπτει στον ευρύτερο τομέα της επίγνωσης σωματικών αισθήσεων (Πολυδιάστατη Αξιολόγηση της Εσωτερικής Επίγνωσης - MAIA). Διαπιστώθηκε ότι σε ένα υγιές δείγμα ανδρών και γυναικών (19-68 ετών), η SS δεν συσχετίστηκε με το κατώφλι κορεσμού (Μελέτη 1). Ομοίως, σε ένα υγιές δείγμα νεαρών γυναικών (18-27 ετών), η SH δεν συσχετίστηκε με το κατώφλι πείνας (Μελέτη 2). Ούτε η MAIA συσχετίστηκε με τα κατώφλια κορεσμού και πείνας, αλλά συσχετίστηκε θετικά με τις SS και SH. Συνήχθη το συμπέρασμα ότι αυτή η έρευνα απέτυχε να συλλέξει ισχυρές αποδείξεις σχετικά με την εγκυρότητα της εννοιολογικής κατασκευής των υποκατηγοριών MIRES. Ωστόσο, το εύρημα ότι αυτές οι υποκατηγορίες εμπίπτουν στο ευρύτερο θεωρητικό κατασκεύασμα που σκοπεύουν να μετρήσουν (δηλ., η εσωτερική επίγνωση) παρέχει προκαταρκτική υποστήριξη για την εγκυρότητα της εννοιολογικής κατασκευής τους.

Τέλος, η παρούσα διατριβή έδωσε επίσης προσοχή σε πιθανές εφαρμογές στον τομέα της εσωτερικά ρυθμιζόμενης διατροφής. Συγκεκριμένα, διερεύνησε την επίδραση μιας σύντομης παρέμβασης ενσυνειδητότητας (δηλ., εστίαση προσοχής στο σώμα) στην αντίληψη των σωματικών σημαδιών κορεσμού και πείνας (Κεφάλαιο 5), εξετάζοντας έτσι το τελευταίο ερευνητικό ερώτημα αυτής της διατριβής. Η ενσυνειδητότητα είναι μια έννοια που μελετάται όλο και περισσότερο στον τομέα της ρύθμισης κατανάλωσης τροφής και αρκετές μελέτες έχουν τεκμηριώσει τις θετικές επιπτώσεις της στην διατροφική πρόσληψη και το βάρος. Ωστόσο, λίγα είναι γνωστά για τους υποκείμενους μηχανισμούς με τους οποίους η ενσυνειδητότητα ασκεί αυτά τα αποτελέσματα. Αυτή η διατριβή εξέτασε έναν τέτοιο πιθανό μηχανισμό που δεν έχει λάβει επαρκή προσοχή σε προηγούμενες έρευνες. Προσθέτοντας μια δεύτερη πειραματική ομάδα (δηλ. ομάδα ενσυνειδητότητας) σε καθεμία από τις μελέτες που παρουσιάστηκαν στο Κεφάλαιο 4, οι μελέτες μετατράπηκαν σε quasi πειράματα, επιτρέποντας έτσι, να μελετηθούν οι επιπτώσεις της ενσυνειδητότητας στην αντίληψη των σωματικών σημαδιών κορεσμού και πείνας κάτω από ελεγχόμενες πειραματικές συνθήκες. Διαπιστώθηκε ότι μια σύντομη άσκηση ενσυνειδητότητας (σάρωση σώματος) δεν επηρέασε την αντίληψη του κορεσμού (Μελέτη 1) αλλά βελτίωσε την ικανότητα αντίληψης σωματικών σημαδιών πείνας (Μελέτη 2). Μετά την κατανάλωση ενός τυποποιημένου προ-φορτίου, οι συμμετέχοντες στην ομάδα ενσυνειδητότητας αντιλήφθηκαν την έναρξη της πείνας 18 λεπτά νωρίτερα από εκείνους στην ομάδα ελέγχου και αυτή η επίδραση παρέμεινε επίσης παρουσία των μεταβλητών ελέγχου. Ως εκ τούτου, συνήχθη το συμπέρασμα ότι ακόμη και μια μεμονωμένη άσκηση ενσυνειδητότητας μπορεί να βελτιώσει σημαντικά την αντίληψη των σημαδιών πείνας, ενώ πιο εντατική εκπαίδευση ενσυνειδητότητας μπορεί να απαιτείται για να επηρεάστεί η αντίληψη των σημαδιών κορεσμού.

Συνολικά, η παρούσα διατριβή παρέχει μία σταθερή θεωρητική βάση για την μελέτη του εσωτερικά ρυθμιζόμενου τρόπου διατροφής, ένα αξιόπιστο εργαλείο που μπορεί να χρησιμοποιηθεί για την μέτρησή του, όπως επίσης και έμπνευση για πιθανές εφαρμογές στην έρευνα και πρακτική σε αυτό το πεδίο. Παρέχει μια αφετηρία για μια ενοποιημένη κατανόηση των υπαρχουσών μή διαιτητικών προσεγγίσεων στη διατροφή, συμπληρώνει (με ευρήματα διαχρονικής έρευνας) υπάρχοντα στοιχεία σχετικά με την προσαρμοστική φύση του εσωτερικά ρυθμιζόμενου τρόπου διατροφής και παράγει γνώσεις που είναι σχετικές με διάφορα κανάλια βιβλιογραφίας, συμπεριλαμβανομένων εκείνων που αφορούν τη μέτρηση, τον έλεγχο εγκυρότητας εννοιολογικής κατασκευής, την ενσυνειδητότητα και την εσωτερική επίγνωση.

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About the Author

Aikaterini Palascha was born in Katerini, Greece on 27 January 1989. In 2010, she completed her bachelor's degree in Science of Dietetics and Nutrition at Harokopio University of Athens, Greece. After working for one year as freelance dietitian and teacher in vocational centres, Aikaterini received a MSc scholarship from the Greek State Scholarships Foundation, which allowed her to join the master's programme Nutrition and Health at Wageningen University & Research. During her studies, she worked as student assistant in statistics and conducted two master theses, thereby contributing to several scientific publications. Shortly after finishing her studies, Aikaterini worked on several EU-funded projects at the European Food Information Council (EUFIC), Belgium and at the Marketing and Consumer Behaviour group of Wageningen University & Research. She then obtained a PhD scholarship from the Wageningen School of Social Sciences (WASS) to conduct her research on internally regulated eating. Aikaterini has presented her research at international conferences and has published several papers.

List of Publications

Palascha, A., van Kleef, E., de Vet, E., & van Trijp, H. C. M. (2021). Sensitivity to Physiological Signals of Satiation and Hunger: Assessment of Construct Validity. *Personality and Individual Differences*, *182*, 111054. https://doi.org/10.1016/j.paid.2021.111054

Palascha, A., van Kleef, E., de Vet, E., & van Trijp, H. C. M. (2021). The effect of a brief mindfulness intervention on perception of bodily signals of satiation and hunger. *Appetite*, *164*, 105280. https://doi.org/10.1016/j.appet.2021.105280

Palascha, A., van Kleef, E., de Vet, E., & van Trijp, H. C. M. (2020). Development and validation of the Multidimensional Internally Regulated Eating Scale (MIRES). *PLOS ONE*, *15*(10), e0239904. https://doi.org/10.1371/journal.pone.0239904

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Gutjar, S., Dalenberg, J. R., de Graaf, C., de Wijk, R. A., **Palascha, A.**, Renken, R. J., & Jager, G. (2015). What reported food-evoked emotions may add: A model to predict consumer food choice. *Food Quality and Preference*, *45*, 140–148. https://doi.org/10.1016/j.foodqual.2015.06.008

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Gutjar, S., Graaf, C. de, **Palascha, A.**, & Jager, G. (2014). Food choice. The battle between package, taste and consumption situation. *Appetite*, *80*, 109–113. https://doi.org/10.1016/j.appet.2014.05.006

Completed Training and Supervision Plan

Aikaterini Palascha
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department/ Institute	Year	ECTS*
A) Project related competences			
Writing of the PhD research proposal	WUR	2016	6
'Development and Validation of the Dutch Intuitive Eating Scale'	WASS PhD day	2017	1
Quantitative data analysis: Multivariate techniques, YRM 50806	WUR	2017	6
Introduction to R for statistical analysis	PE&RC, SENSE	2017	0.6
PhD colloquia series			2
- *Development of the Dutch Intuitive Eating Scale*	MCB PhD day	2017	
- *Trust the body or the mind?*	MCB lunch club	2017	
- *Internally Regulated Eating: Concept and Measurement*	HNH lunch club	2018	
- *Psychometric properties of a new measure of internally regulated eating*	MCB PhD day	2018	
- *Sensitivity to physiological signals of hunger and satiation: A test of validity and the effect of a mindfulness intervention*	MCB lunch club	2020	
B) General research related competences			
Masterclasses (prior learning)	WASS	2015	
- *Priming*			0.5
- *Psychology of health and environmental behaviour: Habits*			0.5
WASS introduction course	WASS	2016	1
The essentials of scientific writing and presenting	Wageningen in'to Languages	2016	1.2
Presenting with impact	Wageningen in'to Languages	2017	1
Advanced sensory methods and sensometrics, MCB 32806	WUR	2017	3
Brain training	WGS	2017	0.3
EDEN doctoral seminar on consumer research	EIASM	2018	4
Systematic approaches to reviewing literature	WASS	2020	4
'SensEat: The effect of a brief mindfulness intervention on perception of bodily signals of satiation and hunger'	45th BFDG annual meeting, online event	2021	1
'Trait vs. state sensitivity to physiological signals of satiation and hunger: Two construct validity studies'	35th EHPS annual conference	2021	1

C) Career related competences/personal development			
MSc theses supervision	MCB	2017, 2018	1.5
Didactic PhD course *Supervising BSc and MSc thesis students*	ESC	2018	0.5
Scientific paper reviews (Journal of Food, Nutrition and Dietetics and Appetite)		2018, 2019	2
Online Mindfulness-Based Eating Awareness Training for professionals	The centre for Mindful Eating	2019, 2020	1.5
Start to teach	ESC	2020	1
Total			**39.6**

*One credit according to ECTS is on average equivalent to 28 hours of study load

Abbreviations
WASS: Wageningen School of Social Sciences
WUR: Wageningen University & Research
PE&RC: Production Ecology & Resource Conservation Graduate School
SENSE: Research School for Socio-Economic and Natural Sciences of the Environment
MCB: Marketing and Consumer Behaviour
HNH: Human Nutrition and Health
WGS: Wageningen Graduate Schools
EIASM: European Institute for Advanced Studies in Management
BFDG: British Feeding and Drinking Group
EHPS: European Health Psychology Society
ESC: Educational Support Centre

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