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ELINA JÄRVELÄ-REIJONEN

STRESS, EATING BEHAVIOR, DIET, AND THE EFFECTS OF ACCEPTANCE AND COMMITMENT THERAPY

Among adults with psychological distress and overweight

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ABSTRACT

Both psychological and physiological processes contribute to health and wellbeing. Chronic stress, meaning insufficient recovery, can lead to ill health via psychological, physiological, and behavioral processes. Chronic stress, as also dietary factors, are closely related to obesity and low-grade inflammation; these are underlying factors in several common diseases, e.g. type 2 diabetes and cardiovascular diseases. An individual's risk for these diseases could be reduced if he/she made lifestyle changes, but making long-term behavioral changes is challenging, partly because of psychological inflexibility. Thus, psychological interventions are needed.

The aim of this doctoral thesis was to investigate (a) how stress and recovery are associated with eating behavior and diet by adopting a cross-sectional approach and (b) whether an intervention based on psychological acceptance and commitment therapy (ACT) could change eating behavior, diet, and circulating biomarkers of stress and low-grade inflammation among working-age adults with psychological distress and overweight/obesity.

A total of 339 volunteers were randomized to the Elixir multicenter randomized controlled trial. In the baseline cross-sectional analyses, 297 participants (84% females, aged 27 – 61 years) provided the data. The post-intervention measurements were conducted after the 8-week intervention at study week 10 with follow-up measurements made on study week 36. With respect to the intervention effects, the analysis focused on the two ACT-based intervention groups (Face-to-face, n=70; six group sessions, and Mobile, n=78; one group session and mobile app) compared to the Control group (n=71; only the measurements). Perceived stress was measured with a questionnaire (PSS-14). Physiological recovery was based on heart rate variability (HRV) recording on three consecutive nights. Eating behavior was assessed with several questionnaires (TFEQ-R18, HTAS, IES-1, ecSI 2.0™, REBS). Diet was assessed with questionnaires (IDQ, AUDIT-C) and 48-h dietary recall. The biomarkers of stress and low-grade inflammation (hsCRP, IL-1Ra, HMW-adiponectin, cortisol, DHEAS) were analyzed from morning fasting blood samples.

Perceived stress was associated with lower levels of intuitive eating, eating competence, and cognitive restraint as well as with higher levels of uncontrolled eating, emotional eating, and using food as a reward. No associations were found between perceived stress and diet. Sleep-time recovery was associated with lower intuitive eating, lower alcohol consumption, and higher diet quality (IDQ score) and fiber intake. A subcomponent of intuitive eating (i.e., eating for physical rather than emotional reasons) increased in both ACT groups and uncontrolled eating decreased in the Face-to-face group as compared to Control. Using food as a reward decreased in the Mobile group as compared to the Face-to-face group. Food acceptance and internal motivation for regulation of eating increased in the Face-to-face group as compared to both Control and Mobile groups. ACT did not seem to have any effect on diet. The hsCRP decreased in the Face-to-face group as compared to the Mobile group but no other effects on stress and inflammation biomarkers were observed. In additional exploratory principal component analyses of psychological, physiological, anthropometric, and lifestyle measures, it was found that weight-related psychological flexibility was the only psychological variable which was linked with stress and inflammation biomarkers in the same principal component.

In conclusion, perceived stress associates with unfavorable eating behavior. Better sleep-time recovery is linked with better diet quality. Thus, perceived stress and physiological recovery are relevant factors in nutrition science and clinical practice. More research and methodological development are needed to clarify the interactions between stress, recovery, eating behavior and dietary intake. ACT improves eating behavior and is thus a promising method for health-promotion and chronic disease prevention in people with psychological distress and overweight/obesity. If improvements in diet quality or physiological biomarkers are expected, it is proposed to focus the ACT intervention content to target that goal.

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Medical Subject Headings: Stress, Psychological; Eating; Feeding Behavior; Diet; Food; Acceptance and Commitment Therapy; Mindfulness; Obesity; Overweight; Recovery of Function; Heart Rate; Inflammation; Biomarkers; Alcohol Drinking; Dietary Fiber; Cognition; Motivation; Sleep; Mobile Applications; Surveys and Questionnaires; Randomized Controlled Trial; Adult; Middle Aged; Finland

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TIIVISTELMÄ

Sekä psykologiset että fysiologiset prosessit vaikuttavat terveyteen ja hyvinvointiin. Krooninen stressi, eli riittämätön palautuminen, voi johtaa terveysongelmiin psykologisten, fysiologisten tai käyttäytymiseen liittyvien prosessien kautta. Krooninen stressi, kuten myös ruokavaliotekijät, liittyvät läheisesti lihavuuteen ja matala-asteiseen tulehdukseen, jotka puolestaan ovat esimerkiksi tyypin 2 diabeteksen ja sydän- ja verisuonitautien taustalla. Sairauksien riskiä voisi vähentää elintapamuutoksilla, mutta pysyvä käyttäytymisenmuutos on kuitenkin haasteellista, osittain johtuen psykologisesta joustamattomuudesta. Psykologisille interventioille on täten suuri tarve.

Tämän väitöskirjan tavoitteena oli tutkia, (a) miten stressi ja palautuminen ovat yhteydessä syömiskäyttäytymiseen ja ruokavalioon poikkileikkausasetelmassa, ja (b) vaikuttaako psykologinen hyväksymis- ja omistautumisterapia (HOT) syömiskäyttäytymiseen, ruokavalioon ja verenkierron stressin ja matala-asteisen tulehduksen merkkiaineisiin työikäisillä aikuisilla, joilla on psyykkistä kuormittuneisuutta sekä ylipainoa tai lihavuutta.

Yhteensä 339 vapaaehtoista satunnaistettiin kontrolloituun Eliksiirit-monikeskustutkimukseen. Heistä 297:ltä (84 % naisia, ikä 27 – 61 vuotta) oli saatavilla tiedot alkutilanteen poikkileikkausanalyyseihin. Interventiojakson (8 viikkoa) jälkeen toteutettiin mittaukset tutkimusviikolla 10 ja seurantamittaukset viikolla 36. Interventiovaikutuksia koskevat analyysit keskittyvät kahteen HOT:iin perustuvaan interventioryhmään (Kasvo-ryhmä, n=70, kuusi ryhmätapaamista, ja Mobiili-ryhmä, n=78, yksi ryhmätapaaminen ja älypuhelinsovellus) verrattuna Kontrolli-ryhmään (n=71, osallistui vain mittauksiin). Koettua stressiä mitattiin kyselyllä (PSS-14). Fysiologinen palautuminen perustui kolmen peräkkäisen yön sykevälivaihtelu-mittaukseen. Syömiskäyttäytymistä mitattiin kyselyillä (TFEQ-R18, HTAS, IES-1, ecSI 2.0™, REBS). Ruokavaliota mitattiin kyselyillä (IDQ, AUDIT-C) ja 48-tunnin ruoankäyttöhaastattelulla. Stressin ja tulehduksen merkkiaineet (hCRP, IL-1Ra, HMW-adiponektiini, kortisoli, DHEAS) määritettiin aamun paastoverinäytteestä.

Koettu stressi oli yhteydessä matalampaan intuitiiviseen syömiseen, syömisen taitoon ja syömisen tietoiseen rajoittamiseen sekä korkeampaan kontrolloimattomaan syömiseen, tunnesyömiseen ja syömisen käyttämiseen itsensä palkitsemiseksi. Koetun stressin ja ruokavalion välillä ei nähty yhteyttä. Unenaikainen palautuminen oli yhteydessä matalampaan intuitiiviseen syömiseen, vähäisempään alkoholin käyttöön ja korkeampaan ruokavalion laatuun (IDQ-pisteet) ja kuidun saantiin. Intuitiivisen syömisen osa-alue (syöminen fyysisistä syistä tunnesyiden sijaan) lisääntyi molemmissa HOT-ryhmissä ja kontrolloimaton syöminen väheni Kasvo-ryhmässä verrattuna Kontrolliin. Ruoan käyttäminen itsensä palkitsemiseen väheni Mobiili-ryhmässä verrattuna Kasvo-ryhmään. Ruoan hyväksyntä sekä syömisen säätelyn sisäinen motivaatio lisääntyivät Kasvo-ryhmässä verrattuna sekä Kontrolli- että Mobiili-ryhmiin. HOT:lla ei nähty vaikutuksia ruokavalioon. Herkkä CRP laski Kasvo-ryhmässä verrattuna Mobiili-ryhmään, mutta muita vaikutuksia stressi- ja inflammaatiomarkkereihin ei nähty. Täydentävänä analyysina tehdyssä psykologisten, fysiologisten, antropometristen ja elämäntapatekijöiden pääkomponenttianalyysissa ainoa psykologinen muuttuja, joka esiintyi samassa pääkomponentissa stressi- tai inflammaatiomarkkereiden kanssa, oli painoon liittyvä psykologinen joustavuus.

Johtopäätöksenä voidaan todeta, että koettu stressi on yhteydessä epäsuotuisiin syömiskäyttäytymisen piirteisiin, ja parempi unenaikainen palautuminen on yhteydessä parempaan ruokavalion laatuun. Koetulla stressillä ja fysiologisella palautumisella on täten merkitystä ravitsemustieteessä ja kliinisessä työssä. Lisää tutkimusta ja menetelmien kehittämistä tarvitaan, jotta stressin, palautumisen, syömiskäyttäytymisen ja ruokavalion välisiä yhteyksiä voidaan ymmärtää paremmin. HOT vaikuttaa myönteisesti syömiskäyttäytymiseen ja on siten lupaava menetelmä terveydenedistämisessä ja kroonisten sairauksien ennaltaehkäisyssä aikuisilla, joilla on psyykkistä kuormittuneisuutta ja ylipainoa tai lihavuutta. Jos ruokavalioon tai fysiologisiin biomarkkereihin halutaan vaikuttaa, HOT-intervention sisältö kannattaa suunnata juuri näihin, joihin sen halutaan vaikuttavan.

Luokitus: QT 235, WD 210, WI 102, WM 172.4, WM 425.5.C6

Yleinen suomalainen ontologia: stressi; syöminen; ravinnonsaanti; ruoka; ruokavaliot; hyväksymis- ja omistautumisterapia; tietoinen läsnäolo; joustavuus; lihavuus; ylipaino; palautuminen; syke; tulehdus; markkerit; alkoholinkäyttö; ravintokuitu; kognitio; motivaatio; uni (lepotila); mobiilisovellukset; kyselytutkimus; satunnaistetut vertailukokeet; aikuiset; keski-ikäiset; Suomi

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Kuopio, November 2019

Elina Järvelä-Reijonen

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications:

I Järvelä-Reijonen E, Karhunen L, Sairanen E, Rantala S, Laitinen J, Puttonen S, Peuhkuri K, Hallikainen M, Juvonen K, Myllymäki T, Föhr T, Pihlajamäki J, Korpela R, Ermes M, Lappalainen R, Kolehmainen M. High perceived stress is associated with unfavorable eating behavior in overweight and obese Finns of working age. Appetite 103: 249-258, 2016.

II Järvelä-Reijonen E†, Järvinen S†, Karhunen L, Föhr T, Myllymäki T, Sairanen E, Lindroos S, Peuhkuri K, Hallikainen M, Pihlajamäki J, Puttonen S, Korpela R, Ermes M, Lappalainen R, Kujala UM, Kolehmainen M‡, Laitinen J‡. Sleep-time physiological recovery is associated with eating habits in distressed adults with overweight. Submitted.

III Järvelä-Reijonen E, Karhunen L, Sairanen E, Muotka J, Lindroos S, Laitinen J, Puttonen S, Peuhkuri K, Hallikainen M, Pihlajamäki J, Korpela R, Ermes M, Lappalainen R, Kolehmainen M. The effects of acceptance and commitment therapy on eating behavior and diet delivered through face-to-face contact and a mobile app: a randomized controlled trial. Int J Behav Nutr Phys Act 15: 22, 2018.

IV Järvelä-Reijonen E, Puttonen S, Karhunen L, Sairanen E, Laitinen J, Kolehmainen M, Pihlajamäki J, Kujala UM, Korpela R, Ermes M, Lappalainen R, Kolehmainen M. How do psychological and physiological processes combine? Results from a randomized controlled acceptance and commitment therapy (ACT) intervention measuring inflammation and stress biomarkers. Submitted.

The publications were adapted with the permission of the copyright owners. In addition, some previously unpublished data are presented.

† Shared first authorship
‡ Shared last authorship

CONTENTS

ABBREVIATIONS

AAQ	Acceptance and Action Questionnaire
AAQW	Acceptance and Action Questionnaire for Weight-Related Difficulties
ACT	Acceptance and Commitment Therapy
AHEI	Alternative Healthy Eating Index
ANCOVA	analysis of covariance
ANS	autonomic nervous system
AUDIT-C	Alcohol Use Disorders Identification Test Consumption
BDI	Beck Depression Inventory
BMI	body mass index
CAR	cortisol awakening response
CBT	Cognitive Behavior Therapy
CRP	C-reactive protein
DASH	Dietary Approaches to Stopping Hypertension
DEBQ	Dutch Eating Behaviour Questionnaire
DHEA	dehydroepiandrosterone
DHEAS	dehydroepiandrosterone sulphate
E%	percentage of total energy intake
ecSI 2.0™	ecSatter Inventory 2.0™
GHQ	General Health Questionnaire
HAES®	Health at Every Size®
HEI	Healthy Eating Index
HMW	high molecular weight
HPA	hypothalamic-pituitary-adrenocortical
HRV	heart rate variability
hsCRP	high-sensitivity C-reactive protein
HTAS	Health and Taste Attitude Scales
IDQ	Index of Diet Quality
IL	interleukin
IL-1Ra	interleukin-1 receptor antagonist
IES	Intuitive Eating Scale
IQR	interquartile range

MBSR	Mindfulness-Based Stress Reduction
MET	metabolic equivalent
MetS	metabolic syndrome
N/A	not applicable
PC	principal component
PCA	principal component analyses
PSS	Perceived Stress Scale
RCT	randomized controlled trial
REBS	Regulation of Eating Behavior Scale
RFT	Relational Frame Theory
RMSSD	root mean square of successive differences
SAFA	saturated fat
SD	standard deviation
SMART	Sequential Multiple Assignment Randomized Trial
TFEQ	Three-Factor Eating Questionnaire

1 INTRODUCTION

Human being is a complex system, and both psychological and physiological processes contribute to its wellbeing. Stress is an excellent example: the stress response can be evident at both the psychological and physiological levels [1,2]. Stress also affects behavior [1,2]. The purpose of a stress response is to protect individual, but without sufficient recovery, the accumulating load and chronic stress leads to ill health [3,4]. For the overall well-being, it can be thus stated that the amount and quality of recovery is more important than stress, although the scientific literature thus far has focused mainly on the presence of stress.

Chronic stress is closely related to obesity [5] and low-grade inflammation [6] which are both underlying factors in the non-communicable diseases such as type 2 diabetes and cardiovascular diseases [7,8]. Thus, adults experiencing psychological distress, and having overweight/obesity are a very vulnerable, but poorly studied, group at a high risk for developing future chronic diseases. Alarmingly, both psychological distress and overweight/obesity are common among Finnish adults: 23% of women and 15% of men report psychological distress [9], 36% of women and 46% of men are overweight, and one in four can be classified as having obesity [10]. Between the years 2011 and 2017, the prevalence of psychological distress has increased among working-age women and obesity has increased in both genders [9,10]. Thus, it is important to study the working-age adults with psychological distress and overweight/obesity in order to find ways to support their well-being and to prevent or delay the onset of non-communicable diseases. The prevention of chronic diseases and maintaining the mental/bodily ability to function would be valuable for both the individual and society.

In society today, in which food is readily available and for most of the people also affordable, several factors in addition to or even instead of, hunger and satiety trigger eating. By studying eating behavior, we can gather knowledge about the reasons and factors why people eat the way they eat. In addition to unfavorable features of eating behavior, such as emotional eating (i.e., eating because of negative emotions), this thesis will provide new information on less studied adaptive features such as intuitive eating (i.e., having unconditional permission to eat whatever desired, and eating relying on hunger and satiety cues and not on emotions [11,12]) and eating competence (i.e., having positive attitudes about eating and food, accepting and eating an ever-increasing variety of foods, eating according to internal hunger and satiety signals, and having skills and resources for managing daily meals [13]). In order to be able to change the dietary intake, a person most likely first needs to undertake changes at the level of his/her eating behavior. Thus, as suggested [14], eating behavior research can reveal novel ways for treatment and innovative means of the prevention of conditions related to dietary factors, such as obesity, metabolic syndrome, and type 2 diabetes.

However, it is challenging to make long-term behavioral changes. For example, regaining weight is common in the majority of people after weight loss [15]. A failure in long-term weight management is often related to problematic inner experiences and psychological processes, such as escaping from or avoiding one's problems [16] and having inflexible thinking style [17,18]. These nonadaptive psychological processes reflect psychological inflexibility (i.e., not being fully in contact with the present moment and not being able to change or maintain behavior which would lead to personally valued outcomes [19]). The individual's autonomy and internal motivation are also emphasized in successful behavior change techniques [20]. Acceptance and commitment therapy (ACT) aims to decrease psychological inflexibility through processes of being present (i.e., mindfulness), acceptance, commitment to own values, and behavior change [19]. Because ACT targets behavior change processes and psychological inflexibility irrespective of diagnoses, it is a promising method for lifestyle interventions. However, ACT has been rarely studied in randomized controlled trials in terms of eating behavior, dietary intake, low-grade inflammation and stress biomarkers among general, non-clinical samples.

Finally, because the demand for behavior change counseling continues to increase but the health care systems have limited resources, it is evident that new methods will be needed to deliver support for people. For example, mobile apps have attracted wide interest [21-24] and there is also some evidence that they can improve health-related behavior [25]. In the Elixir study, on which this thesis is based, the ACT intervention was delivered in face-to-face group sessions or via a mobile app to obtain knowledge for developing future lifestyle counseling methods.

Thus, the aim of this doctoral thesis was to investigate (a) how perceived stress and physiological sleep-time recovery are associated with eating behavior and diet quality cross-sectionally and (b) whether ACT intervention has effects on eating behavior, diet quality, and physiological biomarkers of stress and low-grade inflammation among working-age adults with psychological distress and overweight/obesity.

The uniqueness of this thesis is that it merges together several interrelated topics from different scientific disciplines: psychological stress, physiological stress and recovery, behavioral aspects in nutrition, food intake, and a psychological lifestyle intervention. The following review of the literature will introduce the main themes and previous studies based on research mostly conducted among non-clinical adult samples in the Western countries.

2 REVIEW OF THE LITERATURE

2.1 STRESS

2.1.1 Definition of stress

Stress is an interdisciplinary concept with no uniform definition. However, several definitions of stress include the idea in which “environmental demands tax or exceed the adaptive capacity of an organism, resulting in psychological and biological changes that may place persons at risk for disease” [1]. Thus, in general, stress results from the interplay between the internal or external environment and the individual. Thus a stressor causes a stress response; the stressor can be internal, such as rumination, or external, e.g. a factor in the social or physical environment.

Stress can exist in several levels – social, psychological, and physiological [2]. The research of stress has evolved in three traditions: the environmental/epidemiological tradition focusing on exposure to stressful events or experiences; the psychological tradition focusing on an individual’s subjective perception; and the biological tradition focusing on specific physiological systems [1,26]. Cohen and colleagues have integrated these three aspects in their stage model (Figure 1) [26]. According to the model, when stressful life events occur, the person perceives the environmental demands as stressful which in turn leads to a negative emotional arousal [26]. The next stage involves changes in behavior to cope either with the stressful event or with the emotional response, and the activation of physiological stress response [26]. However, as this model is simplified, it does not incorporate all aspects related to stress response. In addition to the environment, the stressor can also initiate from the person itself. It is typical for humans to ruminate on past stressful events or to worry about the future events. This “perseverative cognition” has an important role in prolonging the stress response [27,28]. The stress response can occur also unconsciously [29,30]. Furthermore, the stress response is also dependent on personal contextual factors (e.g. one’s genetic and cultural background), stress accumulation during the lifespan, protective factors (e.g., social support), habitual processes such as mental filters, and health behaviors such as diet and physical activity [2].

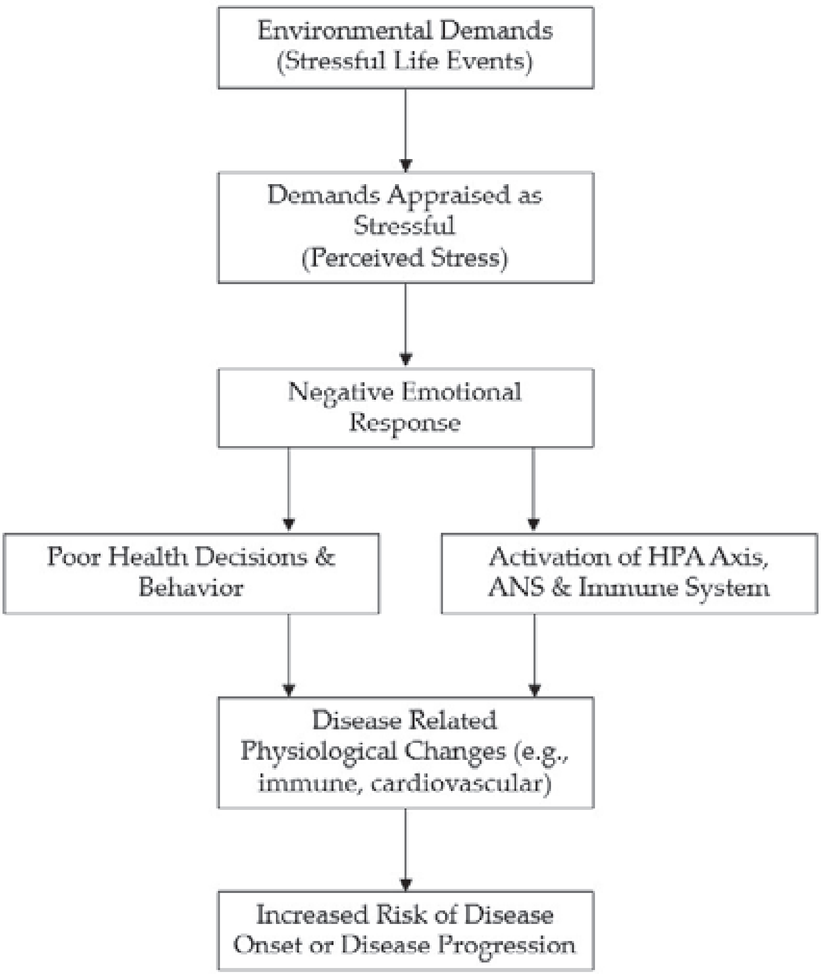

Figure 1. The integrative stage model by Cohen et al. [26]. HPA = hypothalamic-pituitary-adrenocortical, ANS = autonomic nervous system.

2.1.2 Stress as a health risk

The purpose of the stress response is to protect the individual [3,4]. However, if the stress response is prolonged, chronic stress is converted into a negative health risk [3]. One explanation on how exposure to stressors leads to ill health is the allostatic load model [31]. Physiological systems of the body act constantly to maintain the stability needed in the changing circumstances and facing different stressors, which is called "allostasis" [32]. The allostatic load means the cumulative cost of using these systems when environmental challenges are repeated or chronic [3,31]. A normal stress response is initiated by a stressor, should be continued for an appropriate time, and then turned off allowing for recovery [3]. An allostatic load emerges when the stress response is prolonged and there is a lack of recovery, or the stress response is constantly repeated due to a high frequency of stressors or due to the lack of adaptation to the same repeated stressor [3]. In addition, the allostatic load is also emerged if one physiological system does not respond to the stressor and other systems need to be activated to compensate for the inadequate response [3]. Perceived stress can also change behavior (e.g., eating, smoking, drinking, exercise) which in turn can affect physiological responses and lead or contribute to allostatic load [3]. The constant adjustment and accommodation has its cost, and a long-term allostatic (over)load can eventually lead to a disease [3,33]. Thus, it is important for an individual's long-term health that he/she can recover from the stress reactions [34].

2.1.3 Psychological stress response

The psychological tradition of stress research emphasizes the individual's own perception and evaluation of the potential stressor [1]. When a person appraises the demands to be higher than his/her own abilities to cope, he/she evaluates the situation as stressful, experiences negative emotional response, and perceives stress [1]. This negative stress appraisal initiated by a harmful or unpleasant stressor is also named as "distress", the opposite of the positive "eustress" which is initiated by positive emotions [35]. Thus, the perception of stress results from the subjective interpretation of the situation and evaluation of own resources [1].

The process of psychological stress response has been described in detail in *The Cognitive Theory of Stress and Coping* by Lazarus and Folkman [29,36]. According to the theory, two interdependent evaluation processes (primary and secondary appraisal) define whether or not the situation is stressful [29]. The primary appraisal of the situation can be either irrelevant (i.e., no influence on well-being), benign-positive, or stressful, which can be further evaluated as a harm (i.e., some damage or a loss has occurred), a threat (i.e., some harm or loss is anticipated), or a challenge (i.e., something positive is anticipated and the person has a sense of control) [29,36]. A threat is associated with negative emotions whereas a challenge is associated with positive emotions [29]. Some events can be evaluated as both a threat and a challenge, triggering both negative and positive emotions [29]. Usually in a stressful situation, something has to be done, and in this theory, the person's evaluation for survival strategy is called secondary appraisal [29]. In this secondary appraisal, the person evaluates the different coping options available, i.e. an assessment of what different options will lead to, and which options the individual has the ability to carry out [29]. All of this evaluation happens simultaneously, and the person may not even be aware of it [29]. As a result, the person exerts constantly changing cognitive and behavioral efforts to manage the external and/or internal demands that were appraised as taxing or exceeding the personal resources (i.e., coping) [29]. The coping can refer to efforts to manage or change the problem (problem-focused) and/or efforts to manage the emotional response to the problem (emotion-focused) [29,36]. If the outcome of the process of coping is favorable, a positive emotion emerges and a stressful situation has been resolved [29,36]. However, if the coping does not lead to a favorable outcome, the person will experience distress and negative emotions, and needs to reappraise the event [29,36]. It is the repetition of this appraisal-emotion-coping-reappraisal process that leads to a chronic stress response [29,36]. However, the revised model of *The Cognitive Theory of Stress and Coping* [36,37] suggests that after an unfavorable outcome, the need to try again encourages the individual to utilize personal beliefs, values and goals (meaning-focused coping) to support him/herself during this difficult time. Meaning-focused coping generates positive emotions which in turn, affect the stress process by restoring personal resources and help to sustain coping [36,37]. It is also noteworthy that one form of effective coping can be acceptance: if the stressful condition cannot be changed, the most favorable coping solution is to tolerate, minimize, accept or ignore the stressor(s) that cannot be overcome [29].

2.1.4 Physiological stress response

The biological tradition of stress research has focused on the physiological systems that are activated in a stress response [1]. Already the pioneers of stress research in the early 20th century, Walter Cannon and Hans Selye, connected stress responses with the endocrine system and the autonomic nervous system [38]. The physiological stress response increases the glucose level in blood, the heart rate, and blood pressure to provide energy and oxygen to the body so that the individual can survive under the threat or challenge, i.e. the stressor [39]. The stress system is also activated in the central nervous system [40]. The physiological stress response occurs in the interrelated hypothalamic-pituitary-adrenocortical (HPA) axis and autonomic nervous system (ANS), both of which also interact with the immune system [41-43]. The intensity of the activation of each system depends on the type of stressor to which the individual is exposed [38].

HPA axis

The activation of HPA axis ultimately results in the secretion of cortisol and dehydroepiandrosterone (DHEA) hormones from the adrenal cortex [44]. In the acute stress response, the secretions of both cortisol and DHEA are increased [45]. However, in a chronic stress situation, it seems that the cortisol level can be either elevated [46] or reduced [46,47], while the DHEA level appears to decline [44,45].

Under stressful conditions, cortisol is responsible for supplying glucose and thus energy for the tissues [48]. In addition to its effects on glucose metabolism, cortisol also influences the cardiovascular and immune systems in attempts to restore bodily homeostasis [48] and therefore it temporarily suppresses non-essential functions of the body [44]. In the acute stress condition, the higher circulating cortisol level inhibits activity in the HPA axis via a negative feedback loop [44]. Thus, a well-functioning negative feedback loop shuts down the single stress response. In the chronic stress condition, the HPA axis becomes dysregulated, and cortisol levels are elevated [46,49]. However, the stress response is not always equivalent to a higher cortisol level or an elevated cortisol response. According to the meta-analysis regarding chronic stress exposure, cortisol secretion tends to decline in the morning but increases during the rest of the day [46] thus affecting the normal diurnal rhythm in the cortisol secretion (i.e., a high peak after awakening and a decline over the rest of the day [50]). However, the cortisol secretion and its diurnal rhythm are influenced by time which has passed since the onset of exposure to the stress, the nature of the stressor, and personal factors [46]. Furthermore, according to the *Chronic Stress Response Network* model, among people with high chronic stress and visceral fat, HPA axis function is attenuated and thus the cortisol output is lower than among people with less chronic stress and less visceral fat [47].

The other adrenocortical stress hormone, DHEA, is a precursor of estrogens and androgens, but it has also several independent effects in the body [51]. The majority of the circulating DHEA exists in a sulfated form (dehydroepiandrosterone sulfate, DHEAS) [44,52]. DHEAS has a low metabolic clearance rate and a long half-life, and it is thus a stable marker of long-term HPA axis activity and stress responses [44,52]. DHEA(S) has been less extensively studied, but it has been shown to reduce body fat mass, improve physical strength, increase bone density, improve skin structure and function, improve depressive symptoms, improve cognitive function, enhance memory, improve endothelial function, improve cellular immunity, attenuate inflammatory process, improve insulin sensitivity, ameliorate atherosclerosis, provide neuroprotection against ischemia, improve sexual function, and reduce mortality [51]. DHEA(S) is known to counteract several of the effects of cortisol [44,53] and thus the lower levels of DHEA(S) during a chronic stress condition contribute to ill health. The DHEAS concentrations decline during adulthood, and the levels are higher in males than in females [52].

Autonomic nervous system (ANS)

The autonomic nervous system (ANS) comprises the sympathetic nervous system and the parasympathetic nervous system [54]. The sympathetic nervous system is responsible for the acute, "fight or flight" stress responses, mediated by epinephrine (adrenaline) and norepinephrine (noradrenaline) [38,41]. ANS regulates heart rate also directly through sympathetic and parasympathetic (vagal) nerves [55]. When sympathetic activity is predominant, heart rate is increased and heart rate variability (HRV) decreases, whereas under parasympathetic domination, the heart rate is decreased and HRV is increased [55,56]. HRV represents the fluctuation of time between consecutive heart beats, i.e. the beat-to-beat R-R interval of the QRS complex [55-57]. HRV has been used as an indicator of stress and recovery states of the body [58,59]. Indeed, a low HRV is associated with exposure to workplace stressors (reviewed in [60-62]), as well as with worrying, trait anxiety, and trait worry [63]. Furthermore, HRV-based stress state is associated with higher subjective perceived stress [64,65] and subjective burnout symptoms [66].

Recovery from the stress response occurs under resting conditions, when parasympathetic activation predominates and HRV is high [56,57,59]. The most important period for recovery is sleep [64,67-69]. Daytime psychological stress responses impair recovery during sleep; worrying [63], feeling irritated at work [64], general perceived stress [65], and acute stress response in the evening before going to bed [70] decreases parasympathetic activity during sleep in the following night. In addition, older age [71], higher body fat percentage [66], higher body mass index (BMI) [66,71], lower physical activity [71], lower cardiorespiratory fitness [66], and alcohol intake [72,73] are associated with poorer night-time recovery. Healthy individuals with low resting HRV have been shown to exhibit a poor recovery from cardiovascular, HPA axis, ANS, and immune responses after brief mental stress exposure [74]. On the contrary, individuals with a high resting HRV displayed a significantly better recovery from these stress responses [74].

Immune system

The stress response is also evident in the immune system. According to meta-analyses, acute psychological stress increases levels of several circulating proinflammatory cytokines [75,76]. Pro- and anti-inflammatory cytokines are primary mediators, in addition to HPA axis and ANS, from a stress response to health consequences [77]. All these three intertwined stress systems are represented in the nonlinear model of the physiological stress response mediators in which the relationships of the HPA axis (cortisol and dehydroepiandrosterone, DHEA), ANS (sympathetic and parasympathetic nervous systems), and immune system (pro-inflammatory and anti-inflammatory cytokines) are described (Figure 2). For example, chronic hypercortisolemia in chronic stress response can cause visceral fat accumulation and thus increase the secretion of proinflammatory adipokines and suppress the secretion of anti-inflammatory adipokines [78]. On the contrary, DHEA(S) [51,53] and vagus nerve signaling in the parasympathetic system [79] exert anti-inflammatory effects.

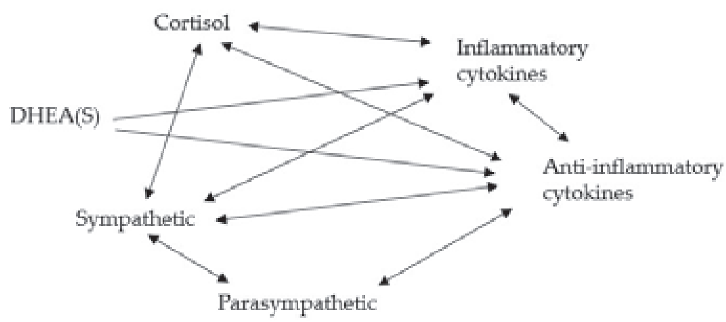

Figure 2. The nonlinear model of the physiological stress response mediators modified from Karatsoreos & McEwen 2011 [42] based on McEwen 2006 [80]. DHEA(S) = dehydroepiandrosterone DHEA or its sulfated form, DHEAS. The simplified figure illustrates at a general level that stress-related systems regulate to each other creating a nonlinear network [42].

Low-grade inflammation

Chronic stress response often co-occurs with chronic low-grade inflammation [6,78]. While originally inflammation was meant to mount an immune response to infection and tissue injury, in low-grade inflammation, however, there is a minor chronic systemic inflammation without any infection or tissue injury [81]. The low-grade inflammation is seen as a response to disturbances in cellular level homeostasis. For example, this can be caused by hypoxia, toxins, and chronic exposure to excess of nutrients and energy [7,8]. The inflammatory and metabolic systems are highly integrated, and thus low-grade inflammation co-occurs with metabolic dysfunctions such as obesity, type 2 diabetes, and cardiovascular disease [7,8].

Low-grade inflammation is characterized as changes in the levels of certain circulating biomarkers. These include acute phase proteins (e.g., C-reactive protein, CRP, produced in liver and interleukin 1 receptor antagonist, IL-1Ra, produced in adipocytes, epithelial and immune cells); cytokines (e.g., interleukins, ILs, produced in immune cells); and adipokines (e.g., adiponectin produced in adipocytes) [82]. The levels of pro-inflammatory markers (e.g. CRP, and ILs) are increased [82]. There is also increase in the level of IL-1Ra which is a receptor antagonist and it therefore inhibits the effects of IL-1 [82]. Furthermore, the levels of anti-inflammatory markers (e.g. adiponectin) are decreased [82]. However, the best indicators of low-grade inflammation or threshold values for pathogenic levels of these biomarkers are still to be determined [81-83]. The most widely used indicator of low-grade inflammation is the minor increase in CRP level [84], as the most increased values (values >10 mg/L) indicate acute infection or inflammation [85]. In order to be able to measure the minor increases at lower concentrations of CRP, highly sensitive assays are used, and the outcome is often called the high-sensitivity CRP (hsCRP) although it is the same CRP as measured with traditional assays [84]. This thesis concentrates on CRP, IL-1Ra, and adiponectin as biomarkers of the inflammatory status of the body. A mild increase in hsCRP, high IL-1Ra and low adiponectin levels have been shown to be associated with [86,87] and predict the course of metabolic syndrome (MetS) [88].

In addition to chronic stress, obesity and lifestyle factors such as diet and physical activity are related to low-grade inflammation [89]. A diet consistent with nutrition recommendations, such as healthy Nordic diet, is associated with better inflammatory status [90,91]. On the contrary, the levels of several inflammatory markers are increased in obesity [89]. Adipose tissue is a metabolically active heterogeneous tissue which includes also several kinds of cells related to inflammatory processes [92]. Thus, adipose tissue is a major source of stress-related pro-inflammatory markers [89].

2.1.5 Definition of recovery

So far, stress research has mostly focused on the aforementioned aspects of stress. However, recovery from stress has attracted much less interest from the scientific community. This is somewhat surprising, as recovery from stress is considered as an important protective link between stress and ill health [3,34,93]. There is no general definition for the term recovery [94]. In the scientific literature, recovery can mean, for example, returning back to the initial level after a single stress response, after physical exercise, after a workday, or after a serious illness or injury. In this thesis, recovery is considered as a factor reducing the overall allostatic load over the long term, it does not represent recovery from a single stress response or event. During recovery, the body is in an anabolic state, meaning that energy reserves and tissues are restored [67]. Sleep is the most important period for recovery [64,67-69]. The recovery measures used in this thesis are based on objective sleep-time ANS activity (HRV reflecting sympathetic and parasympathetic activation) measurement in a real-life setting. The functioning of the autonomic nervous system (ANS) under stress and recovery was described in more detail in the previous chapter.

2.2 EATING BEHAVIOR

2.2.1 Definition of eating behavior

There is no commonly used definition for the term "eating behavior". According to one definition, eating behavior is a broad term that encompasses food choice and motives, feeding practices as well as dieting and eating-related problems such as obesity and eating disorders [95]. Eating involves what, why, where, when and how much one eats or does not eat. The underlying factors in actual food choices and food intake, resulting in nutritional quality of the diet, is a complex system [96]. These factors are physiological, psychological, emotional, cognitive, sensory, and environmental [14,96,97]. Neural and hormonal functions make us feel hungry and satiated, and this physiological regulation is adjusted with bodily needs and the current amount of energy storage (i.e., fat mass of the body) [98]. However, the other aforementioned factors can interact or override these bodily cues [98]. The features of eating behavior are intended to describe the personal phenomena affecting the actual food intake and the attitudes to food and eating. Studying eating behavior is important in finding ways to treat or prevent conditions linked to dietary factors, such as obesity, metabolic syndrome, and type 2 diabetes [14].

In the following sections, the features of eating behavior studied in this thesis are described. The most studied features of eating behavior are cognitive restraint, uncontrolled eating, and emotional eating, (or cognitive restraint, disinhibited eating, and hunger) as these are the aspects of the questionnaires being widely used for already several decades: the Three-Factor Eating Questionnaire, TFEQ [99], its shortened version TFEQ-R18 [100], and the Dutch Eating Behaviour Questionnaire, DEBQ [101]. There are no similarly widely used measures to estimate hedonic drives. Lastly, intuitive eating and eating competence are rather recently introduced concepts intended to describe adaptive eating behavior associated with positive outcomes.

2.2.2 Cognitive restraint

Cognitive restraint describes attempts to restrict food intake in order to control body weight [100]. It involves restricting the amount of food eaten and avoiding certain foods which are tempting or thought to cause a gain in weight. Restraint can be rigid or flexible [102,103]. Rigid control of eating is described as dichotomized, an "all-or-nothing", attitude towards eating, including strict dieting rules to consume less calories [103]. Flexible control refers to a softer approach to dieting, such as eating smaller amounts instead of strict calorie counting and adjusting the amount of eaten in a longer period of time: if a larger portion was eaten during one meal, it can be compensated by eating less at the next meal [103].

The overall cognitive restraint seems to associate with healthier food choices. Higher cognitive restraint has been associated with, for example, higher consumption of fish, green vegetables, and fat-reduced foods [104], and higher frequency to use fruits and vegetables [105] in general populations. Furthermore, higher cognitive restraint has been associated with a lower consumption of French fries, sugar and confectionery [104], and a lower frequency to use energy-dense foods [105,106]. However, cognitive restraint has associated with lower energy intake among adults with overweight/obesity [107] and adults with and without depressive disorders [108] but not among general populations [104,105]. In addition, the relation between restrained eating and BMI is not clear. An increase in cognitive restraint has associated with weight loss and weight loss maintenance in weight-loss interventions [109,110] but, on the contrary, higher restraint has been associated with future increase in BMI in 3-year [111] and 6-year [112] longitudinal cohort studies. To conclude, it is not clear whether the overall cognitive restraint is a favorable or unfavorable feature of eating behavior.

2.2.3 Uncontrolled eating

Uncontrolled eating describes difficulties to keep eating under one's own control [100]. A person with uncontrolled eating very often feels hungry and ready to eat, and stopping eating is difficult. Uncontrolled eating also includes external eating [100] meaning that external cues, such as the odor of delicious food or seeing someone else eating can trigger the urge to eat.

In population level studies, for example, uncontrolled eating has been associated with higher consumption of pork meat, dietary fats, and green vegetables [104] and a higher frequency to use salty-and-fatty foods [106]. External eating has been strongly associated with a higher intake of fast-food and savory snacks among an adult cohort with and without depressive disorders [108]. Higher uncontrolled eating has also been associated with a higher energy intake in a general female population [104], among adults with overweight/obesity [107] and with and without depressive disorders [108], in addition to a higher intake of fat (E%, i.e., as percentage of energy) in the general population [104]. BMI has correlated positively with uncontrolled eating among working-age women [113] and adult twins [106].

Furthermore, a decrease in uncontrolled eating has associated with weight loss and weight loss maintenance in weight-loss intervention [109]. To conclude, uncontrolled eating seems to be an unfavorable feature of eating behavior.

2.2.4 Emotional eating

Emotional eating describes the tendency to eat because of negative feelings [100].

In population level studies, emotional eating has been associated with higher intake of cakes, pastries and biscuits, oleaginous fruits (e.g., peanuts), and sweet beverages [104] and higher frequency to use sweet energy-dense foods [105,106]. However, emotional eating has been associated with both higher [105,108] and lower [106] frequency to use non-sweet energy-dense foods. Furthermore, the relation to energy intake has been inconsistent: emotional eating has associated with a higher energy intake in general male population [104] and in both males and females [105], but there was no association among adults with overweight/obesity [107] and an adult cohort with and without depressive disorders [108]. However, a decrease in emotional eating associated with weight loss and weight loss maintenance in weight-loss intervention [109]. BMI has correlated positively with emotional eating among working-age women [113] and adult twins [106]. Furthermore, emotional eating has been shown to predict a higher increase in BMI in a 7-year prospective study [114]. To conclude, emotional eating seems to be an unfavorable feature of eating behavior.

2.2.5 Hedonic eating

Eating is crucial for survival. Thus, ingested food is supposed to confer pleasure and be rewarding, to ensure that the individual is being fed [115]. Today in modern society, when food is easily available, this mechanism is no longer crucial for survival. However, several forms of hedonic eating do exist. One scale for measuring hedonic aspects, The Health and Taste Attitude Scales, HTAS, depicts (a) Seeking pleasure from food and (b) Using food as a reward as some of the attitudes related to taste and hedonic preferences [116]. When seeking pleasure from food, the individual expects food to be a source of pleasure (in both appearance and taste) and eating delicious food in everyday life is important [116]. When using food as a reward, tasty and delicious food is used to reward, indulge or comfort oneself [116].

These features of hedonic eating have been studied in a choice task, in which a participant has chosen a snack from different options and rated pleasantness and healthiness of different food items. People with a greater tendency to use food as a reward more often have a tendency to choose a snack that they have self-rated as pleasant and not healthy as compared to people with lower tendency to use food as a reward [116]. A higher tendency to use food as a reward has also been associated with lower self-reported frequency of consuming apples [117] and low-fat products [118]. In addition, a higher tendency to use food as a reward has been associated with higher frequency of consuming chocolate bars [117,118], full-fat food items, soft drinks, and food items self-rated as pleasant [118].

Surprisingly, the tendency to seek pleasure from food has not been associated with self-rated pleasantness or healthiness of the chosen snacks [116] or with the actual choice (apple vs. chocolate bar) [117]. Furthermore, a tendency to seek pleasure has not been associated with the self-reported frequency of consuming apples and chocolate bars [117] or the correlations with food items have been rather weak [118]. One explanation may be that the participants rated both apples and chocolate bars pleasant, and thus both options were possible for people with a tendency to seek pleasure [117].

To conclude, a tendency to use food as a reward seems to associate with a higher tendency to eat unhealthier food products. Seeking pleasure from food is not as strongly associated with food choices and consumption. This may be because people can rate all kinds of foods as delicious, including health-promoting food items.

2.2.6 Intuitive eating

Intuitive eating was first introduced to the public in 1995 in the book by the registered dietitians Evelyn Tribole and Elyse Resch [119]. Based on their empirical experiences with patients and the scientific literature, they had noticed how dieting by restricting one's eating is not a successful weight loss method. Instead, the process of dieting seemed to change the patient's relationship with food and body in an unhealthy way. Thus, according to their definition, the main principles of the concept of intuitive eating are to reject the diet mentality, challenge the unreasonable dieting rules echoing in the mind, exercise as a way of feeling better instead of burning calories, respect your body, listen and honor the body's hunger and satiety signals, make peace with food and give yourself an unconditional permission to eat everything, discover the pleasure and satisfaction in eating, cope with emotions without using food, and make pleasurable food choices that honor your health and make you feel good [119].

The intuitive eating principles are captured in the Intuitive Eating Scale (IES) questionnaire developed by Tracy L. Tylka [12]. The scale consists of subscales (a) Unconditional permission to eat, (b) Eating for physical rather than emotional reasons, and (c) Reliance on internal hunger/satiety cues [12]. Later, the scale (IES-2) was further developed and supplemented with a subscale (d) Body-food choice congruence to emphasize making food choices that help the body to function well [120]. Intuitive eating is most often measured with the questionnaires developed by Tylka [12,120], although the first intuitive eating questionnaire was devised by Steven Hawks et al. [121]. Their Intuitive Eating Scale (IES) consists of factors named intrinsic eating, extrinsic eating, antidieting, and self-care [121]. However, the IES by Hawks et al. showed some weaknesses in its validity [121] whereas the IES questionnaires by Tylka have shown adequate psychometric properties [12,120].

Intuitive eating is associated with lower BMI in a large number of studies [12,120,122-132], although one study has also reported no association [133]. Intuitive eating is inversely associated with negative and constrictive body attitudes [12,120,134] and positively associated with body appreciation [120,130,134,135].

People with higher intuitive eating scores seem to have more self-compassion [126], better self-esteem [12,120,126], higher positive affect [120,127,130], optimism [12], life satisfaction [12,120,130], less depressive symptoms [127], higher distress tolerance [126], and more proactive coping [12].

Consistently with the concept of intuitive eating as a feature of eating behavior including not categorizing foods as allowed or forbidden and listening to the body's hunger and satiety cues, intuitive eating has been associated with lower dichotomous thinking [134] and higher interoceptive awareness [12,120,130]. Intuitive eating is also inversely associated with disordered eating behaviors (i.e., eating disorder symptomatology, binge eating, food preoccupation) [12,120,123,130,133,134] and restrained eating [127,133]. Both rigid [130,134] and flexible [130] control of eating are inversely correlated with intuitive eating. Although intuitive eating can be used as a weight loss approach [119], it is a different construct than flexible dietary restraint [130,134] which is also often regarded as an adaptive approach to weight loss [103]. People with higher intuitive eating have also reported lower emotional eating [127], lower uncontrolled eating [127] [134], and slower self-reported eating rate [123]. It is noteworthy that the uniqueness of intuitive eating has also been questioned as some of its subscores correlate so strongly (negatively) with restrained eating and emotional eating [136].

Intuitive eating has been shown to associate with a higher vegetable intake [123] and a diversity of diet [122]. In the general population, intuitive eating has not been correlated with diet quality [137] or only some of the subscales (i.e., Eating for physical rather than emotional reasons and Reliance on hunger and satiety cues) have correlated positively with diet quality [138]. On the contrary, in a large population-based study, the higher IES-2 total score and Unconditional permission to eat were associated with lower diet quality in both men and women [132]. This study showed that intuitive eating total score and subscores correlated differently with several aspects of food intake [132]. It is also possible that people understand the questions related to intuitive eating in different ways if they are not truly familiar with the concept of intuitive eating. Interestingly, in an intervention study, intuitive eating was not associated with better diet quality at baseline, but there was a significant association after participating in the non-dieting HAES® (Health at Every Size®) intervention [137].

Some factors are already found to predict intuitive eating: body appreciation and focusing on bodily function and internal feelings instead of appearance [139], and ability to perceive bodily signals and process the information, i.e. interoceptive sensitivity [124]. In addition, trying to lose weight has decreased intuitive eating scores [127,140].

In conclusion, intuitive eating has been related to lower BMI, better psychological well-being, and health-beneficial eating behavior, whereas the association with dietary measures has been less studied and so far, the results have been contradictory. Moreover, intuitive eating is still rather a new concept, and it is important to notice that almost all of the studies have been cross-sectional.

2.2.7 Eating competence

The Satter Eating Competence Model was created by the registered dietitian Ellyn Satter based on over 40 years of clinical experience, supported with scientific literature [13]. The Satter Eating Competence Model aims to better nutrition by focusing on the variety of diet, enjoying food and eating, trusting on hunger and satiety signals, and meal planning [13]. Eating competence consists of four elements: (1) having positive attitudes about eating and food, (2) accepting and eating an ever-increasing variety of foods, (3) eating according to internal hunger and satiety signals, and (4) having skills and resources for managing daily meals [13]. These elements also constitute the four subscores of the questionnaire measuring eating competence [141,142].

Eating competence is associated with lower BMI [141,143-145], although not in all studies [146,147]. Furthermore, eating competence is shown to be associated with lower cardiovascular risk [147], lower fasting glucose [147], higher HDL-cholesterol [146,147], lower systolic blood pressure [146], higher physical activity [143,145], and higher sleep quality and duration [145,148].

People with higher eating competence have reported less body dissatisfaction, less disordered eating, such as drive for thinness or bulimia, [141,143] less restrained eating [141], and less tendency to eat because of external or emotional reasons [141,143] compared to people with lower eating competence. Eating competence is associated with a better diet quality, such as a higher intake of fruits [147], a higher intake of fiber, several vitamins and minerals, and a higher Healthy Eating Index [149], and a better adherence to the Mediterranean diet [147].

In conclusion, eating competence has been related to lower BMI and other better cardiovascular risk factors, in addition to health-beneficial eating behavior and dietary measures. However, as eating competence is a rather new concept, it is important to be aware that thus far most studies have been cross-sectional.

2.3 ASSOCIATIONS OF STRESS AND RECOVERY WITH EATING BEHAVIOR AND DIET

As already mentioned, the stress response can be related to emotional arousal, psychological changes, and/or physiological changes (HPA axis, autonomic nervous system, and immune system) [26]. An individual can also change his/her behavior as a coping mechanism to survive through a stressful situation [26]. Thus, stress can affect eating in several ways and through several mechanisms [150-154]. Stress-induced eating has been studied in laboratory settings, but more research on the relation between stress and eating in real-life settings is needed [152,153]. Furthermore, there is also a need to find ways to alleviate stress-related eating [154]. Recovery, as a resolution of stress reactions and thus as a potential antidote, is suggested worthy of investigation [154]. This thesis focuses on perceived stress and recovery based on the autonomic nervous system as a way of clarifying the associations of stress and recovery with eating behavior and diet.

2.3.1 Associations of stress and recovery with eating behavior

Perceived stress and eating behavior

The small number of studies examining the relationship between perceived stress and eating behavior have produced inconsistent results. In a female community sample (n=457), perceived stress was associated with higher rigid restraint and lower flexible restraint of eating [155]. However, other studies have not found significant association between perceived stress and cognitive restraint [156,157]. Instead, among women enrolled in a program for low-income women with children (n=101), perceived stress was associated with higher uncontrolled eating and higher emotional eating [156]. Similar findings have been reported among women with occupational burnout (i.e., chronic work stress), i.e. higher uncontrolled and emotional eating compared to women not experiencing burnout [113]. Higher perceived stress associated with higher emotional eating also in a community sample (n=159) of African American adults [158]. The association was stronger among individuals with overweight (n=122) [158]. However, no differences in uncontrolled eating and emotional eating were found among female undergraduate students subdivided into groups of high (n=14) and low (n=16) perceived stress [157].

HRV-based recovery and eating behavior

The previous literature of HRV-based measures and eating behavior among nonclinical populations is limited and the results have been somewhat inconsistent. However, most studies have found that higher HRV, reflecting parasympathetic activation and recovery from stress, is associated with restrictive eating and a lower tendency to uncontrolled eating: a higher HRV has been associated with greater restrained eating and less disinhibited eating among young adults [159]; higher self-control in experimental dietary challenges among young men [160]; less subjective loss-of-control eating among female adolescents [161]; and lower unconditional permission to eat (i.e., a subscale of intuitive eating) among university students [162]. On the contrary, restrained eating has been associated with lower HRV among female university students [163]. Most studies measured HRV in the laboratory during a 3–10 minutes single recording period with the subject in a sitting or semi-supine position [159,160,162,163].

2.3.2 Associations of stress and recovery with diet

Perceived stress and diet

Perceived stress has been rather consistently linked with a higher consumption of energy-rich foods and snacks. Perceived stress has been associated with a higher consumption of palatable non-nutritious food (e.g., chips, burgers, fried foods, and soda) and a lower consumption of nutritious food (e.g., legumes, fruits and vegetables, and whole grains) in a female community sample (n=457) [155]. In addition, perceived stress associated with higher snacking on sweets in a community sample (n=122) of African American adults with overweight [158] and a higher consumption of high-fat snacks and fast food in a community sample (n=65,235) of older adults [164]. However, there was no association between perceived stress and consumption of fruits and vegetables or sweetened drinks [164].

The association of perceived stress with energy intake, energy nutrient intake, and overall diet quality have been inconsistent in previous studies. Department store employees during a high-stress season at work, a period accompanied with higher perceived stress, had higher energy intake, higher saturated fat intake (as grams, g), and higher sugar intake (g) as compared to a low-stress season at work with lower perceived stress [165]. Perceived stress has also associated with higher fat intake (E%) and lower carbohydrate intake (E%) in a community sample (n=65,235) of older adults [164]. Furthermore, a higher perceived stress level associated with higher energy intake and saturated fat intake (E%) in addition to lower diet quality (Alternative Healthy Eating Index, AHEI-2010) compared to lower perceived stress levels in a community sample (n=5,077) of Hispanic/Latino adults [166].

On the contrary, several studies have not found any link between perceived stress and dietary measures. Perceived stress was not associated with the energy density of consumed food and beverages in a community sample (n=87) of working adults with overweight [167] as well as with the intake of added sugars (E%) in a community sample (n=65,235) of older adults [164]. Furthermore, perceived stress has not been associated with the overall diet quality measure Healthy Eating Index-2010 (HEI-2010) among women (n=101) enrolled in a program for low-income women with children [156] and with diet quality indices (the Alternate Healthy Eating Index, AHEI; the Dietary Approaches to Stopping Hypertension, DASH; the Mediterranean Diet Score) among healthy adults (n=640) working at a university and academic health center [168].

HRV-based recovery and diet

The previous literature of HRV-based measures and diet is rather limited. However, the link between HRV and diet is recognized [169]. A higher HRV, reflecting parasympathetic activation and recovery from stress, has been found to associate with health-promoting characteristics of diet. Namely, a higher HRV has been associated with a higher intake of green leafy vegetables among older men [170], Mediterranean diet among middle-aged men [171], and with the overall diet quality among young adults [159]. In these studies, the period of HRV measurement varied from 6–7 minutes [159,170] to ambulatory recording for 24 hours [171]. Furthermore, in randomized controlled trials, regular fatty fish consumption and fish-oil supplementation have increased HRV, reflecting increased parasympathetic activity [172,173].

2.4 TRANSDIAGNOSTIC APPROACH

2.4.1 Process-based care

In behavioral science and psychological treatments, there is a move towards process-based care to target the processes underlying human suffering irrespective of diagnoses (i.e., the transdiagnostic approach) [174-176]. For example, it is claimed that psychological distress arises from several underlying nonadaptive processes such as avoiding or suppressing negative emotions and thoughts, making decisions unconsciously, and having a tendency to notice, remember, and interpret life events in a negative way [174].

The transdiagnostic approach suggests that interventions should target these transdiagnostic processes instead of focusing on separate disorders or illnesses. Thus, with transdiagnostic, process-based care, it would be possible to affect several diseases and symptoms without focusing directly on those diseases or symptoms. This could be especially helpful among people with overweight and psychological distress. Obesity is closely linked to weight stigma (i.e., prejudice, discrimination, and negative attitudes towards people with obesity), which in turn contributes to the individual's psychological distress and obesity [5]. Thus, with process-based psychological care, it would be possible to affect type 2 diabetes risk and low-grade inflammation without focusing on obesity.

2.4.2 Psychological inflexibility

Psychological inflexibility is an underlying process in the transdiagnostic variety in human suffering [177]. Psychological inflexibility means that the person is not able to fully contact the present moment and is not able to change or maintain behavior which would lead to personally valued outcomes [19]. For example, a person with psychological inflexibility attempts to avoid or suppress uncomfortable emotions and thoughts, is convinced that he/she is the same as his/her emotions and thoughts, and believes that his/her emotions and thoughts are equal to the facts about how things really are [19,178]. The person is stuck in ruminating or worrying about the past or the future, and is thus not paying attention to what occurs at the present moment [19,178]. Furthermore, as a person has a conceptualization of oneself (e.g., being a victim, being broken, being always obese), it may become more important to cherish the conceptualization and "be right" rather than to engage in behavior that does not fit with the conceptualization [19]. Thus, behavior has less variety, is less flexible according to the prevailing context, and is not guided according to personal values [19].

Psychological inflexibility is associated with several measures of psychological ill health such as greater depressive symptoms [179-181], anxiety-related symptoms [179,181], perceived stress [179,181], burnout [181], and overall psychological ill health [179]. Psychological inflexibility has also predicted future psychological distress and work absence [179] and has been associated with higher uncontrolled and emotional eating [182].

Furthermore, psychological inflexibility is also seen in weight-related difficulties [183]. Weight-related psychological inflexibility could be described as using food to control emotions, uncontrolled eating, non-acceptance of one's own body, internalized obesity stigma, low belief in one's own abilities, and avoiding emotions related to one's own body, weight or appearance [183,184]. Weight-related psychological inflexibility has been shown to be associated with many negative factors, e.g., disordered eating [184], lower intuitive eating [129], and higher BMI [183]. Thus, promoting psychological flexibility would be one important route to promote health and well-being.

2.5 ACCEPTANCE AND COMMITMENT THERAPY (ACT)

Acceptance and commitment therapy (ACT) is one process-based therapy [175] which belongs to the third wave of cognitive behavior therapy (CBT) [185,186]. The ultimate goal of ACT is to increase psychological flexibility [19]. Although ACT is behavioral, it is closely associated with Relational Frame Theory (RFT) and thus emphasizes human language, cognition, and the relationships that an individual creates among words and events [185,186]. Hayes [185] gives an example of a child who plays with a cat. During the play, the child is scratched, starts to cry and runs away. Afterwards in a different situation, the child's mother sees a cat and says, "Oh, look! A cat." The child starts to cry and runs away again. Although the phrase "Oh, look! A cat." was not present when the child was scratched, the child had connected the word "cat" and getting scratched.

Because relational frames can connect events in many situations and contexts, painful events are difficult to avoid or control [185,186]. Instead, an individual ends up trying to avoid or suppress the painful thoughts and feelings [185,186]. This experiential avoidance or suppression, however, leads to psychological harm and is thus the focus of ACT [185,186]. Another target for ACT is cognitive fusion [185,186]. Because relational networks are elaborate, evolving, and permanent in their nature, it is difficult to shut them down [185,186]. Cognitive fusion means that the use of relational networks is predominating and happens automatically, so that behavioral regulation is reliant on these verbal rules instead of the individual's conscious awareness and contact with the present situation [185,186].

To increase psychological flexibility, ACT consists of six interrelated core processes (Figure 3): (1) clarification of one's own values, (2) a commitment to act based on those values, (3) being in contact with the present moment (i.e., mindfulness), (4) having self as the context (i.e., being aware of thoughts, feelings, etc. without attaching to them), (5) defusion (i.e., altering the way to interact with or relate to thoughts, feelings, etc.), and (6) acceptance [19]. These can be divided into commitment and behavior change processes or mindfulness and acceptance processes [19].

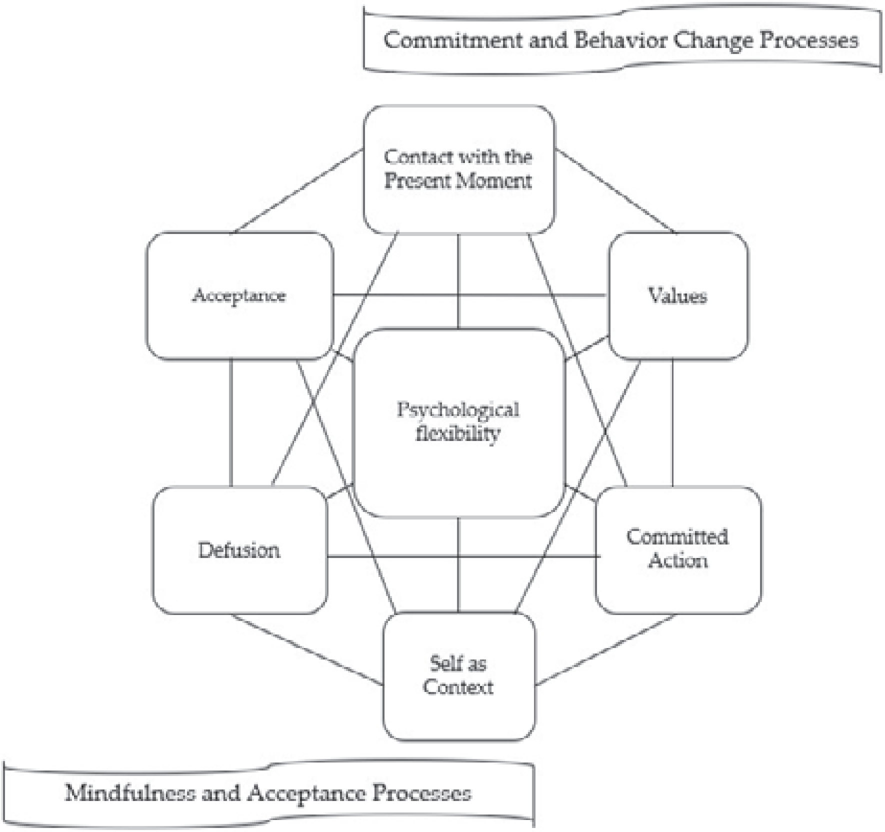

Figure 3. The six core processes of ACT based on Hayes et al. 2006 [19].

2.5.1 Commitment and behavior change processes

ACT encourages the individual to clarify his/her own values, i.e., the ultimate elements in life that he/she personally cares about, such as being a good parent [19,178]. Further, committed action to actually live according to those values is encouraged by setting personal short- and long-term goals [19,178]. Several behavior change methods can be applied as long as they are consistent with the other core processes of ACT [19,178]. Especially being in contact with the present moment and having self as context are important processes related to the commitment and behavior change [19].

ACT can be applied in making health-promoting lifestyle changes. For example, one important thing in life (i.e., a value) for a working-age adult with psychological distress and overweight could be to be able to be actively involved in grandchildren's lives. Thus the goals could be to eat in a more health-promoting way, increase physical activity, and enjoy more relaxation and sleep in order to stay healthy and maintain ability to function during the upcoming years. Thus, ACT targets processes related to motivation. A value is not something that "I should" or "other people want me to" do, but instead it is something that a person intrinsically wants [19]. Thus, values are closely related to internal motivation [187]. Internal motivation and one's own activity to find his/her personal way are seen to associate with sustaining behavior changes [20,187,188]. Furthermore, in an ACT-based weight-loss intervention, it is the change in internal motivation that mediates the intervention effect on long-term weight loss [189].

2.5.2 Mindfulness and acceptance processes

Mindfulness and acceptance processes in ACT are processes which support making behavior change and ultimately live the life according to one's values [19]. Mindfulness refers to awareness while purposely paying attention in the present moment with no judgment [190]. The individual is encouraged to be in contact with inner and external events non-judgementally so that one's behavior could be more flexible [19]. Having self as a context indicates the difference between "I" and one's thoughts and feelings: the person who "I" am, is the one who can be aware of his/her own inner experiences and is not the same as those thoughts and feelings [19,178]. Cognitive defusion techniques aim to change the way how a client interacts with or relates to his/her own thoughts and to decrease the literal meaning of the thoughts [19,178]. Thus, instead of thinking "I am no good" the individual learns to notice "I have a thought that I am no good" [19]. Acceptance is one alternative to be applied with difficult inner experiences: instead of struggling with or trying to change or avoid uncomfortable thoughts and feelings, they could be just accepted as happening [19,178].

In terms of eating, mindfulness has attracted widespread interest [190]. Mindful eating has no universal definition [191] but it generally consists of being aware of physical hunger and satiety sensations, observing the food eaten with all senses, eating mindfully so that pleasure can be obtained from small food portions, being aware of external triggers for eating, and meditation [192]. The emphasis on bodily hunger and satiety cues is also included in two concepts of eating behavior: intuitive eating [11,12] and eating competence [13]. Indeed, mindfulness skills have correlated positively with intuitive eating among adults with psychological distress and overweight [129]. However, in another study with college students, mindful eating scores did not seem to be associated with intuitive eating scores [133].

2.5.3 Effects on eating behavior

Several previous mindfulness-based intervention studies have reported effects on eating behavior, although not all of them have compared the intervention group to a control group [193,194]. Because randomized controlled trials (RCT) are the gold standard in studying effectiveness [195], only studies conducted in a RCT setting and among non-clinical populations are shown in Table 1. Since previous ACT intervention studies are scarce, also mindfulness intervention studies are considered, as mindfulness is one component of ACT [19]. There has been extensive variation in the content and implementation of ACT and mindfulness interventions and in study populations in the previous studies (Table 1). This may account for the controversial results.

In controlled study designs, ACT and mindfulness-based interventions have shown positive effects on the loss of control [196], disinhibited eating [197], uncontrolled eating [198], reward-based eating [199], and mindful eating [200] (Table 1). However, also mixed results have been reported. Restrained eating increased in one study compared to control [197], whereas no effect has also been reported [201,202]. External eating either decreased [201,202] or did not change as compared to control [203,204]. Emotional eating has decreased [198,202], but also no effect on emotional eating [201,203,205], and no effect on internal disinhibition [204] compared to control have been reported. Thus, more research is needed to clarify the effects of ACT and mindfulness on eating behavior.

Although no ACT or mindfulness RCTs have reported effects on intuitive eating, eating competence or eating-related forms of motivation (Table 1), two non-RCT studies have investigated the effects on intuitive eating with promising results. In a single-arm ACT-based pilot study among 40 women with overweight, intuitive eating total and subscores increased [206]. The intervention was aimed to prevent a weight gain and was conducted via a web-based program with 12 modules which all contained skills related to intuitive eating. In a non-randomized mindfulness-based intervention study with a waitlist comparison group among 124 adults, all of the intuitive eating subscores increased in the intervention group [207]. The intervention was a 10-week group intervention designed to target the individual's problematic relationship with food and body. Thus, these both studies with positive effects on intuitive eating have also emphasized intuitive eating markedly in the intervention content.

Table 1. The randomized controlled trials of ACT- and mindfulness-based interventions reporting effects on eating behavior in adult non-clinical populations.

Reference, Country	Population	Design, Intervention length	Intervention components	Eating behavior outcome	Results
Alberts et al. 2010 [196], The Netherlands	Adults with ow/ob 89% female BMI:31.3±4.1 (25.3–40.9)	Intervention (n=10) vs. active control (n=9) 10 weeks	Intervention: acceptance skills, body scan, awareness of bodily sensations, eating behavior, and craving related thoughts, and mindfulness meditation Both groups: dietary information and physical exercise	Food cravings (General Food Craving Questionnaire Trait, G-FCQ-T, total score and subscores preoccupation with food, loss of control, positive outcome expectancy, and emotional craving)	Intervention group reported decreased total amount of food cravings (p=.012), decreased preoccupation with food (p=.036), decreased loss of control (p=.021), and decreased positive outcome expectancy (p<.01) compared to control group.
Alberts et al. 2012 [202], The Netherlands	Adults with problematic eating behavior 100% female BMI: 32.7±6.1 (23.5–45.8)	Intervention (n=12) vs. waiting-list control (n=14) 8 weeks	Intervention: mindfulness-based eating program (mindful eating, awareness of physical sensations, and thoughts and feelings related to eating, acceptance and non-judgment of inner experiences and body, changing daily eating habits, body scan, meditation)	Restrained eating, external eating, emotional eating (DEB-Q, Dutch Eating Behaviour Questionnaire), Dichotomous thinking (DTS, The Dichotomous Thinking Scale), Food cravings (General Food Craving Questionnaire Trait, G-FCQ-T, total score)	Intervention group reported decreased external eating (p=.04), decreased emotional eating (p<.01), decreased dichotomous thinking (p=.01), and decreased food cravings (p<.01) compared to control group.

(Continued)

Table 1, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Eating behavior outcome	Results
Corsica et al. 2014 [208], USA	Adults with stress, risk for weight gain/obesity, and problematic eating behavior 98% female BMI:35.0±9.0 (23.9–60.0)	MBSR (n=19) vs. SEI (n=20) vs. MBSR+SEI (n=14) 6 weeks	MBSR: mindfulness and meditation practice SEI: cognitive-behavioral and exposure-based intervention including stress education, nutrition education, cognitive restructuring, exposure and response prevention for stress-eating, and relapse prevention MBSR+SEI: full content of MBSR and SEI interventions	Emotion- and stress-related eating (Emotion- and Stress-Related Eating subscale of the Eating and Appraisal Due to Emotions and Stress Questionnaire, EADES)	No differences between the groups. Emotion- and stress-related eating decreased in all groups (main effect of time, $p<.001$).
Daubenmier et al. 2011 [201], USA	Adults with ow/ob 100% female BMI:31.2 (inclusion criteria 25–40)	Intervention (n=24) vs. waiting-list control (n=23) 4 months	Intervention: components from MBSR, MBCT, and MB-EAT including mindfulness practice (body scan, yoga, meditation), mindful eating (bodily sensations of hunger and fullness, taste satisfaction, food cravings, emotional and eating triggers, self-acceptance, inner wisdom), awareness of emotions, and forgiveness Both groups: 2-hour session of information on nutrition and physical exercise	Dietary restraint, emotional eating, external eating (Dutch Eating Behavior Questionnaire, DEBQ)	Intervention group reported decreased external eating ($p=.046$) compared to control group.

(Continued)

Table 1, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Eating behavior outcome	Results
Kristeller et al. 2014 [197], USA	Adults with ow/ob who binge eat and are concerned about their weight 88% female BMI: 40.3 (26–78)	MB-EAT (n=53) vs. PECB (n=50) vs. waiting-list control (n=47) 9 weeks + 3 months	MB-EAT: mindful awareness, meditation, mindful eating, physiological vs. emotional hunger cues, satiety cues, and forgiveness PECB: education on obesity and binge eating, triggers for eating, coping strategies, education and skill-building on nutrition and portion control, making lifestyle changes, and stress management	Binge eating (Binge Eating Scale, BES), Restrained eating, disinhibited eating, hunger sensitivity (Three-Factor Eating Questionnaire, TFEQ), Influence of food available, food present, or food tasted on craving (Power of Food Scale, PFS), Eating self-efficacy (Eating Self-Efficacy Scale, ESES)	Group x time interaction significant between all three groups for PFS food tasted ($p<.01$) and all other outcome variables ($p<.001$). MB-EAT group reported decreased binge eating ($d=-1.10$), increased restrained eating ($d=0.26$), decreased disinhibited eating ($d=-1.13$), decreased hunger sensitivity ($d=-0.86$), decreased PFS food available ($d=-1.06$), decreased PFS food present ($d=-0.95$), decreased PFS food tasted ($d=-0.80$), and increased eating self-efficacy ($d=1.13$) compared to control group.

(Continued)

Table 1, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Eating behavior outcome	Results
Lillis et al. 2016 [204], USA	Adults with obesity and high internal disinhibition 85% female BMI:37.6±5.3 (inclusion criteria 30–50)	ABBI (n=81) vs. SBT (n=81) 1 year	ABBI: acceptance and mindfulness strategies for problematic thoughts, emotions, food cravings, values clarification, and commitment to values-based behavior in the presence of difficult thoughts, feelings, and cravings SBT: cognitive and emotional control strategies for negative thoughts, distraction techniques, relaxations skills, and environmental control methods Both groups: Energy intake goal (1,200–1,800 kcal/d; 25% from fat), increase in physical activity, self-monitoring of weight and food intake, and stimulus control, problem solving, and goal setting	Internal disinhibition, i.e., eating in response to cognitive or emotional cues (Internal disinhibition subscale presented by Niemeier et al. 2007 [209], Eating Inventory, EI)	No differences between the groups during the intervention. Internal disinhibition decreased in all groups (main effect of time, $p<.001$).

(Continued)

Table 1, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Eating behavior outcome	Results
Mason et al. 2016a [199], USA	Adults with obesity 82% female BMI:35.5±3.6 (inclusion criteria 30–45)	Mindfulness (n=100) vs. active control (n=94) 5.5 months	Mindfulness: mindfulness training for eating awareness, stress management, emotion regulation, and physical activity Control: information on nutrition and physical activity Both groups: Energy intake goal (-500 kcal/d), focus on reducing energy-dense non-nutritious food intake, and increasing fresh fruit & vegetable, oil, and protein intake. Increase in physical activity.	Reward-based eating (Reward-based Eating Drive, RED)	Intervention group reported decreased reward-based eating (p=.003) compared to control group.
Mason et al. 2016b [200], USA	see above	see above	see above	Mindful eating (Mindful Eating Questionnaire, MEQ, total score and subscores awareness, distraction, disinhibition, emotional, and external)	Intervention group reported greater increase in mindful eating total score (p=.036) and in the awareness subscale (p=.007) compared to control group.

(Continued)

Table 1, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Eating behavior outcome	Results
Palmeira et al. 2017 [198], Portugal	Adults with ow/ob without binge eating 100% female BMI: 34.82±5.26 (intervention), 33.65±4.83 (control)	Kg-Free (n=36) vs. active control (n=37) 3.5 months	Kg-Free: Mindfulness, mindful eating, acceptance, values and committed actions, and self-compassion Both groups: TAU = medical and nutritional appointments, and physical activity prescriptions at primary care unit	Uncontrolled eating and emotional eating (Three-Factor Eating Questionnaire-R21, TFEQ-R21)	Intervention group reported decreased uncontrolled eating ($p=.002$) and emotional eating ($p=.006$) compared to control group.
Tapper et al. 2009 [203], UK	Adults attempting to lose weight 100% female BMI: 31.8±5.61 (intervention), 31.3±6.57 (control), 22.5–52.1	Intervention (n=31) vs. control (n=31) 4 months	Intervention: Values, committed action, cognitive defusion, acceptance, mindfulness, no dietary advice Control: Asked to continue own weight loss attempt	Emotional eating and external eating (Dutch Eating Behavior Questionnaire, DEBQ), Emotional eating (Emotional Eating Questionnaire, EEQ), Binge eating (Shortened 6-item version of Binge Eating Scale, BES)	Intervention group reported decreased binge eating ($p<.05$) compared to control group.
Timmerman & Brown 2012 [205], USA	Healthy peri-menopausal women who eat out frequently 100% female BMI:31.8±6.8 (22.1–54.4)	Intervention (n=19) vs. waiting-list control (n=16) 6 weeks	Intervention: Mindful Restaurant Eating intervention including mindful eating meditations, principles of weight management, strategies to prevent weight gain when eating in a restaurant, and skill-building activities.	Emotional eating (Emotional Eating Scale, EES), Diet-related self-efficacy (Self-Efficacy for Eating Behaviors Scale, SEEBS)	Intervention group reported increased diet-related self-efficacy ($p=.02$) compared to control group.

BMI: mean±SD (range), unless other noted.

Ow/ob = Overweight/obesity, n = number of randomized participants, d = Cohen's d, MBSR = Mindfulness-Based Stress Reduction, SEI = Stress-eating intervention, MBCT = Mindfulness-Based Cognitive Therapy, MB-EAT = Mindfulness-Based Eating Awareness Training, PECB = psychoeducational and cognitive-behavioral intervention, ABBI = Acceptance-Based Behavioral Intervention, SBT = Standard Behavioral Treatment, TAU = Treatment as Usual.

2.5.4 Effects on diet

There is a paucity of research of ACT- and mindfulness-based intervention effects on dietary measures in terms of randomized controlled trials (Table 2). Some studies have had a very specific target in the intervention. An intervention focusing on the consumption of salty snack food did decrease the consumption of these items in the intervention group as compared to the controls [210]. Mindful Restaurant Eating intervention did not have any effect on energy and fat intake in a restaurant, but did alter the average daily intake of energy and fat [205]. More general interventions reported no effects on energy or energy nutrient intake [211] or on the intake of sweet foods and desserts [200]. However, after the treatment phase in the latter study, control group increased their intake of sweet foods and desserts as compared to the intervention group [200]. Nonetheless, based on these four studies (Table 2), it is not possible to draw any conclusions about the effectiveness of ACT and mindfulness-based interventions on dietary factors.

Table 2. The randomized controlled trials of ACT- and mindfulness-based interventions reporting effects on diet in adult non-clinical populations.

Reference, Country	Population	Design, Intervention length	Intervention components	Dietary outcome	Results
Daubenmier et al. 2012 [211], USA	Adults with ow/ob 100% female BMI:31.2±4.8 (inclusion criteria 25–40)	Intervention (n=24) vs. waiting-list control (n=23) 4 months	Intervention: Components from MBSR and MB-EAT Both groups: 2-hour session of information on nutrition and physical exercise	Energy intake, fat (E%), carbohydrates (E%), and protein (E%) (The Block 2005 FFQ)	No differences between the groups during the intervention. Energy intake decreased in both groups (p=.001).
Forman et al. 2016 [210], USA	Undergraduate students, habitual salty snack eaters 62% female BMI:24.45±5.30 (18.40–46.72)	MDT (n=27) vs. ICT (n=27) vs. MDT+ICT (n=22) vs. active control (n=27) 1–4 days	MDT: Developing skills to be aware and override mindless decision processes, and noticing internal and external cues to eat ICT: Computer-based modified stop signal task to train inhibitory control Control: Information about nutrition labels and salty snack foods related to health All groups: training focused on salty snack foods	Salty snack food consumption (EMA)	MDT group reported decreased salty snack food consumption (p=.046) compared to control group.

(Continued)

Table 2, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Dietary outcome	Results
Mason et al. 2016b [200], USA	Adults with obesity 80% female BMI:35.5±3.6 (inclusion criteria 30–45)	Mindfulness (n=100) vs. active control (n=94) 5.5 months	Mindfulness: mindfulness training for eating awareness, stress management, emotion regulation, and physical activity Control: information on nutrition and physical activity Both groups: Energy intake goal (-500 kcal/d), focus on reducing energy-dense non-nutritious food intake, and increasing fresh fruit & vegetable, oil, and protein intake. Increase in physical activity.	E% from sweet foods and desserts (The Block 2005 FFQ)	No differences between the groups during the intervention. During the post treatment phase, participants in control group increased eating sweet foods and desserts compared to intervention group (p=.035).
Timmerman & Brown 2012 [205], USA	Healthy peri-menopausal women who eat out frequently 100% female BMI:31.8±6.8 (22.1–54.4)	Intervention (n=19) vs. waiting-list control (n=16) 6 weeks	Intervention: Mindful Restaurant Eating intervention including mindful eating meditations, principles of weight management, strategies to prevent weight gain when eating in a restaurant, and skill-building activities.	Mean energy and fat intake per day and per restaurant eating episode (24-hour dietary recall of 3 days)	Intervention group reported decreased mean energy intake (p=.002) and fat intake (p=.001) per day compared to control group.

BMI: mean±SD (range), unless other noted.

Ow/ob = Overweight/obesity, n = number of randomized participants, MBSR = Mindfulness-Based Stress Reduction, MB-EAT = Mindfulness-Based Eating Awareness Training, E% = Percent of energy, FFQ = Food Frequency Questionnaire, MDT = Mindful Decision Making Training, ICT = Inhibitory Control Training, EMA = Ecological Momentary Assessment.

2.5.5 Effects on stress and inflammation biomarkers

There is increasing interest in using ACT- and mindfulness-based interventions to affect circulating biomarkers of stress and inflammation. For example, meta-analyses have found evidence that several kinds of mindfulness and meditation interventions can decrease circulating levels of certain inflammation markers and measures of physiological stress [212,213]. This thesis focuses on cortisol and dehydroepiandrosterone sulfate (DHEAS) as stress biomarkers, and C-reactive protein (CRP), interleukin-1 receptor antagonist (IL-1Ra), and adiponectin as markers of low-grade inflammation. Thus, only the results of these biomarkers are presented in the following sections.

Randomized controlled trials in non-clinical study populations are still scarce (Table 3). The intervention contents have emphasized mindfulness, meditation, and stress reduction. Most studies have measured effects on cortisol concentrations. Mindfulness-based interventions in non-clinical samples have not affected morning serum cortisol levels [201], single time point cortisol level (from 11 a.m. to 8 p.m.) [214], and cortisol levels at different time points during the day [215,216]. Some studies [201,217] have measured the cortisol awakening response (CAR), i.e., the peak in cortisol secretion after awakening, which is a part of the diurnal rhythm in cortisol secretion [50]. Mindfulness interventions had not an overall effect on CAR, but a reduction in the intervention group was seen in further analyses only among men and on the last (i.e., third) measurement day in both genders [217]. No overall effects of mindfulness-based interventions on CRP have reported [215,218,219].

No randomized controlled ACT- and mindfulness-based interventions among non-clinical populations have reported effects on DHEAS, IL-1Ra and adiponectin. However, the results from certain patient groups and non-controlled studies show that mindfulness-based interventions may not affect these biomarkers. Among early stage breast and prostate cancer patients (n=59), a single-arm Mindfulness-Based Stress Reduction (MBSR) intervention did not change the participants' DHEAS levels [220]. Another mind-body approach, yoga intervention (n=16), did not have an effect on IL-1Ra levels as compared to health education control group (n=15) among fatigued breast cancer survivors [221]. Two further studies also have not found any significant intervention effects on adiponectin levels: a single-arm mindfulness-based pilot study among people with obesity (n=10) [222] and a mindfulness-based intervention (n=9) compared to patients in standard intervention (n=9) among bariatric post-surgery patients [223].

Table 3. The randomized controlled trials of ACT- and mindfulness-based interventions reporting effects on inflammation and stress biomarkers[a] in adult non-clinical populations.

Reference, Country	Population	Design, Intervention length	Intervention components	Inflammation and stress biomarkers[a]	Results (group x time interaction)
Basso et al. 2018 [214], USA	Healthy adults 64% female BMI not reported	Intervention (n=21) vs. active control (n=21) 8 weeks	Intervention: short meditation recording including breathing exercises and full-body scans Control: podcast recording of various topics not related to meditation	Cortisol (saliva sample at the study visit between 11:00 AM to 8:00 PM)	No differences between the groups.
Creswell et al. 2012 [218], USA	Healthy older adults 83% female BMI: 25.2±4	Intervention (n=20) vs. waiting-list control (n=20) 8 weeks	Intervention: standardized MBSR (includes mindfulness meditation exercises, mindful yoga and stretching, and discussions aiming to increase mindful awareness)	hsCRP	No differences between the groups.
Christopher et al. 2018 [217], USA	Law enforcement officers 11% female BMI not reported	Intervention (n=31) vs. waiting-list control (n=30) 8 weeks	Intervention: MBRT based on MBSR (includes experiential and didactic exercises, body scan, meditations, mindful movement, and discussions)	Cortisol awakening response (CAR), AUC_I (saliva samples at home on three days three times per day: at 0, 30, and 45 minutes after awakening)	No differences between the groups in overall AUC_I changes. On day three ($p=.03$), intervention group had lower post-intervention AUC_I compared to the control group ($p=.02$). Gender was a significant covariate ($p=.05$); in men only, intervention group had reduction in overall AUC_I ($p=.05$) whereas control group had no change ($p=.47$).

(Continued)

Table 3, continued

Reference, Country	Population	Design, Intervention length	Intervention components	Inflammation and stress biomarkers[a]	Results (group x time interaction)
Daubenmier et al. 2011 [201], USA	Adults with ow/ob 100% female BMI:31.2 (inclusion criteria 25–40)	Intervention (n=24) vs. waiting-list control (n=23) 4 months	Intervention: Components from MBSR, MBCT, and MB-EAT including mindfulness practice (body scan, yoga, meditation), mindful eating (bodily sensations of hunger and fullness, taste satisfaction, food cravings, emotional and eating triggers, self-acceptance, inner wisdom), awareness of emotions, and forgiveness Both groups: 2-hour session of information on nutrition and physical exercise	Cortisol awakening response (CAR), cortisol slope (saliva samples at home on four days three times per day: upon awakening, 30 minutes after awakening and prior to bedtime) Serum morning cortisol	No differences between the groups. Obesity status x group interaction (p=.046) showed that intervention group had a decrease in CAR compared to no-change in the control group among participants with BMI≥30 (p=.07), whereas there was no significant effect among participants with BMI<30.
Daubenmier et al. 2016 [219], USA	Adults with obesity 82% female BMI: 35.4±3.5 (intervention), 35.6±3.8 (control) (inclusion criteria 30–45.9)	Intervention (n=100) vs. active control (n=94) 5.5 months	Intervention: Mindfulness for stress management, eating, and physical activity utilizing MBSR and MB-EAT Control: Information on nutrition and physical activity, strength training, and muscle relaxation Both groups: Diet and exercise guidelines including energy intake reduction (typically -500 kcal/d) and increasing physical activity	CRP[b]	No differences between the groups.

(Continued)

Table 3, continued

Reference, Country	**Population**	**Design, Intervention length**	**Intervention components**	**Inflammation and stress biomarkers**[a]	**Results (group x time interaction)**
Malarkey et al. 2013 [215], USA	University faculty and staff with elevated hs-CRP level (>3.0 mg/ml) 88% female BMI: 32.4±0.5[c] (intervention), 32.8±0.5 (control)	Intervention (n=93) vs. active control (n=93) 8 weeks	Intervention: Mindfulness instruction, mindful eating, yoga, mindfulness meditation for stress reduction utilizing MBSR, and information on the health effects of chronic stress Control: Information on healthy lifestyle and healthy decisions related to nutrition, physical activity, stress, and weight	hs-CRP[d] Cortisol (saliva samples at home on three days four times per day: 20 min after arising, noon, 5 p.m., and at bedtime)	No differences between the groups. Baseline BMI x group interaction (p=.04) showed that the intervention group had a larger decrease in hs-CRP as compared to the control group among participants with BMI<30 (p=.009), whereas there was no significant effect among participants with BMI>30.
Roeser et al. 2013 [216], USA, Canada	Schoolteachers from Canada 90% female BMI not reported	Intervention (n=26) vs. waiting-list control (n=32) 8 weeks	Intervention: Mindfulness, yoga, body scan, loving-kindness meditation, and information on how to use mindfulness to emotion and stress regulation	Cortisol (saliva samples at home on a working Monday three times per day: upon awakening, 30 minutes after awakening and at bedtime)	No differences between the groups.

BMI: mean±SD (range), unless other noted. [a] Focusing on cortisol, dehydroepiandrosterone sulfate (DHEAS), C-reactive protein (CRP), interleukin-1 receptor antagonist (IL-1Ra), and adiponectin. [b] CRP values > 30 mg/L were Winsorized to 30. [c] Mean±SE. [d] Inclusion criteria for hs-CRP >3.0 mg/ml and < 10 mg/ml.

ACT = Acceptance and commitment therapy, CAR = Cortisol awakening response, AUC_I = Area under the curve$_{(increase)}$, Ow/ob = Overweight/obesity, n = number of randomized participants, MBRT = Mindfulness-Based Resilience Training, MBSR = Mindfulness-Based Stress Reduction, MBCT = Mindfulness-Based Cognitive Therapy, MB-EAT = Mindfulness-Based Eating Awareness Training, CRP = C-reactive protein, hs-CRP = high sensitivity-C-reactive protein.

2.6 SUMMARY OF THE REVIEW OF THE LITERATURE

Chronic stress with insufficient recovery is a risk for future health. The stress response can be seen in both psychological and physiological systems; in both mind and body. The stress response is initiated in cognitive and psychological processes when internal or external demands exceed one's own abilities. Psychological inflexibility, i.e. the inability to fully keep in contact with the present moment and inability to change or to persist in a behavior that would lead to outcomes considered personally important, is also one factor behind perceived stress. Perceived stress leads to changes in behavior, such as eating, and changes in physiology, such as hormonal secretion, autonomic nervous system, and inflammatory system.

In real-life, perceived stress has been associated with higher uncontrolled eating and emotional eating. The association of perceived stress with adaptive eating behavior, such as intuitive eating and eating competence, has not been reported. Higher perceived stress seems to associate with unhealthier food choices but the association with actual nutrient intake and overall diet quality is not clear. Thus, more research is needed.

As chronic stress is a health risk, surprisingly the other side of the coin, i.e. recovery from stress, has been rarely studied in terms of eating behavior and diet. Physiological recovery can be measured utilizing heart rate variability (HRV) which reflects the activity of the autonomic nervous system. There is a rather limited literature on HRV and eating behavior and diet. The majority of the studies have found that higher HRV, reflecting parasympathetic activation and thus recovery from stress, associates with restrictive eating, lower tendency to uncontrolled eating, and health-promoting characteristics of diet. However, the number of studies is limited and may not reflect the real-life situation, as the HRV has often been measured in a laboratory during a period of 3–10 minutes. Sleep is the most important period for recovery, but there is no previous literature about the association between sleep-time HRV-based recovery and eating behavior and diet.

Acceptance and commitment therapy (ACT) aims to decrease psychological inflexibility and to increase psychological flexibility. ACT targets several psychological processes related to commitment, behavior change, mindfulness, and acceptance. It can be applied in making health-promoting lifestyle changes and improve mental health without focusing on specific diseases or diagnoses. Interventions based on ACT and mindfulness have shown positive effects on eating behavior in non-clinical adult samples, although the results have not been consistent. The effects on actual food and nutrient intake have been studied in only a few RCTs; these have examined so many different intervention components that it is not possible to draw any firm conclusions. In addition, the effects on stress and inflammation biomarkers have been rarely studied in randomized controlled settings. Most of the previous interventions have been based on mindfulness, and not on the more enlarged form i.e. as an ACT intervention. Thus, more research on the effects of ACT is needed.

3 AIMS OF THE STUDY

The general aim of this study was to investigate (a) how stress and recovery are associated with eating behavior and diet, and (b) the effects of a psychological lifestyle intervention on eating behavior, diet and biomarkers of stress and low-grade inflammation (Figure 4) among working-age Finns with psychological distress and overweight/obesity. In more detail, the aims of the study were to investigate:

1. cross-sectional associations of different levels of perceived stress with eating behavior and diet quality (*Study I*),
2. cross-sectional associations of sleep-time physiological stress-recovery with eating behavior and diet quality (*Study II*),
3. the effects of acceptance and commitment therapy on eating behavior and diet quality (*Study III*), and
4. the effects of acceptance and commitment therapy on inflammation and stress biomarkers (*Study IV*).

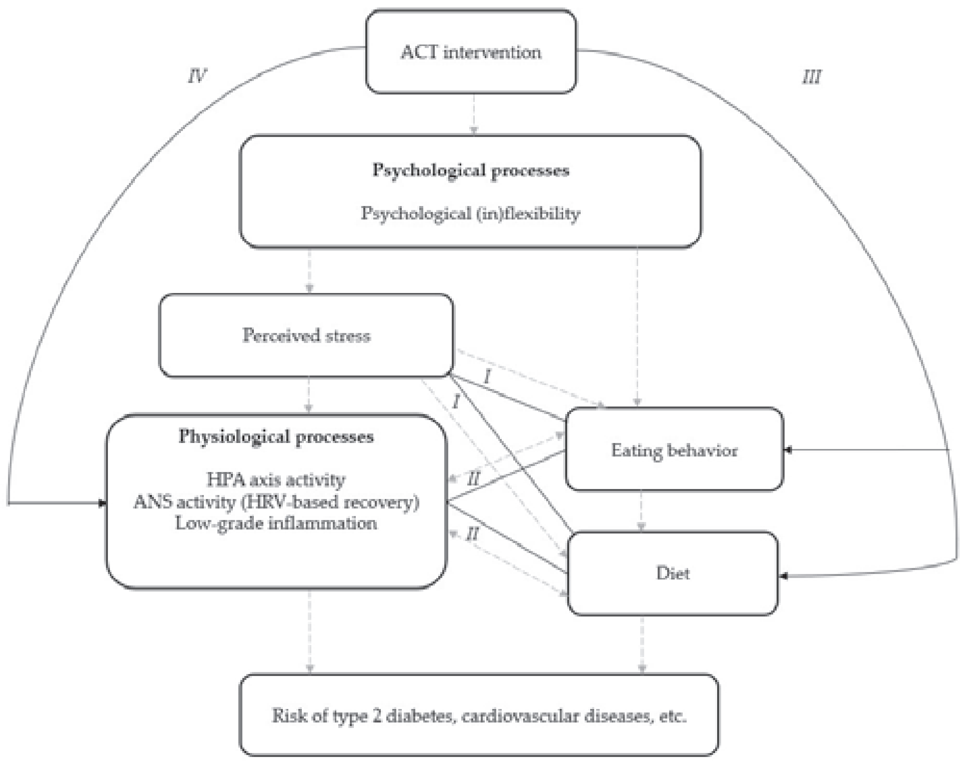

Figure 4. Theoretical basis (gray dashed lines) and the aims (black lines) of the studies *I – IV*. ACT = Acceptance and Commitment Therapy, HPA = hypothalamic-pituitary-adrenocortical, ANS = autonomic nervous system, HRV = heart rate variability.

It was hypothesized that a higher level of perceived stress would associate with unfavorable eating behavior and poorer diet quality as compared to a lower level of perceived stress. Higher sleep-time HRV-based recovery was hypothesized to associate with more favorable eating behavior and better diet quality as compared to lower sleep-time recovery. The ACT intervention was hypothesized to have beneficial effects on eating behavior, some beneficial effects on dietary measures, and some beneficial effects on circulating stress and inflammation biomarkers, although the ACT intervention was not specifically designed to target these measures. Based on the theory, ACT could be hypothesized to effect many of the measured features of eating behavior (Figure 5).

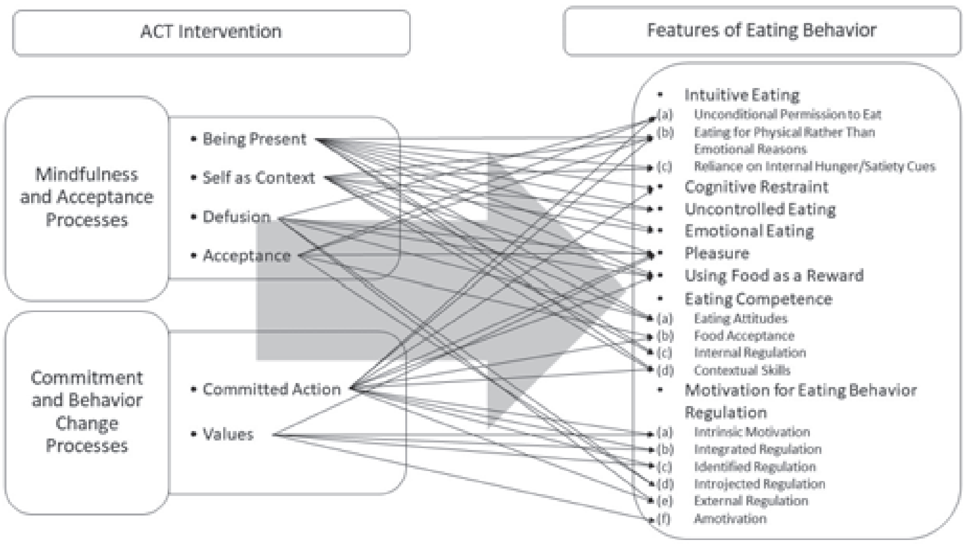

Figure 5. Theoretical model. The hypothesized effects of the core processes of Acceptance and Commitment Therapy (ACT) on the reported features of eating behavior (*Study III*). Originally published in colors by Järvelä-Reijonen et al. (*Study III*). The figure is licensed under the Creative Commons Attribution 4.0 International License.

4 SUBJECTS AND METHODS

4.1 STUDY DESIGN AND STUDY POPULATION

4.1.1 Study design

This doctoral thesis is based on the Elixir intervention which was a randomized controlled trial conducted as a part of the SalWe (Strategic Center for Science, Technology and Innovation in Health and Well-being) Research Program for Mind and Body. The main aim of the Elixir study was to investigate the effectiveness, applicability, and acceptability of lifestyle interventions based on cognitive behavioral approaches among adults with psychological distress and overweight/obesity. The trial was pre-registered at ClinicalTrials.gov with the identifier NCT01738256. The study protocol is described in detail by Lappalainen et al. [224].

The multicenter study was conducted in three cities in Finland (Jyväskylä, Kuopio, and Helsinki) in two phases. The participants in the first phase entered the study in autumn 2012 and the second phase started in spring 2013. This was due to practical reasons, as only a limited number of participants could be handled in the morning in the study laboratory where the measurements were made. The study participants were recruited from August 2012 until January 2013 by advertisements in local newspapers and screened for eligibility via telephone and on-line questionnaire. The eligible persons were randomly allocated to four groups: Face-to-face group, Mobile group, Internet group, and Control group (Figure 6). The Face-to-face and Mobile groups received an intervention based on Acceptance and Commitment Therapy (ACT) in group sessions (Face-to-face) or via a smartphone app (Mobile). The Internet group received an intervention based on Cognitive Behavioral Therapy (CBT) via web-based application and emails. The Control group did not receive any intervention and participated only in the measurements. After all the measurements were completed, the participants in the Control group were offered one group session in which the principles of ACT were presented and the use of the Internet-based lifestyle coaching program was provided and described.

All the measurements were conducted before the intervention (baseline, study week 00), after the 8-week intensive intervention period (post-intervention, study week 10), and 36 weeks after baseline measurements (follow-up, study week 36). The participants filled in electronic questionnaires, visited the local study center for clinical and biochemical measurements, wore a device collecting data of heart rate variability, and reported their food consumption in a 48-hour dietary recall by telephone. The measurements were collected from August 2012 until December 2013.

The study protocol of the Elixir intervention study was approved by the ethics committee of the Central Finland Health Care District (reference number 7U/2012)

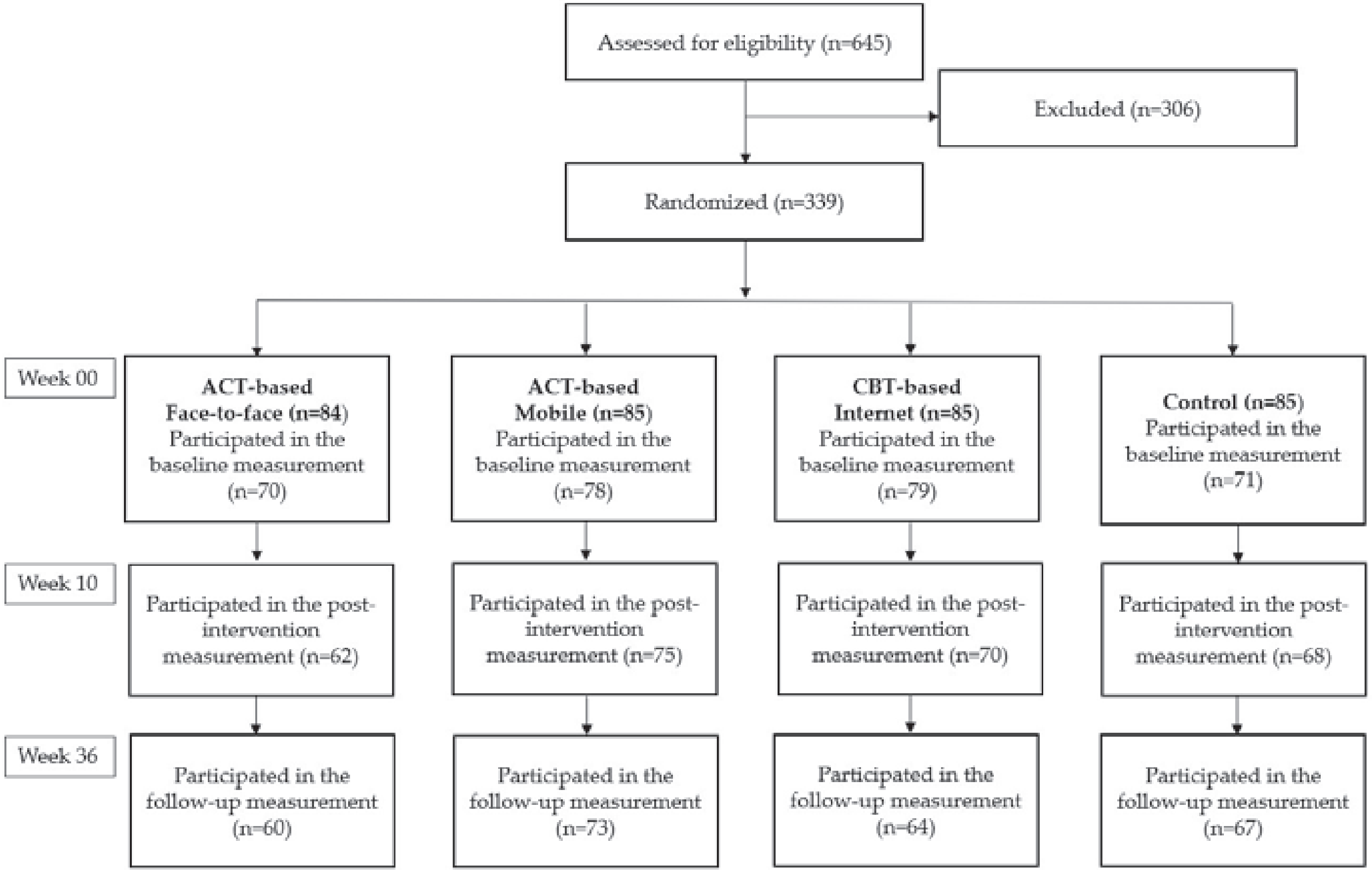

Figure 6. Flow chart of the Elixir study. Modified from the version published previously by Lappalainen et al. 2014 [224]. ACT = Acceptance and Commitment Therapy, CBT = Cognitive Behavioral Therapy.

and was performed in accordance with the Declaration of Helsinki. The participants gave their written informed consent before participating.

This doctoral thesis utilizes the data from the Elixir study so that cross-sectional associations at baseline (*Study I, II, IV*), longitudinal associations of changes during the entire study period (*Study IV*), and the effects of the ACT-based interventions (*Study III, IV*) are investigated.

4.1.2 Study population

According to the inclusion criteria for the screening of the volunteers [224], the participants had to be 25–60 years old and have a self-reported body mass index (BMI) 27–34.9 kg/m². The participants also had to be psychologically distressed (≥3/12 points on the General Health Questionnaire, GHQ-12 [225]) and have a computer and Internet access. There were also several exclusion criteria, such as a diagnosis of a severe chronic illness (including symptomatic cardiovascular disease, type 1 and 2 diabetes, and eating disorder), disabilities/illnesses substantially affecting physiological or mental health, regular oral cortisone medication, pacemaker, three-shift work or night work, pregnancy or breastfeeding within the past 6 months, psychotherapy or other psychological or mental treatment at least twice a month, disability pension for psychological reasons, and participation in other intervention studies during the present study. Altogether 339 volunteers passed this initial screening and were randomized to one of the four groups (Figure 6). The Elixir study sample size was calculated based on the previous available results from a similar ACT-based intervention conducted by the research group. The resulting sample size of n=80–85 per group was based on the power calculation for one of the main outcomes, i.e., changes in symptoms of depression [224].

At the baseline measurements, the randomized participants visited the study laboratory for the first time. Additional blood samples were drawn to determine the participants' health status, i.e. the function of liver, thyroid glands, and kidneys as well as glucose metabolism. Participants with values outside the reference values or having any other exclusion criteria at this point were excluded before starting in the intervention. Furthermore, of those who participated in the baseline measurements and met all the inclusion criteria (n=298), four participants dropped out before starting in the allocated intervention or control group (n=2 in the Face-to-face group, n=1 in the Internet group, and n=1 in the Control group).

The population in *Study I* consisted of all the study participants at baseline with available data from the Perceived Stress Scale (PSS) questionnaire (n=297) because this study investigated the cross-sectional association of perceived stress with eating behavior and diet at baseline (Table 4). *Study II* concentrated on the cross-sectional associations of objectively measured HRV-based recovery with eating behavior and diet at baseline. Participants (n=252) with successful HRV recordings and not using α- or β-adrenergic blocking agents affecting HRV [226] were included. *Studies III and IV* investigated the effects of ACT-based intervention groups, and thus the study populations consist of participants in the Face-to-face, Mobile, and Control groups.

Table 4. Study population in the original studies (*Studies I – IV*).

Study	Number of participants, week 00, 10, 36	Females[a]	Age, years mean ± SD (range)[a]	BMI, kg/m² mean ± SD (range)[a]	GHQ-12 mean ± SD (range)[a]	Inclusion criteria
Study I	297, N/A, N/A	84%	49 ± 8 (27 – 61)	31.3 ± 3.0 (25.3 – 40.1)[c]	7.1 ± 2.8 (3.0 – 12.0)	Participants at baseline with PSS data available.
Study II	252, N/A, N/A	83%	48 ± 8 (27 – 61)	31.3 ± 3.1 (25.3 – 40.1)	7.0 ± 2.8 (3.0 – 12.0)	Participants at baseline with HRV data available and no use of α- or β-adrenergic blocking agents affecting HRV.
Study III	219, 205, 200	85%	50 ± 7 (27 – 61)	31.3 ± 2.9 (25.7 – 40.1)	7.1 ± 2.8 (3.0 – 12.0)	Participants in the ACT-based intervention groups (Face-to-face and Mobile) and in the Control group.
Study IV	204[a] 192[b], 179[b], 174[b]	84%	50 ± 7 (27 – 61)	31.2 ± 2.9 (25.7 – 40.1)	7.1 ± 2.9 (3.0 – 12.0)	Participants in the ACT-based intervention groups (Face-to-face and Mobile) and in the Control group. In addition, hsCRP ≤ 10 mg/L (no acute infection or inflammation) and IL-1Ra and HMW-adiponectin not an outlier (within 5 SDs ± mean).

[a] At baseline, [b] In the analysis of the intervention effects, only participants meeting the additional inclusion criteria at each time point were included.
[c] BMI classified as overweight (25 – 29.9 kg/m²) for 36% and obesity (≥30 kg/m²) for 64% of the participants.
SD = standard deviation, BMI = laboratory-measured body mass index, GHQ-12 = 12-item General Health Questionnaire, N/A = not applicable, PSS = Perceived Stress Scale, HRV = heart rate variability, ACT = Acceptance and Commitment Therapy, hsCRP = high-sensitivity C-reactive protein, IL-1Ra = Interleukin-1 receptor antagonist, HMW = high molecular weight.

Study IV focused on biomarkers of stress and low-grade inflammation. Participants with high hsCRP values (> 10 mg/L) indicating acute infection or inflammation [85] were excluded, as well as participants with IL-1Ra and HMW-adiponectin values considered as outliers (over 5 SDs ± mean).

The background characteristics, such as age and sex, of the participants did not differ between the intervention groups (Table 5). Of the 219 participants providing baseline data for *Study III*, 14 participants (6%) dropped out before the post-intervention measurement, and 5 participants (2%) dropped out before the follow-up measurement. There were no significant differences in intervention group, sex, age, baseline BMI, or baseline psychological distress between those who completed and those who dropped out of the study.

Table 5. Baseline characteristics of the participants (n=219) in the study groups (*Study III*).

	Face-to-face	**Mobile**	**Control**	**p[a]**
Number of participants (n)	70	78	71	
Starting time of the study (n)				.642
Autumn	35	37	30	
Spring	35	41	41	
Study center (n)				.970
Jyväskylä	20	22	17	
Kuopio	22	25	23	
Helsinki	28	31	31	
Sex (n)				.670
Female	61	66	58	
Male	9	12	13	
Age (years)	50.3 ± 7.2	49.1 ± 7.7	49.2 ± 7.4	.575
Weight (kg)	86.1 ± 10.3	88.4 ± 10.4	88.3 ± 11.5	.342
BMI (kg/m^2)	31.0 ± 3.1	31.6 ± 2.7	31.2 ± 2.8	.423
Psychological distress (GHQ-12 score)	7.2 ± 3.0	6.8 ± 2.8	7.4 ± 2.7	.408[b]
Perceived stress (PSS score)	25.8 ± 8.0	26.9 ± 7.8	26.9 ± 7.6	.597

Values are n / mean ± SD; Autumn = September – October 2012; Spring = January – February 2013; BMI = body mass index; GHQ-12 = General Health Questionnaire-12; PSS = Perceived Stress Scale.
[a] p-value for differences between the study groups (Pearson chi-square for categorical variables and one-way ANOVA for continuous variables unless other noted).
[b] Non-parametric Kruskal-Wallis test.

4.1.3 The ACT-based interventions

Although all of the three intervention arms in the Elixir study were based on CBT [224], this doctoral thesis focuses on the effects of the two intervention arms based on the third wave CBT, namely ACT. The Face-to-face and Mobile interventions were based on the same ACT program constructed by the same research group. Thus, the only difference was in the delivery method of the intervention.

Both the Face-to-face and Mobile interventions included the following main components: value clarification, acting according to one's own values, mindfulness skills, the observing self (e.g., observing thoughts without being caught up in them), and acceptance skills (e.g., making room for unpleasant feelings and urges allowing them to come and go). The main focus was on ACT skills but minor parts of mindful eating, relaxation, and everyday physical activity were also included. Mindful eating was the topic of one group session in the Face-to-face intervention group and of one section in the Mobile group's app. The mindful eating component of the intervention consisted of learning to be present while eating; observe eating-related thoughts and feelings; observe and trust hunger and satiety cues; notice challenges for eating based on physical cues; be aware of the effects of not eating mindfully; recognize individual needs and feelings related to meal rhythm; and practicing mindful grocery shopping. The intervention did not include nutrition education. Only a hyperlink to a public nutritional web site was provided to the participants in the intervention groups, which was to be utilized if the dietary changes were according to one's values.

ACT utilizes metaphors, stories, exercises, behavioral tasks, and experiential processes [185,186], and these were also included to the current intervention. The Face-to-face group had six group sessions led by a psychologist during the 8-week intervention period. Each session took approximately 90 minutes, and each group consisted of 6–12 participants. The sessions included exercises, pair and group discussions, and homework for which the participants received a workbook. Of the Face-to-face group participants included in *Study III*, the majority attended either all six group sessions (n=16, 23%) or five group sessions (n=31, 44%). One participant did not attend any group sessions (n=1, 1%) or attended only one (n=1, 1%) or two group sessions (n=1, 1%). The participants attended on average 4.7 group sessions (approximately 7 hours in total).

The Mobile group had one group session in which the participants were acquainted with the principles of ACT and received smartphones with the pre-installed Oiva mobile app [227]. The Oiva app contains 46 exercises in text and audio formats and introduction videos about ACT skills. The user experiences of the app were positive [227]. The participants were free to choose exercises and videos in any order and to perform them as many times as they wanted during the 8-week intervention period. The participants returned the smartphones at the post-intervention laboratory study visit. Of the Mobile group participants included in *Study III*, the median number of usage sessions of the mobile app was 21 (range 4–91, interquartile range IQR 11–33), according to the usage log files of the smartphones. The median number of usage days was 15 (range 4–59, IQR 8–23). The median total duration of use was 274 minutes (range 43–2001, IQR 181–421). The participants' usage of the mobile app has been reported in more detail by Mattila et al. [228].

4.2 METHODS

The main measures used in the original studies are summarized in Table 6 and described in more detail in the following chapters.

Table 6. Summary of the main measures used in the original studies (*I-IV*).

Main measures	*Study I* Cross-sectional associations	*Study II* Cross-sectional associations	*Study III* Intervention effects	*Study IV* Intervention effects
Stress and recovery				
Psychological stress state: PSS	X			
Physiological stress-recovery: HRV		X		
Physiological stress biomarkers: Cortisol, DHEAS				X
Low-grade inflammation: hsCRP, IL1-Ra, HMW-adiponectin				X
Eating behavior				
TFEQ-R18, HTAS, IES, ecSI 2.0™	X	X	X	
REBS			X	
Diet				
IDQ, 48-hour dietary recall, AUDIT-C	X	X	X	

Measures used in cross-sectional analyses (*Study I-II*) are measured at baseline (study week 00). Measures used to study intervention effects (*Study III-IV*) are measured at all time points (study week 00, 10, and 36). PSS = Perceived Stress Scale; HRV = heart rate variability; DHEAS = dehydroepiandrosterone sulfate; hsCRP = high-sensitivity C-reactive protein; IL-1Ra = Interleukin-1 receptor antagonist; HMW = high molecular weight; TFEQ-R18 = The 18-item Three-Factor Eating Questionnaire; HTAS = Health and Taste Attitude Scales; IES = Intuitive Eating Scale; ecSI 2.0™ = The Satter Eating Competence Inventory 2.0; REBS = Regulation of Eating Behavior Scale; IDQ = Index of Diet Quality; AUDIT-C = Alcohol Use Disorders Identification Test Consumption.

4.2.1 Assessment of stress and recovery

Psychological stress state

The 12-item General Health Questionnaire, GHQ-12 [225], was used to screen the volunteers for psychological distress. The GHQ-12 has been found to be a valid screening tool for common mental health problems in the Finnish population [229]. The respondents were asked to consider the past few weeks and then answer questions such as “Have you recently felt constantly under strain?” In the screening, a bimodal scoring was used: “not at all” (0 points); “same as usual” (0); “rather more than usual” (1); and “much more than usual” (1), with the total sum score ranging from 0 to 12. Cronbach’s alpha ranged between 0.72 – 0.73 (*Study I, III, IV*). To achieve larger variation in the GHQ-12 scores for statistical analytical purposes, a Likert scoring system (0,1,2,3 points; possible range 0 – 36) was used. Cronbach’s alpha using Likert scoring ranged between 0.80 – 0.82 (*Study I, IV*). Higher GHQ-12 score were indicative of higher psychological distress.

The 14-item Perceived Stress Scale, PSS-14 [230], was used to assess the degree to which a person perceives life as stressful. The questionnaire has demonstrated acceptable psychometric properties worldwide [231]. The questions assess how often a person has experienced certain feelings and thoughts during the previous month, e.g., "In the last month, how often have you found that you could not cope with all the things that you had to do?" The 5-point Likert scale from "never" (0) to "very often" (4) was summed to create a total score (possible range 0–56). Cronbach's alpha was 0.88 (*Study I, II, III, IV*). Higher PSS-14 score indicates higher perceived stress.

Physiological stress-recovery

Sleep-time heart rate variability (HRV) was measured to collect information on physiological recovery from stress. To collect the continuous beat-to-beat R-R interval data, the participants were instructed to wear a Bodyguard device (Firstbeat Technologies Ltd, Jyväskylä, Finland) with two electrodes attached on the chest for three consecutive days and nights. The participants reported in the study diary the time they went to bed and their sleeping time. The majority (81%) of the recordings lasted for 3 days (range 1–4 days). From these data, HRV-based recovery measures were derived using the Firstbeat Analysis Server software (v 5.3.0.4). The software first detects and corrects falsely detected, missed, and premature beats, i.e., artifacts [59,232]. The maximum allowed percentage of artifacts was 15%. The software utilizes personal background information in calculating the physiological variables when modelling an individual's physiological reactions [59]. The artifact-corrected R-R intervals are re-sampled at a rate of 5 Hz using linear interpolation to achieve equidistantly sampled time series [59,233]. Second-by-second HRV indices are calculated with the short-time Fourier transform method [233,234], and specific physiological parameters are created e.g. utilizing neural network data modeling [59,233]. This process utilizes both time-domain (such as the root mean square of successive differences, RMSSD) and frequency-domain (such as high and low frequency power) HRV variables [59]. The software categorizes the data into different physiological states, such as stress, recovery, and physical activity, by taking into account e.g. individual levels of heart rate (HR), HRV, and respiratory variables [59,234]. Stress is detected when the sympathetic nervous system is predominating, parasympathetic (vagal) activation is low, and no additional metabolic requirements due to physical activity are present [59]. In the R-R interval data, the stress state consists of elevated individual HR, decreased HRV, and low respiration rate compared to HR. Recovery is detected when parasympathetic (vagal) activation predominates in the autonomic nervous system. In the R-R interval data, the recovery state consists of low individual HR accompanied by a large and uniform HRV. [59]

The sleep-time recovery measures used were mean values of Recovery Index and Stress Balance over the period of the 1-4 recording days. The Recovery Index indicates the magnitude of an individual's recovery processes during sleep [66]. The first hours of sleep contain most of the slow-wave sleep stages, i.e., quiet sleep periods with fewer disturbances affecting heart rate [235]. The recommended 4-hour window for determining the Recovery Index was set to start 30 minutes after the self-reported time of going to bed. Possible theoretical values range from 0 to ∞ [65] with higher values indicating a higher magnitude of recovery reactions. Stress Balance indicates the temporal ratio of recovery to stress reactions during the self-reported sleep periods [66]. Possible values range from -1 to 1 with values from -1 to 0 indicating weak recovery, values from 0 to 0.5 moderate recovery, and values from 0.5 to 1 good recovery [66].

Physiological stress and inflammation biomarkers

An antecubital venous blood sample was taken after a 12-h overnight fast at the study laboratory between 7 and 10 a.m. The plasma samples were collected into prechilled EDTA tubes and centrifuged as soon as possible. The serum samples were centrifuged after the blood had clotted. The samples were stored at -80 °C until analyzed at the University of Eastern Finland, Kuopio, Institute of Public Health and Clinical Nutrition as follows.

Plasma total cortisol was measured with a chemiluminescent immunoassay (LIAISON® Cortisol, DiaSorin, Saluggia, Italy) with a quantitation limit of 4.1 nmol/L and a dilution threshold of 2208 nmol/L. Plasma dehydroepiandrosterone sulphate (DHEAS) was measured with a chemiluminescent immunoassay (LIAISON® DHEA-S, DiaSorin, Saluggia, Italy) with a quantitation limit of 0.027 μmol/L and a dilution threshold of 20.3 μmol/L. The Cortisol/DHEAS ratio was used as a more sensitive index of the HPA axis activation and the catabolic/anabolic balance under stress condition. The Cortisol/DHEAS ratio was calculated by dividing the raw value of cortisol (ng/ml) by the raw value of DHEAS (ng/ml) [236]. The ratio between cortisol and DHEAS, i.e., the balance of these catabolic and anabolic stress hormones, has been proposed to be more informative of psychiatric and health status than the individual hormone levels [45]. Although the DHEAS concentration increases in an acute stress response [45], it declines under chronic stress conditions [44,45]. DHEAS is related to several positive health effects [51] and is shown to counteract several effects of cortisol [44,53]. Thus, a higher Cortisol/DHEAS ratio is postulated to indicate higher chronic stress and to contribute to ill health [45].

Inflammation markers known to be associated with metabolic syndrome (MetS) components (i.e., high hsCRP and IL-1Ra levels and low adiponectin level) [87] were also analyzed. Plasma high-sensitivity C-reactive protein (hsCRP) concentration was determined with a photometric immunoturbidimetric method (Konelab, Thermo Fisher Scientific, Vantaa, Finland), with a measurement range from 0.1 to 10 mg/L, and extended range using automatic dilution from 0.1 to 40 mg/L. Plasma interleukin-1 receptor antagonist (IL-1Ra) was measured with an enzyme immunoassay (Quantikine® ELISA Kits, R&D Systems Inc., Minneapolis, USA) with a measurement range from 31.2 to 2000 pg/mL. Serum high molecular weight (HMW) adiponectin was measured with enzyme immunoassay (Quantikine® ELISA for Human HMW Adiponectin/Acrp Immunoassay, R&D Systems Inc., Minneapolis, USA) with a measurement range from 0.39 to 25 μg/mL.

4.2.2 Assessment of eating behavior

The Three-Factor Eating Questionnaire, TFEQ-R18 [100,104], was used to measure (a) Cognitive Restraint (6 items, e.g., "I deliberately take small helpings as a means of controlling my weight."), (b) Uncontrolled Eating (9 items, e.g., "Sometimes when I start eating, I just can't seem to stop."), and (c) Emotional Eating (3 items, e.g., "When I feel blue, I often overeat."). The answers are given by 4-point Likert scale, except for one item, which is answered using an 8-point Likert scale. The possible range of the total scores was 0–100. Higher scores represent a higher amount of the feature. Cronbach's alphas were 0.68 – 0.71 for the Cognitive Restraint, 0.87 – 0.88 for the Uncontrolled Eating, and 0.88 – 0.89 for the Emotional Eating (*Study I, II, III*). The Finnish translation of the questionnaire had been validated in young, mostly normal weight, females and has demonstrated good structural validity [237].

Of the Health and Taste Attitude Scales, HTAS [116], subcategories (a) Pleasure (6 items, e.g., "When I eat, I concentrate on enjoying the taste of food.") and (b) Using Food as a Reward (6 items, e.g., "I reward myself by buying something really tasty.") were used. The statements were answered using a 7-point Likert scale. The scores were averaged; thus, the possible ranges were 1–7. Higher scores represent higher amount of the feature. Cronbach's alphas were 0.71 – 0.72 for the Pleasure and 0.78 – 0.81 for the Using Food as a Reward (*Study I, II, III*). The questionnaire developed in Finland had been validated among several general Finnish adult samples [116-118].

The Intuitive Eating Scale, IES [12], consists of 21 items with subcategories of intuitive eating: (a) Unconditional Permission to Eat (9 items, e.g., "If I am craving a certain food, I allow myself to have it."), (b) Eating for Physical Rather Than Emotional Reasons (6 items, e.g., reversely scored "I find myself eating when I am bored, even when I'm not physically hungry."), and (c) Reliance on Internal Hunger/Satiety Cues (6 items, e.g., "I trust my body to tell me <u>when</u> to eat."). The statements are answered with a 5-point Likert scale. The scores are averaged; thus, the possible ranges of the IES total score and its subscales are 1–5. Higher scores represent higher amount of the feature. Cronbach's alphas were 0.79 – 0.80 for the entire scale and 0.66 – 0.69 for the Unconditional Permission to Eat, 0.84 – 0.86 for the Eating for Physical Rather Than Emotional Reasons, and 0.76 – 0.77 for the Reliance on Internal Hunger/Satiety Cues (*Study I, II, III*). The original questionnaire had been validated among college women in the USA [12].

Eating competence was measured using a preliminary Finnish translation of ecSatter Inventory 2.0™, ecSI 2.0™ [143,238,239]. According to the definition of eating competence, the 16-item questionnaire consists of the subcategories: (a) Eating Attitudes (5 items, e.g., "I am relaxed about eating."), (b) Food Acceptance (3 items, e.g., "I experiment with new food and learn to like it."), (c) Internal Regulation (3 items, e.g., "I eat as much as I am hungry for."), and (d) Contextual Skills (5 items, e.g., “I generally plan for feeding myself. I don’t just grab food when I get hungry.”). The statements were answered: “always” (3 points), “often” (2), “sometimes” (1), “rarely” (0), or “never” (0). The possible ranges of the sum scores were as follows: Eating Competence total score, 0–48; Eating Attitudes and Contextual Skills, 0–15, and Food Acceptance and Internal Regulation, 0–9. This initial scoring [141] was used throughout the thesis, although according to a recent confirmatory factor analysis by the questionnaire developers [142], it is advised that one item should be relocated from the subscore Internal Regulation to Eating Attitudes. Higher scores represent a higher amount of the feature. A total sum score ≥ 32 indicates a competent eater [141] meaning that the person has positive attitudes about eating and about food, accepts and eats an ever-increasing variety of foods, eats intuitively enough according to internal hunger and satiety signals, and has skills and resources for managing daily meals [13]. Cronbach’s alphas were 0.76 for the whole scale and 0.58 – 0.62 for the Eating Attitudes, 0.65 – 0.68 for the Food Acceptance, 0.58 – 0.59 for the Internal Regulation, and 0.74 – 0.76 for the Contextual Skills (*Study I, II, III*). The questionnaire had been validated among mostly female, overweight and educated adult sample [141], low-income females [143,238] and parents of preschool-age children [239] in the USA.

The motivation for eating regulation was measured using the 24-item Regulation of Eating Behavior Scale, REBS [187]. The participants were asked to answer the question “Why are you regulating your eating behaviors?” with a 7-point scale ranging from “Does not correspond at all” (1) to “Corresponds exactly” (7). The scale measured autonomous forms of motivation: (a) Intrinsic motivation (e.g., “It is fun to create meals that are good for my health”), (b) Integrated regulation (e.g., “Eating healthy is an integral part of my life”), and (c) Identified regulation (e.g., “It is a good idea to try to regulate my eating behaviors”). In addition, there were controlled forms of motivation: (d) Introjected regulation (e.g., “I don’t want to be ashamed of how I look.”), (e) External regulation (e.g., “People around me nag me to do it.”), and (f) Amotivation (e.g., “I can’t really see what I’m getting out of it.”). Each category (a–f) included four items. The scores were averaged; thus, the possible ranges were 1–7. Higher scores represent higher amount of the feature. Cronbach’s alphas were 0.86, 0.89, 0.75, 0.60, 0.89, and 0.71 for a, b, c, d, e, and f, respectively (*Study III*). The questionnaire had been validated among female university students in Canada [187]. The Finnish version used in this study had been pilot-tested among a general adult sample (n=37).

4.2.3 Assessment of diet

A concise measure of food consumption, the Index of Diet Quality (IDQ) [240], consisted of 18 questions about frequency, portion size, and/or type of certain foods and drinks consumed during the previous month and was used to evaluate adherence to Nordic and Finnish nutrition recommendations. The questions were concerned with whole-grain products, fat-containing foods, liquid dairy products, vegetables, fruits and berries, sugary products, and the regularity of meal pattern.

The answers were scored as either reflecting health-promoting diet (1 point) or not (0 points). Part of the questions (regarding both frequency and the portion of the food or drink) were combined for the scoring, and thus the possible IDQ total score was 0–15. Higher scores indicate better diet quality. Points below 10 indicate non-adherence, and points from 10 to 15 indicate adherence to the health-promoting diet [240]. Answers that seemed possibly unrealistic or outliers (e.g., 27 slices of bread per day) were checked with the participant, and corrections were made when needed. Answers that remained unverified (n=1 at baseline, n=2 at post-intervention) were coded as missing. The IDQ had been developed and validated among Finnish healthy, mostly normal weight, adult females using a seven-day food record [240].

Alcohol consumption during the previous six months was measured using the Finnish version of the questionnaire Alcohol Use Disorders Identification Test Consumption, AUDIT-C [241]. This questionnaire has been shown to have a strong correlation with alcohol consumption in a general Finnish population [242]. The questionnaire contained three questions regarding the frequency and amounts of alcohol usage. For the questions concerning the amount of drinks consumed, a list of typical Finnish serving sizes and their corresponding amounts as standard drinks (e.g., 33 cl bottle of beer is one drink) were provided. The responses were scored from 0 to 4 and summed, and the possible total score was from 0 to 12. Higher scores indicate higher alcohol consumption.

The 48-h dietary recall was conducted to collect information on nutrient intake. The participants were asked to describe all of the foods and drinks consumed during the previous full 48 hours (beginning at midnight and ending at midnight over two consecutive 24 hour periods). The interview was conducted by trained nutritionists by telephone at a pre-scheduled time. The participants were told that the interview considered diet, but anything regarding 48-h recall was not mentioned beforehand. An electronic picture book [243] was used to help to describe portion sizes. The interviews were performed from Tuesdays to Fridays. The nutrient intake was calculated using AivoDiet software version 2.0.2.2 (Aivo Ltd., Turku, Finland) and the Fineli® Finnish Food Composition Database (National Institute for Health and Welfare, Nutrition Unit, Helsinki, Finland). The interview protocol of the 48-h dietary recall was created based on the face-to-face 48-h dietary recall conducted in the national FINDIET 2012 survey [244]. The 48-h dietary recall protocol of the Elixir study was designed by the three nutritionists who also conducted the interviews. The participants were encouraged to be truthful in the 48-h dietary recall and were told that the interviewer would not assess or comment on their eating and drinking or give any dietary counseling. The reporting of the foods and beverages consumed during the 48 hours was repeated at the end, and the interviewer encouraged the participant to make additions or modifications while repeating the course of the days' events.

4.2.4 Other assessments

Background information, such as age, marital status, education, aiming to lose weight, use of medication, and type of working hours (daytime job, two-shift work, or irregular work), was gathered in a questionnaire. Leisure time physical activity and commuting activity were assessed by a questionnaire. Leisure-time metabolic equivalent (MET) index (MET-h/day) was calculated as a sum score of the different activities multiplied by the intensity (MET), duration (h), and frequency of the activity [245,246].

Anthropometric measurements were conducted during the study laboratory visit. Weight and height were measured at the study laboratory in the morning after a 12-h overnight fast with calibrated instruments. BMI was calculated as kilograms per meters squared. Waist circumference was measured halfway between the lowest rib and the iliac crest. Body composition (% of body fat) was measured with multi-frequency bioelectrical impedance analysis using In Body 720 device (Mega Electronics, Kuopio, Finland) or Tanita BC 418 MA device (Tanita, Japan).

Psychological flexibility was measured with two questionnaires. The Acceptance and Action Questionnaire, AAQ-II, [179] measures general psychological flexibility. The 7 items (e.g., "I worry about not being able to control my worries and feelings") are answered with a 7-point Likert scale from "never true" (1) to "always true" (7). The possible score range is 7 – 49 with a lower score reflecting more psychological flexibility. Cronbach's alpha was 0.91 (*Study IV*). The Acceptance and Action Questionnaire for Weight-Related Difficulties, AAQW, [183] measures weight-related psychological flexibility. The 22 items (e.g., "I try hard to avoid feeling bad about my weight or how I look") are answered with a 7-point Likert scale from "never true / not at all believable" (1) to "always true / completely believable" (7). The possible score range is 22 – 154 with a lower score reflecting more psychological flexibility related to difficult weight-related thoughts and feelings. Cronbach's alpha was 0.90 (*Study IV*).

Symptoms of depression were measured by the 21-item Beck Depression Inventory-II, BDI-II [247]. The 4-point Likert scale was scored from 0 to 3, and the scores were summed for the total score (possible range 0–63). Cronbach's alpha was 0.87 (*Study IV*). Higher scores indicate higher depressive symptoms. Total scores were categorized as follows; no/minimal depression (0 – 13 points), mild depression (14 – 19 points), moderate depression (20 – 28 points), and severe depression (29 – 63 points) [247].

4.2.5 Statistical methods

Data were analyzed using IBM SPSS Statistics versions 21 (*Study I, III*), 23 (*Study IV*), and 25 (*Study II*), Mplus version 7.3 (*Study III*), and MATLAB R2017b (*Study IV*). A two-tailed p-value <.05 was considered as statistically significant.

In *Study I*, the participants were divided into tertiles based on the 33.3 and 66.7 percentiles of the baseline PSS-14 sum scores because there are no cut-off scores for the scale [248]. To test the differences of normally distributed continuous variables in PSS tertiles, adjusting for study center and starting time of the study, analysis of covariance (ANCOVA) with Tukey HSD post hoc comparisons was used. Further analyses adjusting for sex and aim to lose weight were conducted.

In *Study II*, two variables for the stress-recovery were used: the Recovery Index and Stress Balance. The participants were divided into three groups according to the previously established cut-off values for the interpretation of the Stress Balance (i.e., weak recovery with values from -1 to 0, moderate recovery from 0 to 0.5, and good recovery from 0.5 to 1) [66]. For the Recovery Index, no general cut-off points have been determined, so the participants were divided into tertiles based on the 33.3 and 66.7 percentiles of the baseline values. To test the differences of normally distributed continuous variables in the recovery groups, adjusting for study center and starting time of the study, ANCOVA with Šidák-corrected post hoc comparisons was used. Further analyses adjusting for sex and BMI were conducted. Pearson correlation was used to assess the relation of continuous normally distributed variables and Spearman correlation for non-normally distributed variables.

In *Studies I and II*, the normality assumption was assessed by the histograms of the standardized residuals. When necessary, logarithmic or square root transformations were performed to achieve normally distributed residuals. Estimates for effect sizes were measured with partial eta squared (partial η^2). Categorical variables in the tertiles were assessed by Pearson chi-square test or Fisher's exact test.

In *Study III*, hierarchical linear modeling (HLM, Wald test, Mplus version 7.3) was used to analyze the group x time interaction, i.e., whether the three study groups changed differently between the measured time points (study weeks 00, 10, and 36). If there was a difference, post hoc tests were conducted to compare between the three study groups and to determine whether a difference occurred during the intensive intervention period (from study week 00 to 10) or after the intensive intervention period (from study week 10 to 36). HLM accounts for missing values at random (MAR) and includes all of the available data. The parameters were estimated using the full-information maximum likelihood method (MLR estimation in Mplus). The analyses were adjusted for study center and starting time of the study. *Emotional eating*, *External regulation*, and intake of *monounsaturated fat (E%)* differed significantly between the groups at baseline, and these analyses were conducted also adjusting for the baseline value. Cohen's d was calculated from baseline to follow-up (Δ 36 weeks) within- and corrected between-groups to estimate effect sizes using the estimated values. A within-group effect size of 0.5 is considered small, 0.8

medium, and 1.1 large, and a corrected between-group effect size of 0.2 is considered small, 0.5 medium, and 0.8 large [249]. Fisher's exact test and Kruskal-Wallis test were used to compare the characteristics of the participants who completed the study and the participants who dropped out before post-intervention measurement and follow-up measurement.

Further, in *Study III*, baseline perceived stress was tested as mean-centered as a moderator of the intervention effects on the change in eating behavior from baseline to follow-up (Δ 36 weeks). Each outcome variable was tested separately in a single, saturated, moderation model in which the intervention groups were compared separately to the Control group using Mplus software. Maximum Likelihood (MLR) estimation was used.

In *Study IV*, a general linear mixed model (IBM SPSS version 23) was used to analyze the differences between the three study groups using all three time points (group x time interaction) and the main effect of time on outcome variables. Participants were included as random effects and intercept, group, time, interaction term, and covariates as fixed effects. The analysis utilizes all the data available with missing data as "missing at random". In case of statistically significant group x time interaction, Šidák-corrected post hoc test was conducted for pairwise comparisons. The normality assumption was assessed by the residual histograms. The non-normally distributed outcome variables were log-transformed. All the analyses were adjusted for study center and starting time of the study. Further analyses adjusting also for age, sex and baseline BMI were conducted. Furthermore, to study the effect of baseline BMI on the intervention effects, group x time x baseline BMI interaction term was added into the model. Pearson's correlation was used to determine the effect size.

Furthermore, in *Study IV*, exploratory principal component analyses (PCA, MATLAB R2017b) were conducted for psychological, physiological, anthropometric, and lifestyle measures at baseline and for changes from baseline to week 36 (Δ36 = week 36 value – week 00 value). The PCA analyses were intended to be descriptive and hypothesis generating instead of formal hypothesis testing. With these post-hoc analyses, it was explored whether psychological flexibility would associate with psychological and physiological wellbeing among the study participants. In the PCA analysis with the changes from baseline to week 36, missing data was handled by excluding the cases with any missing data. PCA analyses were conducted with standardized values. Humphrey-Ilgen Parallel Analysis was used to determine the number of components [250,251]. The components were rotated using varimax rotation [252]. Loadings of the rotated components are reported. A threshold of 0.3 was used for interpreting the baseline components' loadings. A threshold of 0.25 was used for interpreting the change components' loadings to obtain the stress and inflammation markers included into the components.

5 RESULTS

5.1 ASSOCIATION OF PERCEIVED STRESS WITH EATING BEHAVIOR AND DIET (*STUDY I*)

Descriptive characteristics

The participants were evenly distributed in the PSS tertiles in terms of their descriptive characteristics. There were no statistically significant differences between the PSS tertiles (lowest tertile of PSS scores 7 – 23, n=104; middle tertile 24 – 30, n=102; and highest tertile 31 – 52, n=91) in terms of sex, age, BMI, and education level. The majority of the participants (79%) had at least college education with 43% reporting university education as the highest level of schooling. Most participants (89%) reported currently aiming to lose weight. Aiming to lose weight was more common in the lowest and middle PSS tertiles (92% and 91% of the participants in the tertile, respectively) than in the highest (81%) tertile (χ^2 (2) = 6.837, p=0.033). Furthermore, also self-reported depressive symptoms were different among the PSS tertiles (Fisher's exact test = 102.215, p<0.001). Of the participants reporting moderate (n=37) or severe (n=7) depressive symptoms, the majority (77% and 100%, respectively) were in the highest PSS tertile.

Perceived stress and eating behavior

Perceived stress was associated with several features of eating behavior (Table 7). *Intuitive eating* total score and *Eating for physical rather than emotional reasons* were lower in the highest PSS tertile as compared to the middle (p=0.006, p=0.001, in the post hoc test, respectively) and the lowest (p=0.018, p=0.002, respectively) PSS tertiles. *Reliance on internal hunger/satiety cues* (p=0.018), *Eating competence* total score (p=0.007), *Contextual skills* (p=0.002), and *Cognitive restraint* (p=0.024) were lower in the highest PSS tertile compared to the lowest PSS tertile. *Uncontrolled eating* and *Emotional eating* were higher in the highest PSS tertile in comparison to the middle (p=0.001, p=0.001, respectively) and the lowest (p<0.001, p<0.001, respectively) PSS tertiles. *Using food as a reward* (p=0.007) was higher in the highest PSS tertile compared to the middle PSS tertile.

The statistically significant associations remained after further adjusting for sex. However, after adjusting further for the aim to lose weight, the association of perceived stress with *Cognitive restraint* (F[2, 290]=2.41, p=0.092) was no longer statistically significant.

Table 7. Eating behavior in the tertiles of perceived stress (*Study I*).

	PSS tertiles					
	Lowest (7 – 23) (n = 104)	**Middle (24 – 30) (n = 102)**	**Highest (31 – 52) (n = 91)**	**F (df)**	**Partial η²**	**p-value**
IES total score	3.0 ± 0.5[a]	3.0 ± 0.5[a]	2.8 ± 0.5[b]	5.31 (2, 291)	.035	**.005**
Unconditional Permission to Eat	3.1 ± 0.6	3.2 ± 0.6	3.1 ± 0.6	0.93 (2, 291)	.006	.395
Eating for Physical Rather Than Emotional Reasons	2.6 ± 0.8[a]	2.6 ± 0.9[a]	2.2 ± 0.7[b]	7.97 (2, 291)	.052	**<.001**
Reliance on Internal Hunger/Satiety Cues	3.3 ± 0.6[a]	3.2 ± 0.6	3.0 ± 0.7[b]	3.23 (2, 291)	.022	**.041**
ecSI 2.0™ total score	27.3 ± 6.1[a]	26.2 ± 6.1	24.7 ± 5.7[b]	4.22 (2, 291)	.028	**.016**
Eating Attitudes	10.2 ± 2.2	9.8 ± 2.5	9.5 ± 2.5	2.09 (2, 291)	.014	.125
Food Acceptance	5.1 ± 1.9	5.1 ± 1.8	4.8 ± 1.9	0.54 (2, 291)	.004	.584
Internal Regulation	4.8 ± 1.8	5.0 ± 1.7	4.7 ± 1.8	0.52 (2, 291)	.004	.597
Contextual Skills	7.2 ± 2.9[a]	6.4 ± 3.2	5.7 ± 2.6[b]	5.81 (2, 291)	.038	**.003**
TFEQ-R18						
Cognitive Restraint	46.8 ± 14.8[a]	45.4 ± 14.7	41.0 ± 16.9[b]	3.54 (2, 291)	.024	**.030**
Uncontrolled Eating	45.6 ± 16.6[b]	46.0 ± 20.4[b]	55.9 ± 19.1[a]	8.78 (2, 291)	.057	**<.001**
Emotional Eating	53.8 ± 25.2[b]	57.2 ± 28.8[b]	71.2 ± 24.3[a]	11.30 (2, 291)	.072	**<.001**
HTAS						
Pleasure	4.7 ± 1.0	4.6 ± 1.1	4.9 ± 0.9	1.74 (2, 287)[1]	.012	.178
Using Food as a Reward	4.3 ± 1.1	4.2 ± 1.2[b]	4.7 ± 1.1[a]	4.49 (2, 291)	.030	**.012**

Values are unadjusted means ± SD. P-values are adjusted for the study center and starting time of the study (ANCOVA).
[a] Significantly higher value than the value marked with [b], based on the Tukey HSD post hoc comparisons. [1] The interaction PSS tertiles x study center was significant (p=.020) and thus included in the model. No interactions were included in the other models.
PSS = Perceived Stress Scale (possible score range 0 – 56); IES = Intuitive Eating Scale (possible score range 1 – 5); ecSI 2.0 ™ = preliminary Finnish translation of Satter Eating Competence Inventory 2.0 (possible score range for the total score 0 – 48, Eating Attitudes and Contextual Skills 0 – 15, Food Acceptance and Internal Regulation 0 – 9); TFEQ-R18 = The Three-Factor Eating Questionnaire-R18 (possible score range 0 – 100); HTAS = Health and Taste Attitude Scales (possible score range 1 – 7). Higher scores represent a higher amount of the feature in all of the scales.

Perceived stress and diet

Perceived stress was not associated with the dietary measures (Table 8). There were no significant differences among the PSS tertiles in the IDQ score, alcohol use or energy nutrient intake. Although the percentage of energy from saturated fat was statistically significant in the main analysis (F[2, 287]=3.50, p=0.032), no statistically significant differences between the PSS tertiles were detected in the post hoc analysis. In addition, no statistically significant associations were found after adjusting further for sex or the aim to lose weight.

Most participants (n=193, 65%) reported high adherence to the health-promoting diet (IDQ score ≥10). The adherence to the health-promoting diet did not differ significantly among the PSS tertiles (69% in the lowest, 67% in the middle, and 59% in the highest PSS tertile, χ^2 [2, N=296] = 2.106, p=0.349).

Table 8. Diet quality, alcohol use and intake of energy nutrients in the tertiles of perceived stress (*Study I*).

	PSS tertiles					
	Lowest (7 – 23) (n = 104)	**Middle (24 – 30) (n = 102)**	**Highest (31 – 52) (n = 91)**	**F (df)**	**Partial η^2**	**p-value**
Diet quality and alcohol use						
IDQ score	10.4 ± 1.9[1]	10.3 ± 2.1	9.8 ± 2.3	2.15 (2, 290)	.015	.119
AUDIT-C score	3.6 ± 2.1	4.0 ± 2.6	4.0 ± 2.3	1.01 (2, 291)	.007	.366
Intake of energy nutrients						
Energy (kcal)	1922 ± 554	1980 ± 602	2022 ± 535	0.93 (2, 291)	.006	.395
Protein (E%)	17.3 ± 3.5	17.9 ± 4.2	17.1 ± 4.5	0.72 (2, 291)	.005	.488
Total fat (E%)	37.3 ± 7.6	37.1 ± 8.4	38.2 ± 7.6	0.50 (2, 291)	.003	.609
Saturated fat (E%)	13.2 ± 3.4	13.3 ± 3.7	14.3 ± 4.3	3.50 (2, 287)[2]	.024	**.032**[3]
Monounsaturated fat (E%)	13.1 ± 3.6	12.6 ± 3.4	13.0 ± 3.0	0.63 (2, 291)	.004	.536
Polyunsaturated fat (E%)	6.3 ± 1.9	6.4 ± 2.1	6.5 ± 2.3	0.35 (2, 291)	.002	.704
Carbohydrate (E%)	41.5 ± 7.2	40.7 ± 7.9	40.3 ± 7.6	0.51 (2, 291)	.003	.602
Sucrose (E%)	8.9 (6.0)	7.6 (4.5)	8.3 (5.9)	1.67 (2, 291)	.011	.191
Fiber (g)	22.5 ± 8.2	23.9 ± 10.1	22.0 ± 9.4	0.92 (2, 291)	.006	.402
Fiber (g/MJ)	2.9 ± 1.0	2.9 ± 1.0	2.6 ± 1.0	2.06 (2, 291)	.014	.131

Values are unadjusted mean ± SD for variables with normally distributed residuals and median (IQR) for non-normally distributed residuals. P-values are adjusted for the study center and starting time of the study (ANCOVA).

[1] n=103 because of one missing value in the IDQ score. [2] The interaction PSS tertiles x study center was significant (p=.005) and thus included in the model. No interactions were included in the other models. [3] No significant differences between the tertiles in the Tukey HSD post hoc comparisons.
PSS = Perceived Stress Scale (possible score range 0 – 56); IDQ = Index of Diet Quality (possible score range 0 – 15); AUDIT-C = three alcohol consumption questions from the Alcohol Use Disorders Identification Test (possible score range 0 – 12); E% = percentage of energy. Higher scores represent a higher amount of the feature/consumption in the PSS, IDQ, and AUDIT-C scales.

5.2 ASSOCIATION OF RECOVERY WITH EATING BEHAVIOR AND DIET (*STUDY II*)

Descriptive characteristics

Sleep-time RMSSD, the traditional HRV measure, correlated positively with sleep-time Recovery Index (i.e., magnitude of the recovery reactions) and Stress Balance (i.e., recovery-stress ratio) (r=0.92, p<0.001, and r=0.32, p<0.001, respectively). Furthermore, the sleep-time Recovery Index and Stress Balance correlated positively with each other (r=0.43, p<0.001). Among the Recovery Index and Stress Balance categories, there were no statistically significant differences in sex, BMI, and perceived stress. However, the mean age of the participants in the highest Recovery Index tertile was lower (44.0 ± 8.0 years) than that of the middle (49.8 ± 6.9 years, p<0.001) and the lowest tertiles (50.7 ± 6.3 years, p<0.001) ($F[2,249] = 21.790$, p<0.001).

Recovery and eating behavior

Sleep-time recovery was associated with some features of eating behavior, all of which related to intuitive eating (Table 9). *Intuitive eating* total score and *Eating for physical rather than emotional reasons* were lower in the highest Recovery Index tertile compared to the lowest Recovery Index tertile (p=0.040, p=0.019, in the post hoc test, respectively). Furthermore, *Unconditional permission to eat* was lower among the participants in good Stress Balance compared to the participants in weak Stress Balance (p=0.009). These associations remained statistically significant after further adjusting for sex and BMI.

Table 9. Eating behavior in the categories of sleep-time HRV-based recovery, i.e., magnitude of the recovery reactions (Recovery Index) and recovery-stress ratio (Stress Balance) (*Study II*).

	Recovery Index tertiles						**Stress Balance categories**					
	Lowest (9.70 – 54.49) (n = 84)	**Middle (54.50 – 81.74) (n = 84)**	**Highest (81.75 – 201.10) (n = 84)**	**F (df)**	**Partial η^2**	**p-value**	**Weak (-1 – <0) (n = 59)**	**Moderate (0 – <0.5) (n = 87)**	**Good (0.5 – 1) (n = 106)**	**F (df)**	**Partial η^2**	**p-value**
IES total score	3.0 ± 0.5[a]	3.0 ± 0.5	2.9 ± 0.4[b]	2.441 (2, 249)	0.019	**.036**	3.0 ± 0.5	3.0 ± 0.5	2.9 ± 0.5	1.576 (2, 249)	0.013	.114
Unconditional Permission to Eat	3.2 ± 0.6	3.2 ± 0.6	3.1 ± 0.6	1.426 (2, 249)	0.011	.150	3.3 ± 0.7[a]	3.2 ± 0.6	3.0 ± 0.6[b]	5.367 (2, 249)	0.041	**.008**
Eating for Physical Rather Than Emotional Reasons	2.7 ± 1.0[a]	2.4 ± 0.9	2.3 ± 0.7[b]	3.175 (2, 249)	0.025	**.023**	2.3 (1.0)	2.5 (1.2)	2.3 (0.7)	0.946 (2, 249)	0.008	.320
Reliance on Internal Hunger/Satiety Cues	3.2 ± 0.6	3.2 ± 0.6	3.1 ± 0.7	0.151 (2, 249)	0.001	.679	3.2 (0.8)	3.2 (0.8)	3.3 (0.8)	1.146 (2, 249)	0.009	.514
ecSI 2.0™ total score	26.1 ± 5.9	26.3 ± 5.4	26.4 ± 6.7	0.057 (2, 249)	0.000	.972	26.0 ± 6.3	25.7 ± 5.7	26.9 ± 6.1	1.051 (2, 249)	0.008	.231
Eating Attitudes	10.2 ± 2.3	9.8 ± 2.3	9.8 ± 2.4	0.686 (2, 249)	0.005	.535	10.3 ± 2.4	9.7 ± 2.4	9.9 ± 2.3	1.290 (2, 249)	0.010	.467
Food Acceptance	4.6 ± 1.9	5.1 ± 1.7	5.3 ± 2.1	2.706 (2, 249)	0.021	.107	4.5 ± 1.8	4.9 ± 1.9	5.3 ± 1.9	3.514 (2, 249)	0.027	.116
Internal Regulation	4.9 ± 2.0	4.9 ± 1.4	4.9 ± 1.9	0.034 (2, 249)	0.000	.946	5.0 ± 1.9	4.6 ± 2.0	5.1 ± 1.5	2.771 (2, 249)	0.022	.071
Contextual Skills	6.5 ± 2.9	6.6 ± 2.8	6.4 ± 3.3	0.047 (2, 249)	0.000	.967	6.2 ± 2.9	6.5 ± 2.9	6.6 ± 3.1	0.450 (2, 249)	0.004	.735

(Continued)

Table 9, continued

	Recovery Index tertiles						Stress Balance categories					
	Lowest (9.70 – 54.49) (n = 84)	**Middle (54.50 – 81.74) (n = 84)**	**Highest (81.75 – 201.10) (n = 84)**	**F (df)**	**Partial η^2**	**p-value**	**Weak (-1 – <0) (n = 59)**	**Moderate (0 – <0.5) (n = 87)**	**Good (0.5 – 1) (n = 106)**	**F (df)**	**Partial η^2**	**p-value**
TFEQ-R18												
Cognitive Restraint	43.8 ± 14.7	41.7 ± 16.8	45.3 ± 14.8	1.130 (2, 249)	0.009	.325	42.6 ± 17.3	41.2 ± 14.1	46.2 ± 15.2	2.697 (2, 249)	0.021	.089
Uncontrolled Eating	47.1 ± 19.2	47.8 ± 20.6	51.8 ± 16.7	1.509 (2, 249)	0.012	.200	46.5 ± 19.9	50.2 ± 17.9	49.1 ± 19.2	0.687 (2, 249)	0.005	.368
Emotional Eating	57.3 ± 30.9	60.4 ± 26.2	62.3 ± 23.8	0.738 (2, 249)	0.006	.373	66.7 (33.3)	66.7 (44.4)	66.7 (33.3)	0.580 (2, 249)	0.005	.482
HTAS												
Pleasure	4.9 ± 1.0	4.6 ± 1.2	4.7 ± 0.8	3.223 (2, 249)	0.025	.050	4.9 ± 1.0	4.7 ± 1.0	4.7 ± 1.0	1.604 (2, 249)	0.013	.383
Using Food as a Reward	4.2 ± 1.3	4.5 ± 1.2	4.6 ± 0.9	2.045 (2, 249)	0.016	.113	4.7 (1.5)	4.3 (1.8)	4.7 (1.2)	0.859 (2, 249)	0.007	.534

Values are unadjusted means ± SD for variables with normally distributed residuals and median (IQR) for non-normally distributed residuals. P-values are adjusted for the study center and the starting time of the study (ANCOVA).

[a] Significantly higher value than the value marked with [b], based on the Šidák-corrected post hoc comparisons.

IES = Intuitive Eating Scale (possible score range 1 – 5); ecSI 2.0 TM = preliminary Finnish translation of Satter Eating Competence Inventory 2.0 (possible score range for the total score 0 – 48, Eating Attitudes and Contextual Skills 0 – 15, Food Acceptance and Internal Regulation 0 – 9); TFEQ-R18 = The Three-Factor Eating Questionnaire-R18 (possible score range 0 – 100); HTAS = Health and Taste Attitude Scales (possible score range 1 – 7). Higher scores represent a higher amount of the feature in all of the scales.

Recovery and diet

Sleep-time recovery was associated with some dietary measures (Table 10). Diet quality (IDQ score) and fiber intake were higher among participants with good Stress Balance as compared to the participants with weak Stress Balance ($p=0.001$, $p=0.029$, in the post hoc test, respectively). In addition, alcohol consumption (AUDIT-C score) was higher among participants with weak Stress Balance as compared to the participants with moderate and good Stress Balance ($p<0.001$, $p<0.001$, respectively). These associations remained statistically significant after further adjusting for sex and BMI.

Table 10. Diet quality, alcohol use and intake of energy nutrients in the categories of sleep-time HRV-based recovery, i.e., magnitude of the recovery reactions (Recovery Index) and recovery-stress ratio (Stress Balance) (*Study II*).

	Recovery Index tertiles						**Stress Balance categories**					
	Lowest (9.70 – 54.49) (n = 84)	**Middle (54.50 – 81.74) (n = 84)**	**Highest (81.75 – 201.10) (n = 84)**	**F (df)**	**Partial η^2**	**p-value**	**Weak (-1 – <0) (n = 59)**	**Moderate (0 – <0.5) (n = 87)**	**Good (0.5 – 1) (n = 106)**	**F (df)**	**Partial η^2**	**p-value**
Diet quality and alcohol use												
IDQ score	10.0 ± 2.1	10.1 ± 2.0	10.6 ± 2.1[1]	1.753 (2, 248)	0.014	.248	9.3 ± 2.2[2b]	10.2 ± 2.0	10.7 ± 1.9[a]	8.611 (2, 248)	0.065	**.001**
AUDIT-C score	4.3 ± 2.5	3.5 ± 2.3	3.7 ± 2.2	2.235 (2, 249)	0.018	.115	5.2 ± 2.7[a]	3.7 ± 2.1[b]	3.3 ± 2.1[b]	14.531 (2, 249)	0.105	**<.001**
Intake of energy nutrients												
Energy (kcal)	1921 ± 537	1958 ± 493	2075 ± 593	1.858 (2, 249)	0.015	.195	1898 (736)	2042 (845)	1912 (514)	0.487 (2, 249)	0.004	.588
Protein (E%)	17.2 ± 3.9	17.2 ± 4.0	17.7 ± 3.8	0.598 (2, 249)	0.005	.434	16.5 (6.0)	16.5 (5.4)	17.3 (5.0)	0.671 (2, 249)	0.005	.545
Total fat (E%)	38.2 ± 8.6	36.8 ± 7.7	37.5 ± 7.4	0.619 (2, 249)	0.005	.586	38.7 ± 8.2	37.0 ± 6.8	37.2 ± 8.6	0.914 (2, 249)	0.007	.519
Saturated fat (E%)	13.8 ± 3.4	13.3 ± 3.7	13.7 ± 3.8	0.530 (2, 249)	0.004	.641	14.2 ± 3.8	13.5 ± 3.3	13.3 ± 3.8	1.330 (2, 249)	0.011	.429
Monounsaturated fat (E%)	13.3 ± 3.9	12.4 ± 3.2	13.0 ± 2.8	1.726 (2, 249)	0.014	.158	13.3 ± 3.5	12.6 ± 3.1	12.9 ± 3.4	0.658 (2, 249)	0.005	.557
Polyunsaturated fat (E%)	5.7 (2.5)	6.1 (3.1)	6.3 (1.8)	0.204 (2, 249)	0.002	.881	6.0 (3.3)	6.1 (2.4)	6.2 (2.7)	0.147 (2, 249)	0.001	.824
Carbohydrate (E%)	40.1 ± 7.8	42.1 ± 7.6	41.2 ± 7.3	1.453 (2, 249)	0.012	.212	39.8 ± 6.9	41.3 ± 6.8	41.8 ± 8.4	1.386 (2, 249)	0.011	.292
Sucrose (E%)	9.3 ± 5.4	9.4 ± 3.6	8.9 ± 4.8	0.313 (2, 249)	0.003	.599	8.1 (4.9)	8.6 (5.3)	8.9 (5.4)	0.068 (2, 249)	0.001	.881
Fiber (g/MJ)	2.8 ± 1.0	2.9 ± 1.1	2.7 ± 0.9	0.963 (2, 249)	0.008	.373	2.6 (1.5)[b]	2.5 (1.4)	2.8 (1.3)[a]	4.236 (2, 249)	0.033	**.028**

Values are unadjusted means ± SD for variables with normally distributed residuals and median (IQR) for non-normally distributed residuals. P-values are adjusted for the study center and starting time of the study (ANCOVA).

[a] Significantly higher value than the value marked with [b], based on the Šidák-corrected post hoc comparisons. [1] n=83 because of one missing value in the IDQ score. [2] n=58 because of one missing value in the IDQ score.

IDQ = Index of Diet Quality (possible score range 0 – 15); AUDIT-C = three alcohol consumption questions from the Alcohol Use Disorders Identification Test (possible score range 0 – 12); E% = percentage of energy. Higher scores represent a higher amount of the feature/consumption in the IDQ and AUDIT-C scales.

5.3 EFFECTS OF ACT INTERVENTION ON EATING BEHAVIOR AND DIET (*STUDY III*)

Among the three study groups during the entire study period (study weeks 00, 10, and 36), group x time interactions were found in several features of eating behavior: *Eating for physical rather than emotional reasons*, *Food acceptance*, *Uncontrolled eating*, *Using food as a reward*, and *Integrated* and *Identified regulation*, with small or small-to-medium effect sizes (Table 11). These results are described in more detail in the following paragraphs. However, there were no statistically significant differences in the changes in dietary measures between the groups (Table 12).

Changes from baseline to post-intervention (study weeks 00–10)

There were improvements in the subcomponents of intuitive eating (IES), health and taste attitudes (HTAS), and regulation of eating behavior (REBS) (Table 11). *Eating for physical rather than emotional reasons* increased in both the Face-to-face and Mobile groups as compared to the Control group (p=0.007 and p=0.006, respectively). *Using food as a reward* decreased in the Mobile group as compared to the Face-to-face group (p=0.027). *Integrated regulation* increased in the Face-to-face group as compared to both the Control group and Mobile group (p=0.001 and p=0.027, respectively). Similarly, *Identified regulation* increased in the Face-to-face group as compared to both the Control group and Mobile group (p=0.033 and p=0.004, respectively).

Changes from post-intervention to follow-up (study weeks 10–36)

There were improvements in the subcomponents of eating competence (ecSI 2.0™) and TFEQ-R18 (Table 11). *Food acceptance* increased in the Face-to-face group as compared to both the Control group and Mobile group (p=0.007 and p=0.011, respectively). *Uncontrolled eating* decreased in the Face-to-face group as compared to the Control group (p=0.014).

Moderating effect of perceived stress

Baseline perceived stress did not moderate the effects on the abovementioned features of eating behavior from baseline to follow-up (Supplementary Table 1. Appendix 1).

Table 11. The effects of ACT-based Face-to-face and Mobile interventions on eating behaviour (*Study III*).

	Face-to-face				**Mobile**				**Control**				**p[a]**	**d[b]**
	0 wk	**10 wk**	**36 wk**	**d[c]**	**0 wk**	**10 wk**	**36 wk**	**d[c]**	**0 wk**	**10 wk**	**36 wk**	**d[c]**		
IES total score	2.9 ± 0.4	3.0 ± 0.5	3.1 ± 0.4	0.45	2.9 ± 0.5	3.0 ± 0.4	3.1 ± 0.5	0.29	3.0 ± 0.5	3.0 ± 0.5	3.0 ± 0.5	0.16	.090	0.27 0.13
Unconditional Permission to Eat	3.0 ± 0.5	3.0 ± 0.5	3.1 ± 0.5	0.10	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.7	-0.05	3.1 ± 0.6	3.0 ± 0.7	3.1 ± 0.6	-0.01	.277	0.11 -0.05
Eating for Physical Rather Than Emotional Reasons	2.4 ± 0.8	2.6 ± 0.7	2.8 ± 0.8	0.50	2.4 ± 0.8	2.6 ± 0.8	2.7 ± 0.8	0.44	2.6 ± 0.9	2.6 ± 0.8	2.7 ± 0.8	0.10	**.019**	0.40 0.33
Reliance on Internal Hunger/Satiety Cues	3.2 ± 0.6	3.3 ± 0.7	3.4 ± 0.6	0.36	3.2 ± 0.7	3.3 ± 0.6	3.4 ± 0.6	0.29	3.2 ± 0.7	3.2 ± 0.6	3.4 ± 0.6	0.27	.967	0.04 -0.01
ecSI 2.0[TM] total score	26.2 ± 6.0	26.6 ± 6.3	28.1 ± 6.6	0.22	26.3 ± 5.7	26.8 ± 6.2	26.2 ± 6.2	-0.04	25.8 ± 6.4	25.8 ± 5.9	26.5 ± 6.4	0.07	.164	0.14 -0.11
Eating Attitudes	10.0 ± 2.1	9.7 ± 2.1	10.0 ± 2.5	-0.03	9.7 ± 2.2	9.8 ± 1.9	9.4 ± 2.4	-0.12	9.7 ± 2.6	9.5 ± 2.6	9.7 ± 2.2	-0.03	.144	0.00 -0.09
Food Acceptance	4.9 ± 2.0	4.9 ± 1.9	5.5 ± 1.6	0.25	5.2 ± 1.9	5.1 ± 2.0	5.0 ± 2.0	-0.09	4.9 ± 1.8	4.9 ± 1.9	4.8 ± 1.9	-0.04	**.048**	0.31 -0.06
Internal Regulation	4.7 ± 1.9	4.8 ± 1.8	5.1 ± 1.7	0.22	5.0 ± 1.6	5.1 ± 1.6	4.7 ± 1.8	-0.17	4.8 ± 1.8	5.0 ± 1.5	4.9 ± 1.8	0.02	.077	0.20 -0.18
Contextual Skills	6.7 ± 3.1	7.3 ± 3.1	7.6 ± 3.1	0.24	6.5 ± 3.0	6.8 ± 3.0	7.1 ± 3.2	0.18	6.4 ± 3.1	6.4 ± 2.6	7.1 ± 2.9	0.20	.720	0.05 -0.02
TFEQ-R18														
Cognitive Restraint	43.1 ± 16.6	49.4 ± 14.4	51.5 ± 17.0	0.47	45.2 ± 16.2	47.6 ± 17.6	48.7 ± 15.3	0.26	45.8 ± 15.3	48.4 ± 15.3	47.7 ± 16.2	0.11	.252	0.37 0.15
Uncontrolled Eating	49.3 ± 18.3	44.7 ± 20.1	39.5 ± 20.5	-0.46	49.4 ± 20.1	44.6 ± 19.2	43.9 ± 20.3	-0.30	50.2 ± 20.9	48.4 ± 21.0	47.7 ± 19.0	-0.11	**.020**	-0.34 -0.20
Emotional Eating	64.9 ± 25.3	57.3 ± 24.6	54.6 ± 25.6	-0.40	62.4 ± 27.5	56.3 ± 26.0	52.8 ± 25.8	-0.36	55.9 ± 27.9	54.4 ± 28.9	53.8 ± 25.1	-0.08	.083[d]	-0.31 -0.27

(Continued)

Table 11, continued

	Face-to-face				Mobile				Control				p[a]	d[b]
	0 wk	10 wk	36 wk	d[c]	0 wk	10 wk	36 wk	d[c]	0 wk	10 wk	36 wk	d[c]		
HTAS														
Pleasure	4.7 ± 0.9	4.8 ± 0.8	4.8 ± 0.9	0.16	4.9 ± 1.0	4.8 ± 0.9	4.7 ± 1.0	-0.16	4.7 ± 1.0	4.7 ± 1.1	4.8 ± 1.0	0.15	.066	-0.01 -0.30
Using Food as a Reward	4.3 ± 1.2	4.2 ± 1.2	4.0 ± 1.2	-0.21	4.6 ± 1.1	4.2 ± 1.2	4.1 ± 1.2	-0.39	4.3 ± 1.2	4.2 ± 1.1	4.2 ± 1.2	-0.10	**.048**	-0.11 -0.29
REBS														
Intrinsic motivation	5.1 ± 1.2	5.3 ± 1.2	5.4 ± 1.2	0.19	5.1 ± 1.3	5.2 ± 1.2	5.2 ± 1.4	0.05	4.9 ± 1.4	4.9 ± 1.3	5.0 ± 1.4	0.09	.831	0.09 -0.04
Integrated regulation	3.9 ± 1.3	4.5 ± 1.3	4.7 ± 1.4	0.55	4.3 ± 1.3	4.4 ± 1.1	4.3 ± 1.4	0.09	4.1 ± 1.3	4.0 ± 1.3	4.2 ± 1.4	0.12	**.003**	0.41 -0.04
Identified regulation	5.8 ± 0.9	6.0 ± 0.8	6.0 ± 0.8	0.17	5.9 ± 0.9	5.7 ± 1.0	5.7 ± 0.9	-0.20	5.7 ± 0.9	5.6 ± 1.1	5.7 ± 0.9	0.02	**.023**	0.15 -0.21
Introjected regulation	4.2 ± 1.1	4.0 ± 1.2	4.0 ± 1.2	-0.13	4.2 ± 1.2	4.0 ± 1.2	4.1 ± 1.3	-0.09	4.3 ± 1.2	4.1 ± 1.2	4.1 ± 1.3	-0.19	.955	0.08 0.10
External regulation	3.0 ± 1.6	3.0 ± 1.6	2.9 ± 1.8	0.04	3.5 ± 1.6	3.5 ± 1.5	3.3 ± 1.6	-0.11	3.7 ± 1.7	3.5 ± 1.8	3.6 ± 1.7	-0.04	.489[e]	0.10 -0.07
Amotivation	2.1 ± 1.0	1.8 ± 0.9	1.7 ± 0.8	-0.39	2.1 ± 1.0	2.1 ± 1.0	2.1 ± 1.0	-0.00	2.1 ± 1.0	2.2 ± 1.0	2.1 ± 1.1	-0.00	.059	-0.36 0.00

Notes: Values are unestimated mean ± SD; IES = Intuitive Eating Scale (possible score range 1 – 5); ecSI 2.0 ™ = preliminary Finnish translation of Satter Eating Competence Inventory 2.0 (possible score range for the total score 0 – 48, Eating Attitudes and Contextual Skills 0 – 15, Food Acceptance and Internal Regulation 0 – 9); TFEQ-R18 = The Three-Factor Eating Questionnaire-R18 (possible score range 0 – 100); HTAS = Health and Taste Attitude Scales (possible score range 1 – 7); REBS = Regulation of Eating Behavior Scale (possible score range 1 – 7). Higher scores represent higher amount of the feature in all scales. There were missing values of one (n=1) participant in the Mobile group at week 36 and of three participants (n=3) in the Control group at weeks 10 and 36.

[a] p-value for differences in changes between the three study groups using all measured time points (study weeks 00, 10, and 36) adjusted for study center and starting time using estimated parameters (hierarchical linear model, Wald test). Bold text indicates significant p-value <0.05.

[b] Cohen's d from baseline to follow-up between the Face-to-face and Control groups (above) and between the Mobile and Control groups (below) using estimated parameters.

[c] Cohen's d from baseline to follow-up within the group using estimated parameters.
[d] After adding baseline value to the adjustments, $p=0.088$.
[e] After adding baseline value to the adjustments, $p=0.569$.

Table 12. The effects of ACT-based Face-to-face and Mobile interventions on diet (*Study III*).

	Face-to-face				**Mobile**				**Control**				p[a]	d[b]
	0 wk	**10 wk**	**36 wk**	**d[c]**	**0 wk**	**10 wk**	**36 wk**	**d[c]**	**0 wk**	**10 wk**	**36 wk**	**d[c]**		
Diet quality and alcohol use														
IDQ score[d]	10.3 ± 2.1	10.8 ± 2.2	11.1 ± 2.2	0.25	10.5 ± 2.0	10.8 ± 2.4	10.8 ± 2.0	0.14	10.2 ± 2.1	10.4 ± 2.3	10.9 ± 1.8	0.33	.471	-0.05 -0.19
AUDIT-C score[e]	3.4 ± 2.2	2.7 ± 2.1	2.7 ± 2.0	-0.24	3.9 ± 2.2	3.4 ± 2.2	3.4 ± 2.4	-0.24	4.0 ± 2.5	3.9 ± 2.5	3.6 ± 2.4	-0.15	.147	-0.07 -0.07
Intake of energy nutrients[f]														
Energy (MJ)	8.3 ± 1.9	7.7 ± 2.2	7.5 ± 2.1	-0.36	7.9 ± 2.1	7.9 ± 2.5	7.9 ± 2.2	-0.01	8.5 ± 2.7	8.7 ± 2.5	8.2 ± 2.4	-0.11	.148	-0.19 0.10
Protein (E%)	17.3 ± 4.2	19.0 ± 6.9	19.0 ± 5.0	0.37	18.0 ± 3.7	18.5 ± 5.1	19.3 ± 6.6	0.28	17.9 ± 4.4	17.6 ± 4.4	17.2 ± 5.0	-0.13	.173	0.48 0.35
Total fat (E%)	37.7 ± 8.5	35.5 ± 7.7	36.9 ± 6.9	-0.07	38.2 ± 8.1	37.5 ± 7.8	37.2 ± 6.5	-0.14	36.2 ± 7.6	37.9 ± 6.4	37.4 ± 7.3	0.14	.215	-0.20 -0.27
Saturated fat (E%)	13.3 ± 4.0	12.6 ± 3.8	12.7 ± 2.9	-0.17	13.8 ± 3.7	13.8 ± 4.4	13.3 ± 3.6	-0.14	13.4 ± 3.9	13.8 ± 3.2	13.3 ± 3.2	-0.04	.686	-0.15 -0.09
Monounsaturated fat (E%)	13.4 ± 3.8	12.2 ± 3.1	13.1 ± 3.4	-0.06	13.2 ± 3.1	13.0 ± 3.2	12.8 ± 2.7	-0.12	12.1 ± 3.3	12.9 ± 2.7	12.9 ± 3.3	0.23	.102[g]	-0.26 -0.35
Polyunsaturated fat (E%)	6.5 ± 2.1	6.0 ± 1.8	6.5 ± 1.8	0.04	6.5 ± 2.2	6.2 ± 2.1	6.3 ± 1.8	-0.06	6.2 ± 2.2	6.4 ± 2.3	6.5 ± 2.4	0.09	.530	-0.06 -0.15
Carbohydrate (E%)	41.3 ± 8.1	41.2 ± 7.2	40.3 ± 7.0	-0.17	39.4 ± 8.2	39.8 ± 8.0	39.6 ± 7.9	0.02	41.5 ± 7.2	40.4 ± 8.2	40.7 ± 7.8	-0.11	.810	-0.06 0.12
Sucrose (E%)	9.3 ± 5.3	9.4 ± 4.6	9.5 ± 4.9	0.03	8.9 ± 4.0	8.0 ± 4.1	8.4 ± 3.8	-0.14	9.5 ± 5.6	9.4 ± 4.7	8.8 ± 4.3	-0.14	.411	0.18 0.01
Fiber (g)	22.3 ± 7.7	20.1 ± 6.7	20.3 ± 7.9	-0.31	21.5 ± 7.9	20.7 ± 7.9	20.7 ± 7.9	-0.11	24.6 ± 11.6	22.3 ± 8.6	22.3 ± 8.1	-0.24	.578	-0.07 0.11
Fiber (g/MJ)	2.7 ± 0.8	2.7 ± 0.9	2.7 ± 0.8	0.01	2.8 ± 0.9	2.8 ± 1.0	2.7 ± 0.9	-0.11	2.9 ± 1.1	2.6 ± 0.8	2.8 ± 1.0	-0.12	.171	0.13 0.01

Notes: Values are unestimated mean ± SD; IDQ = Index of Diet Quality (possible score range 0 – 15); AUDIT-C = three alcohol consumption questions from the Alcohol Use Disorders Identification Test (possible score range 0 – 12); E% = percentage of energy.

[a] p-value for differences in changes between the three study groups using all measured time points (study weeks 00, 10, and 36) adjusted for study center and starting time using estimated parameters (hierarchical linear model, Wald test).

[b] Cohen's d from baseline to follow-up between the Face-to-face and Control groups (above) and between the Mobile and Control groups (below) using estimated parameters.

[c] Cohen's d from baseline to follow-up within the group using estimated parameters.

[d] n=61 in the Face-to-face group at week 10, and n=66 in the Control group at week 36.

[e] n=66 in the Control group at week 36.

[f] n=74 in the Mobile group at week 10.

[g] After adding baseline value to the adjustments, p=0.207.

5.4 EFFECTS OF ACT INTERVENTION ON STRESS AND INFLAMMATION BIOMARKERS (*STUDY IV*)

In the three study groups during the entire study period (study weeks 00, 10, and 36), a group x time interaction was found in hsCRP but not in other biomarkers (Table 13). The hsCRP decreased significantly in the Face-to-face group from week 00 to week 36 (p=0.045 in the post hoc test) and from week 10 to week 36 (i.e. the post-intervention period; p=0.014). The hsCRP was lower among the participants in the Face-to-face group in comparison with the Mobile group at the week 36 (p=0.035) with a small-to-medium effect size (r = -0.196, p=0.035). The intervention effect was not dependent on baseline BMI (group x time x baseline BMI interaction non-significant for all stress and inflammation biomarkers).

After adjusting further for age, sex and baseline BMI, the difference in hsCRP between the Face-to-face and Mobile groups at week 36 was no longer quite statistically significant; instead only a trend (p=0.062, in the post hoc test) was detected. However, the within-group decrease from week 00 to week 36 (p=0.048) and from week 10 to week 36 (i.e. the post-intervention period; p=0.014) remained significant in the Face-to-face group.

Table 13. The effects of ACT-based Face-to-face and Mobile interventions on stress and inflammation biomarkers (*Study IV*).

	Face-to-face			**Mobile**			**Control**			**p[a] (group x time)**
	0 wk n=64	**10 wk n=57**	**36 wk n=55**	**0 wk n=67**	**10 wk n=64**	**36 wk n=62**	**0 wk n=61**	**10 wk n=58**	**36 wk n=57**	
hsCRP (mg/L)[b]	1.2 (0.6 – 2.3)	1.5 (0.5 – 2.6)	1.2 (0.4 – 2.0)	1.6 (0.5 – 3.7)	1.6 (0.9 – 2.7)	1.7 (0.8 – 3.3)	1.5 (0.5 – 3.0)	1.4 (0.6 – 2.9)	1.5 (0.6 – 3.3)	**.012**
IL-1Ra (pg/mL)[b]	356.5 (258.8 – 528.1)	383.6 (263.3 – 522.3)	301.1 (248.5 – 425.5)	366.6 (265.9 – 607.8)	366.1 (258.3 – 559.4)	333.1 (246.5 – 482.1)	417.1 (277.2 – 572.8)	387.0 (281.7 – 594.8)	367.1 (292.5 – 526.3)	.883
HMW-adiponectin (µg/mL)[b]	4.9 (2.8 – 7.3)	4.9 (3.2 – 6.7)	5.1 (2.8 – 7.8)	5.0 (3.3 – 7.8)	4.7 (3.3 – 7.1)	4.8 (3.0 – 7.4)	4.8 (3.1 – 6.7)	4.7 (3.0 – 6.9)	4.8 (3.0 – 7.1)	.353
Cortisol (ng/mL)	115.6 ± 45.9	109.7 ± 39.2	117.3 ± 42.6	123.1 ± 47.9	117.3 ± 42.5	118.5 ± 39.0	108.9 ± 35.8	116.1 ± 41.4	119.2 ± 40.3	.272
DHEAS (ng/mL)	982.3 ± 518.4	969.1 ± 468.5	952.7 ± 495.0	1013.7 ± 540.0	1015.1 ± 547.2	997.3 ± 493.4	939.4 ± 424.6	951.7 ± 440.6	908.3 ± 440.6	.887
Cortisol/DHEAS ratio[b]	0.12 (0.09 – 0.19)	0.12 (0.08 – 0.17)	0.13 (0.07 – 0.20)	0.12 (0.08 – 0.19)	0.12 (0.08 – 0.18)	0.13 (0.08 – 0.20)	0.12 (0.09 – 0.16)	0.13 (0.09 – 0.16)	0.13 (0.10 – 0.21)	.129

Notes: The values are unestimated medians (inter-quartile range) / means ± SD. hsCRP = high-sensitivity C-reactive protein, IL-1Ra = Interleukin-1 receptor antagonist, HMW = high molecular weight, DHEAS = dehydroepiandrosterone sulfate. There were no statistically significant differences (p values>.186) in the baseline values between the groups.

[a] p-value for differences between the three study groups using all measured time points (study weeks 00, 10, and 36) analyzed with linear mixed model adjusting for study center and starting time.

[b] Analyzed with logarithmic transformed values. Values presented in the table are non-transformed.

5.4.1 Associations of psychological wellbeing, physiological health, and lifestyle factors (*Study IV*)

To explore the associations between psychological wellbeing with inflammation and stress biomarkers, as well as considering if there was a relationship with clinical and lifestyle factors related to low-grade inflammation, post-hoc, exploratory PCA analyses were conducted to assess (a) the variables measured at baseline and (b) the changes occurring during the entire study period.

At baseline

Six principal components (PC) emerged explaining a large proportion of variation (61%) of the baseline data (Table 14). PC1 represented poor mental well-being; PC2 metabolic syndrome; PC3 age and diet; PC4 metabolic syndrome, weight-related psychological inflexibility and dieting; PC5 diet quality; and PC6 physical activity (Table 14). With respect to the inflammation and stress biomarkers, higher IL-1Ra and lower HMW-adiponectin were present with the higher BMI and higher waist circumference in PC2. A lower DHEAS level was present with higher age, higher diet quality index and higher fiber intake in PC3. In addition, higher hsCRP concentrations were present with lower weight-related psychological flexibility, higher BMI, higher body fat percent, and lower energy intake in PC4.

Changes during the entire study period

Five principal components (PC) emerged explaining half of the variation (51%) of the data regarding changes during the entire study period (Table 14). PC1 represented a change in poor mental well-being; PC2 a change in weight-related psychological inflexibility and metabolic syndrome; PC3 a change in inflammation and diet; PC4 age and a change in weight-related psychological flexibility and DHEAS; and PC5 a change in psychological distress and physical inactivity (Table 14). Of the inflammation and stress biomarkers, a decrease in the HMW-adiponectin level was present with decreased weight-related psychological flexibility, increased BMI, increased waist circumference, and increased body fat percent in PC2. Increased hsCRP was present with increased energy intake, increased saturated fat intake, and decreased fiber intake in PC3. In addition, elevated DHEAS levels were present with older age at baseline and with an increase in weight-related psychological flexibility in PC4.

Table 14. Principal component analyses (PCA) of psychological wellbeing and stress and inflammation biomarkers, considering also clinical and lifestyle factors related to low-grade inflammation at baseline (n=204) and of the changes during the entire study period (n=173). The components were rotated using orthogonal (varimax) rotation (*Study IV*).

Baseline							**Change (week 36 – 00)**					
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**		**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Age	0.005	-0.046	**0.746**	-0.081	-0.053	-0.172	Age (baseline)	0.131	0.150	-0.099	**0.486**	-0.107
GHQ	**0.620**	0.031	0.096	-0.256	0.125	0.172	GHQ Δ36	**0.694**	0.009	-0.020	0.089	**0.268**
PSS	**0.777**	-0.017	-0.081	-0.026	0.064	-0.164	PSS Δ36	**0.789**	0.062	-0.057	0.034	-0.011
BDI-II	**0.799**	-0.009	0.042	-0.054	0.211	0.042	BDI-II Δ36	**0.680**	0.024	0.129	0.121	0.067
AAQ-II	**0.789**	-0.027	-0.038	0.056	-0.053	-0.226	AAQ-II Δ36	**0.686**	0.037	-0.026	-0.028	-0.128
AAQW	**0.515**	0.109	-0.164	**0.339**	-0.049	-0.293	AAQW Δ36	**0.520**	**0.307**	-0.035	**-0.253**	0.051
BMI	0.038	**0.773**	0.038	**0.311**	0.153	0.079	BMI Δ36	0.129	**0.976**	0.110	0.000	0.007
Waist circumference	0.070	**0.907**	0.085	-0.064	0.048	-0.205	Waist circumference Δ36	0.182	**0.739**	0.065	0.129	0.140
Body fat%	0.034	0.246	0.296	**0.849**	0.224	0.133	Body fat% Δ36	0.030	**0.644**	0.057	0.224	0.129
hsCRP	-0.175	0.263	-0.107	**0.358**	0.062	-0.01	hsCRP Δ36	-0.063	0.196	**0.274**	0.146	0.119
IL-1Ra	-0.047	**0.332**	-0.14	0.122	0.001	0.157	IL-1Ra Δ36	0.106	-0.016	-0.040	0.004	0.201
HMW-adiponectin	-0.022	**-0.309**	0.285	0.206	0.068	0.014	HMW-adiponectin Δ36	0.022	**-0.280**	-0.015	0.056	0.080
Cortisol	0.023	-0.005	-0.063	-0.169	0.024	0.108	Cortisol Δ36	-0.084	0.027	0.094	0.239	0.059
DHEAS	0.023	0.032	**-0.566**	-0.207	0.059	0.014	DHEAS Δ36	-0.008	-0.086	0.016	**0.413**	-0.006
IDQ	-0.056	0.068	**0.408**	-0.080	**-0.333**	0.288	IDQ Δ36	-0.113	0.007	-0.169	0.086	0.214
AUDIT-C	0.137	-0.021	-0.008	-0.086	0.080	-0.231	AUDIT-C Δ36	0.077	0.117	-0.054	0.189	-0.041

(Continued)

Table 14, continued

Baseline							Change (week 36 – 00)					
	PC1	PC2	PC3	PC4	PC5	PC6		PC1	PC2	PC3	PC4	PC5
Energy intake (kJ)	-0.001	0.006	0.021	**-0.399**	0.131	-0.025	Energy intake Δ36	-0.059	0.045	**0.450**	-0.150	-0.025
SAFA intake (E%)	0.169	0.075	-0.035	-0.092	**0.618**	-0.110	SAFA intake Δ36	0.047	0.060	**0.804**	0.207	0.078
Fiber intake (g/MJ)	-0.025	-0.094	**0.414**	0.026	**-0.526**	0.094	Fiber intake Δ36	-0.046	-0.003	**-0.473**	0.022	0.203
MET	-0.062	-0.027	-0.137	-0.188	-0.249	**0.378**	MET Δ36	-0.018	-0.091	-0.065	0.162	**-0.657**

PC = Principal component; GHQ = 12-item General Health Questionnaire; PSS = 14-item Perceived Stress Scale; BDI-II = Beck Depression Inventory-II; AAQ-II = Acceptance and Action Questionnaire (higher score indicate less general psychological flexibility); AAQW = Acceptance and Action Questionnaire for Weight-Related Difficulties (higher score indicate less weight-related psychological flexibility); BMI = body mass index; hsCRP = high-sensitivity C-reactive protein; IL-1Ra = interleukin-1 receptor antagonist; HMW = high molecular weight; DHEAS = dehydroepiandrosterone sulphate; IDQ = Index of Diet Quality; AUDIT-C = Alcohol Use Disorders Identification Test Consumption; SAFA = saturated fat; E% = percentage of energy; MET = Leisure-time metabolic equivalent index.

6 DISCUSSION

6.1 PRINCIPAL FINDINGS

The results of this doctoral thesis indicate that among adults with psychological distress and overweight/obesity, higher perceived stress is associated with unfavorable eating behavior but not with actual dietary intake whereas a better physiological HRV-based sleep-time recovery is associated with better diet quality and not as widely with eating behavior. Furthermore, the psychological ACT intervention used in this study can improve eating behavior but does not seem to affect either dietary intake or the levels of physiological stress and inflammation biomarkers. The main results are presented in Figure 7.

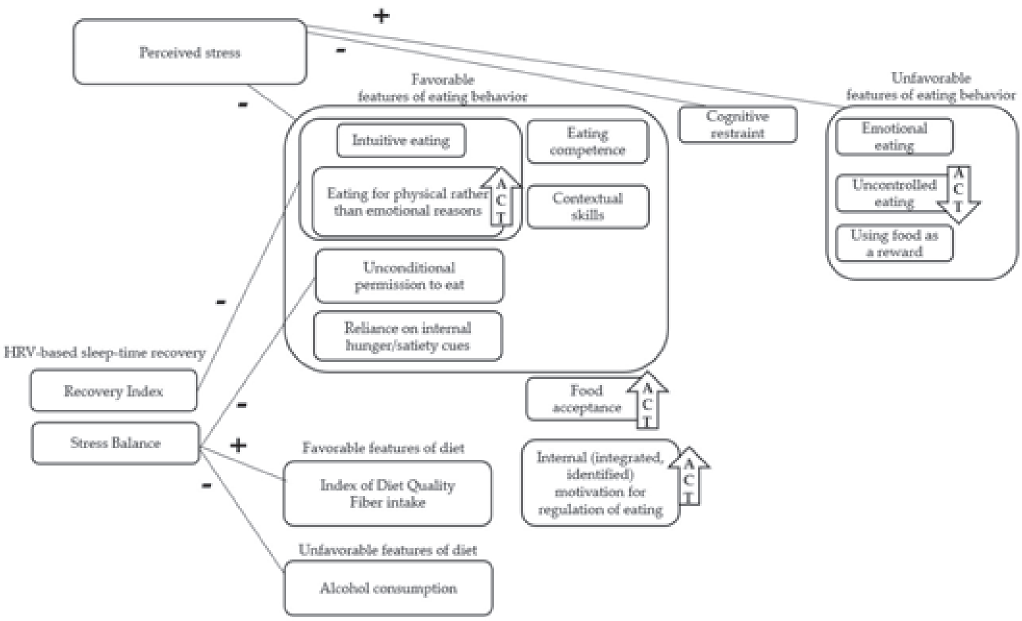

Figure 7. The main statistically significant results of the thesis. Only the statistically significant associations and intervention effects (compared to control) are presented. The mark – / + denotes negative / positive cross-sectional association. The arrow up or down denotes positive or negative effect of the Acceptance and Commitment Therapy (ACT) intervention compared to a control. HRV = heart rate variability, Recovery Index = magnitude of the recovery reactions, Stress Balance = recovery-stress ratio.

In comparison to the theoretical basis and the aims of the thesis presented in Figure 4, no cross-sectional associations between perceived stress and diet were observed. In addition, the ACT intervention did not exert appreciable effects on diet or physiological stress and inflammation biomarkers as compared to control. However, ACT delivered in the Face-to-face group decreased hsCRP, although the difference was seen only in comparison to the Mobile group. In the exploratory principal component analysis, psychological wellbeing did not associate widely with stress and inflammation biomarkers, body composition, and lifestyle factors. Only weight-related psychological flexibility was present in the same principal components with body composition, some biomarkers (hsCRP, HMW-adiponectin or DHEAS), and energy intake.

6.2 ASSOCIATIONS OF STRESS AND RECOVERY WITH EATING BEHAVIOR AND DIET (*STUDY I, II*)

6.2.1 Stress and recovery associated with eating behavior

Previous studies reporting associations between perceived stress and eating behavior have focused on uncontrolled eating, emotional eating, and cognitive restraint. The present results are in line with the previous studies reporting associations between chronic or perceived stress and higher uncontrolled [113,156] and emotional eating [113,156,158]. In addition in our study, a higher perceived stress associated with a higher tendency to use food as a reward, which also supports the interactions between stress, food, and emotions.

Previous studies on perceived stress and cognitive restraint have not found significant associations between these two factors [156,157]. In the present study, higher perceived stress associated with lower cognitive restraint. However, after adjusting for the aim to lose weight, the association no longer remained statistically significant. This is quite logical, because this aim of losing or maintaining weight is, by definition, associated with cognitive restraint of eating [104] and the study participants with the highest level of perceived stress were less likely to be aiming to lose weight. This finding may suggest that those persons with highest perceived stress were so burdened that they were unable to actively aim to lose weight.

To the best of our knowledge, this is the first study to investigate the associations between perceived stress and the favorable features of eating behavior, i.e., intuitive eating and eating competence. The results are in line with the findings related to uncontrolled and emotional eating. The participants with higher perceived stress were less likely to eat and drink intuitively, i.e., according to their inner feelings of hunger and satiety. Instead, their eating was more likely to be triggered by emotions and external cues. Indeed, chronic stress affects interoception (i.e., the perception of bodily processes, such as sensing information from the receptors of visceral organs)

[253] but how it relates to eating remains unclear. In addition, the results showed that higher perceived stress associated with lower eating competence and especially lower contextual skills were indicative of several negative traits e.g. irregular meal timing, not planning for meals, and less concentrating on food while eating. This may reflect the time constraints often related to the stressful life situations.

Surprisingly, the physiological HRV-based sleep-time recovery was not as widely associated with different features of eating behavior as the perceived stress. A better sleep-time recovery was associated with lower intuitive eating, which seems to be in line with the previous, although limited, literature: a higher HRV was also associated with lower unconditional permission to eat in a small sample (n=39) of university students [162]. Lower unconditional permission to eat reflects some restrictions on one's eating and may thus indicate a higher self-regulation capacity. A higher HRV has been shown to indicate higher emotional regulation [254] and self-control (although the meta-analysis showed that because of the publication bias, the association may not be significant) [255]. However, in the present study, sleep-time HRV was not associated with cognitive restraint and uncontrolled eating, factors which have been previously associated with HRV [159,161,163].

To conclude, the results of this thesis support the previous findings that higher perceived stress is associated with eating behavior not being in control of one's self and driven by emotions. The previous knowledge is also extended with the results that higher perceived stress is associated with both lower intuitive eating and eating competence. The eating behavior associated with higher perceived stress may lead to poorer diet quality and unsuccessful weight management. Higher sleep-time recovery was, surprisingly, also associated with lower intuitive eating. This may reflect higher self-regulation among participants with better sleep-time recovery.

6.2.2 Stress and recovery associated with diet

The hypothesis that higher perceived stress would be related to poorer diet was not confirmed: perceived stress was not associated with the diet quality index, alcohol consumption, and energy nutrient intake. Although in the published literature, perceived stress has been associated with higher consumption of energy-rich foods and snacks [155,158,164], the association with diet quality indices and energy nutrient intake has been more inconsistent. The conflicting results may be due to differences in the study samples or in the different ways to measure stress, dietary indices, and nutrient intake. The failure to detect a significant association between perceived stress and energy nutrient intake or diet quality indices in the present study is in line with the previous studies conducted in older adults [164], low-income mothers [156], and healthy adults [168].

Some methodological aspects should be pointed out here, although the assessments will be discussed more thoroughly later. It may be that the measures used to assess dietary intake were not capable of detecting stress-related eating. Due to practical reasons, Fridays and Saturdays were not included in the energy nutrient intake data which may have influenced our results. Energy intake typically increases on weekends [256,257]. Among working-aged people, chronic stress may increase eating after the workweek, on Friday evening and Saturday. Furthermore, this kind of stress-related overeating may be compensated by eating less or paying more attention to the food quality during weekdays, which can explain the findings of this thesis. Nevertheless, the present results showed that perceived stress was not associated with energy nutrient intake during mostly weekdays or with long-term diet quality and alcohol consumption. To the best of our knowledge, a weekday-weekend fluctuation has not been studied in stress-driven eating. However, no differences have been observed between weekdays and weekend days in the associations between perceived stress and hunger [258] or between the number of daily hassles and the number of snacks consumed [259] among students. In addition, misreporting may have had an influence on the results of this thesis. Especially people with obesity tend to underreport consumption of snack-type foods [260], which are particularly consumed when the individual is feeling stressed [155,261,262]. Finally, approximately every third person will eat less than usual when stressed [262,263], but we did not have information on how many participants in this study population reacted to perceived stress by decreasing eating and if so, to what extent. All these aspects demonstrate how challenging it is to investigate the association between perceived stress and dietary intake especially among people with overweight/obesity.

On the contrary to the perceived stress, a higher sleep-time recovery was associated with a better diet quality, a higher fiber intake, and a lower alcohol consumption. These results are well in line with the previous, although scarce, literature in which higher HRV has been associated with a healthier dietary pattern, i.e., Mediterranean diet, [171], higher intake of green leafy vegetables [170], and overall diet quality [159]. Thus, relaxation and recovery may serve as an antidote to stress-related unhealthier eating as already suggested [154]. However, this did not appear to be true in the current study population, as the associations between recovery and diet differed from the associations between perceived stress and diet, i.e., there was a lack of any associations.

Higher alcohol consumption during the previous six months was associated with weaker sleep-time recovery. This is in line with the studies in which the acute effect of alcohol consumption has been investigated. Alcohol intake is known to impair sleep-time HRV-based recovery on the following night [72,73].

To conclude, the results of this thesis support the inconsistency of the previous literature on associations between perceived stress and diet quality and nutrient intake and highlight the importance of the methods applied to test the relationships. Furthermore, the present results add to the initial findings that there is a link between sleep-time physiological recovery and better diet quality.

6.2.3 The linkages between eating behavior and diet

This thesis was based on the assumption that certain features of eating behavior lead to certain kinds of dietary intake. Although the combinations of different features of eating behavior or the relationships between the features of eating behavior and diet were not investigated here, two questions emerge from the results of this thesis: (1) What are the actual correlations between the different features of eating behavior? and (2) How are the different features of eating behavior related to dietary measures among adults with psychological distress and overweight/obesity?

The different features of eating behavior, and the questionnaires to measure these features, have been developed independently from each other. Thus, some of them seem to be overlapping or opposite by their definition: such as Reliance on internal hunger/satiety cues (a subcomponent of intuitive eating) and Internal Regulation (a subcomponent of eating competence), or Unconditional Permission to Eat (a subcomponent of intuitive eating) and Cognitive Restraint. To our surprise, the results in this thesis did not suggest that these features of eating behavior would act in line with these assumptions. For example, participants with higher perceived stress reported less reliance on internal hunger/satiety cues but reported similar levels of internal regulation as participants with lower perceived stress.

Furthermore, although perceived stress was associated with uncontrolled and emotional eating, which in turn have been associated with non-beneficial food choices [105,106] and higher energy intake [104], no significant associations between perceived stress and diet quality or energy nutrient intake were found. This may be partially because of the dietary assessment methods used. For example, emotional eating may lead to overeating [264], but the overeating occasions may not have occurred during the period of the 48-h dietary recall or involved the food items inquired in the IDQ questionnaire.

Another important aspect is the assumption concerning the timeline. As these were cross-sectional analyses, it is not possible to draw conclusions about the temporal sequence between stress, recovery, eating behavior, and diet. However, based on the results, it can be assumed that perceived stress leads to unfavorable eating behavior (which in turn may lead to an unfavorable diet, although this was not found in the present study). Thus, the sequence may be perceived stress → eating behavior (→ diet). The associations regarding sleep-time recovery were different i.e. they were not widely associated with features of eating behavior but instead with features of diet. These results may suggest that a higher diet quality leads to a better sleep-time recovery. Some randomized controlled trials have already shown that diet (i.e., regular fatty fish consumption and fish-oil supplementation) can increase HRV [172,173]. Further experimental and intervention research will be needed to elucidate the causalities between stress, recovery, eating behavior, and diet.

6.2.4 Intuitive eating as a contradictory phenomenon

Intuitive eating is considered as a favorable feature of eating behavior and it is associated with e.g. lower BMI [12,120,122-132] and several measures of psychological well-being [12,120,126,127,130]. However, the results of this thesis indicate that intuitive eating is a complex and controversial phenomenon among adults with psychological distress and overweight/obesity. The participants with the highest perceived stress scored lowest in intuitive eating, which was also in line with scoring highest in uncontrolled eating and emotional eating, and scoring lowest in another favorable feature of eating behavior (i.e., eating competence). Surprisingly, also participants with highest sleep-time recovery scored lowest in intuitive eating. In addition, they had the highest diet quality and the lowest alcohol consumption. Could this mean that in order to have a better diet quality, lower intuitive eating (i.e., having some restrictions in one's eating and not eating based on hunger and satiety cues) is needed? This may be only specific to this kind of population, i.e., adults with psychological distress and overweight/obesity, the majority of whom are aiming to lose weight. The relationship between intuitive eating and food intake is still unclear and has not been extensively studied. It is also unclear how well did the study participants understand the questions related to intuitive eating because they were not likely to be familiar with this concept. The association between intuitive eating and dietary measures may be different depending on how familiar the respondents are with the concept [137].

6.3 EFFECTS OF ACT INTERVENTION ON EATING BEHAVIOR, DIET, AND BIOMARKERS OF STRESS AND INFLAMMATION (*STUDY III, IV*)

6.3.1 The effects of ACT on eating behavior

Meta-analyses have shown that third-wave behavioral interventions (mostly mindfulness-based interventions) have the potential to reduce unfavorable eating behavior [193,194,265]. It has also been evident that the effect, although statistically significant, has been smaller in RCTs than in non-controlled studies [193]. This thesis expands the knowledge of the effects of mindfulness-based interventions to the effects of a broader, ACT-based intervention on eating behavior in a randomized controlled study design.

Previous ACT- and mindfulness-based randomized controlled trials have described decreases in several forms of uncontrolled eating among adults with overweight/obesity [196-198,201] and adults with problematic eating behavior [202] as was also seen in the present study. However, not all previous controlled studies have detected an effect on eating behavior reflecting uncontrolled eating [203,204].

We observed a statistically significant increase in eating for physical rather than emotional reasons, a decrease in using food as a reward, and a marginally significant decrease in emotional eating as measured with TFEQ-R18. This can be interpreted that ACT can decrease eating for emotional reasons. This is in line with the decrease seen in reward-based eating among adults with obesity [199] and the decrease in emotional eating among adults with problematic eating behaviors [202] and among adults with overweight/obesity but not binge eating [198] examined in controlled study designs. However, not all previous studies have detected an effect on emotional eating as compared to either passive or active control group [201,203,205,208].

In the present study, there was no effect on cognitive restraint, which is in line with a previous study of a mindfulness-based eating intervention among adults with overweight/obesity [201]. On the contrary, an increase in cognitive restraint was seen in another study of mindfulness-based eating intevention among adults with overweight/obesity who were binge eating and concerned about their weight [197]. It can be debated whether ACT- and mindfulness-based interventions should increase or decrease cognitive restraint, which is a controversial feature of eating behavior. On the one hand, restricting one’s eating is not in accordance with the principles of mindful eating. On the other hand, restricting one’s eating to lose or maintain weight may be viewed as a behavior according to one’s internal goals and values.

To the best of our knowledge, there are no previous controlled studies on the effects of mindfulness or ACT interventions on intuitive eating, eating competence, and forms of motivation for eating regulation. ACT improved the subcomponents of all of them: eating for physical rather than emotional eating, food acceptance, and internal motivation to eat in a healthier way. These results are consistent with the ACT theory. However, there was no effect on total scores of intuitive eating and eating competence. This may be because the intervention was not designed to specifically target these features of eating behavior. In the previous non-RCT mindfulness interventions with a special emphasis on intuitive eating, all subcomponents of intuitive eating were improved [206,207].

In this study, the ACT intervetion was not specifically targeted to eating behavior, dietary changes or weight loss, but the intervention included a minor part of mindful eating. The results of this thesis suggest that a general ACT intervention with only a small part of mindful eating can improve eating behavior by converting the reasons for eating from emotional or environmental triggers towards internal hunger and satiety cues, increase the acceptance of a variety of foods, and help the individual to perceive healthy eating more consistently with his or her own values and goals. These results are consistent with the ACT theory and linked to all of the core processes of ACT. Furthermore, although perceived stress was associated with features of unfavourable eating behavior at baseline (*Study I*), ACT was able to change the eating behavior, and furthermore the baseline level of perceived stress did not influence the effectiveness of the ACT intervention (*Study III*).

6.3.2 The effects of ACT on diet

The published literature of the effects of mindfulness-based interventions on dietary intake is very limited [266]. In previous interventions based on mindfulness and mindful eating, energy intake has decreased when compared to waiting-list controls among healthy peri-menopausal women [205], but among women with overweight/obesity, energy intake was decreased in both the intervention and waiting-list control groups [211]. However, our general ACT intervention did not cause any changes in energy intake. The participants of our study were free to utilize ACT intervention in the way they wanted, and it is not possible to estimate how many had applied or even tried to apply the ACT intervention to dietary changes. Furthermore, on average the participants' diet quality index scores were at a level already indicating a health-promoting diet [240] at the baseline, and thus there was no room for drastic improvement during the intervention. It is also possible that the effects on diet would have required a longer intervention period, or a longer follow-up period.

The intervention content seems to be important when assessing the effectiveness of mindfulness and ACT interventions on dietary changes. For example, a mindfulness-based intervention targeting the consumption of salty snack foods did decrease their intake as compared to controls who only received general information [210].

Although the ACT intervention in the present study exerted several beneficial effects on eating behavior, there were no parallel effects on diet quality, alcohol consumption, and energy nutrient intake. In contrast to our finding, two previous mindfulness-based RCTs have reported changes in both eating behavior and actual food intake. Among adults with obesity, a mindfulness-based intervention increased mindful eating as compared to a control group and after the intervention, the control group increased their consumption of sweet foods and desserts as compared to the intervention group [200]. In another study among healthy peri-menopausal women who were eating out frequently, a mindful restaurant eating intervention increased diet-related self-efficacy and decreased energy and fat intake as compared to a control group [205]. The reason for different results may be in the contents of the interventions. The previous interventions had a strong emphasis on certain food choices and weight management [200,205] whereas our intervention did not include nutritional counseling or information on food choices or weight management. We only provided a hyperlink to a public nutritional web site which could be utilized if dietary changes were included in the individual's personal goals. Furthermore, the ACT intervention in the Elixir study focused on psychological processes and overall behavior changes. In order to detect changes in diet, the participants may have required more nutrition education and more time to implement the changes into their everyday lives. It is also important to notice that on average the participants' diet was already at a health-promoting level at the beginning of the intervention, based on the scores of the Index of Diet Quality [240].

6.3.3 The effects of ACT on stress and inflammation biomarkers

Meta-analyses have found evidence that mindfulness and meditation interventions decrease circulating levels of some inflammation markers and measures of physiological stress [212,213]. Previous studies have focused on stress reduction/management [212,213], whereas our study utilized a broader ACT intervention targeting several psychological processes. Thus, this seems to be the first ACT-based randomized controlled intervention study which has investigated the effects on hsCRP, IL-1Ra, HMW-adiponectin, morning cortisol, DHEAS, and cortisol/DHEAS ratio in a non-clinical adult sample in a real-life setting.

Our results indicate that an ACT intervention delivered in face-to-face group sessions seemed to exert some beneficial effect on hsCRP whereas there were no effects on the other studied markers of low-grade inflammation (i.e., IL-1Ra and HMW-adiponectin) and markers of stress (i.e., cortisol and DHEAS). Over a third (36%) of the participants had a low hsCRP level (< 1 mg/L) already at baseline making it difficult to observe a large intervention effect. However, as hsCRP increases the risk for cardiovascular disease linearly [267], any decrease in hsCRP is beneficial.

The previous literature of mindfulness-based RCTs in non-clinical study populations in this area of research is still limited. The intervention effect on hsCRP is partly similar to the previous mindfulness-based RCTs. No significant effect compared to control was observed among adults with obesity [215,219], and among healthy older adults hsCRP decreased only marginally significantly compared to control [218].

The lack of an effect on morning cortisol levels is also in line with previous mindfulness-based interventions in non-clinical samples i.e. they detected no effect on serum morning cortisol [201], single time point cortisol level (from 11 a.m. to 8 p.m.) [214], and cortisol levels at different time points during the day [215,216].

This is the first study to report the effects of mindfulness or ACT intervention in a non-clinical RCT setting on the levels of DHEAS, IL-1Ra and adiponectin. Similar to the results of this thesis, also previous non-controlled mindfulness intervention studies found no effect on DHEAS levels among cancer patients [220] or adiponectin levels among people with obesity [222] and among bariatric post-surgery patients [223]. However, the numbers of participants were very small in these previous non-controlled studies and thus no conclusions of the effectiveness of mindfulness or ACT on DHEAS, IL-1Ra and adiponectin can be drawn.

When interpreting the results of our study, it is important to remember that the ACT intervention was not designed to specifically target physiological stress biomarkers or low-grade inflammation. However, in view of the previous literature one can hypothesize that affecting psychological well-being and allostatic load could be ways to improve also physiological well-being [3,26,33,77].

6.3.4 The mind-body connection

It can be stated that problems in psychological processes (e.g., psychological inflexibility) are closely related to behavior (e.g., poor diet and sedentary lifestyle leading to obesity) and subjective psychosocial distress (Figure 4). These factors (psychological processes, unhealthy behavior, obesity, and psychosocial distress) are linked to chronic low-grade inflammation and a chronic physiological stress response [6,26,89]. These physiological processes, in turn, are a risk for future ill health and major chronic diseases [7,8,77]. Because the psychological and physiological factors are intertwined, post-hoc, exploratory analyses with PCA were conducted to assess whether psychological flexibility would associate with psychological and physiological wellbeing in this study population. Surprisingly, the mind and body did not seem to be tightly connected. Most of the variance of the data was explained by the psychological variables alone. Only weight-related psychological flexibility was associated with some of the inflammation and stress biomarkers in the principal components. This may be explained by the fact that weight-related psychological flexibility is more of a "bodily" measure as by definition, it is closely associated with body weight and BMI [183]. However, in terms of the PCA analyses, it is important to notice that some of the loadings of the rotated components were rather low, and thus the results should be interpreted with caution.

In addition, the other results of the present thesis showed some division in terms of mind and body. Perceived stress, eating behavior, and psychological ACT intervention can be considered as representing the "mind" part in the thesis, whereas HRV-based recovery, actual dietary intake, and biomarkers of stress and inflammation represent the "body". In *Study I*, the "mind" factors were associated with each other (perceived stress was associated with eating behavior but not with dietary intake) whereas in *Study II*, bodily measures were associated (HRV-based recovery was associated with diet but not as widely with eating behavior). Furthermore, in *Studies III* and *IV*, the psychological ACT intervention affected the "mind" but not the "body" (effects on eating behavior but not on dietary intake or hardly any inflammation and stress biomarkers). The results of the intervention are actually in line with the primary aim of the Elixir study. The overall aim of the ACT intervention was to affect psychological processes, i.e. there were no aims set that the participants should undertake changes in diet or lose weight.

6.3.5 The intervention delivery via face-to-face versus a mobile app

Most of the previous mindfulness and ACT interventions have been based on group sessions, and this is the first study to examine the effects of a mobile app ACT intervention investigating eating behavior, diet quality, and circulating biomarkers. Mobile-based solutions are seen as promising because they may save time and costs in health care and be readily accessible to patients [21-24]. The ACT intervention content was the same in the two intervention arms of our study, but only the delivery method differed. The impact of face-to-face group sessions seemed to be larger than that observed in the mobile app intervention. The Face-to-face group intervention showed improvements in a wider range of features of eating behavior and showed a within-group improvement in low-grade inflammation. In addition, all of the effects in the Mobile group occurred during the intensive intervention period, i.e. there was an effect when the app was in active use. Among the study participants, there was a dose-response relationship between the usage and the change in psychological flexibility [228].

The responsibility for using the mobile app was based on the participants' own willingness and memory. The study was conducted in 2012 – 2013 when although having a mobile phone was commonplace, this was not the case for owning a smartphone with an internet connection. Thus, all participants received a smartphone with the preinstalled ACT mobile app but they used their own mobile phones in their daily lives. Thus, six years ago, the mobile app usage situation was rather different from what it would have been in 2019, when almost every working-aged person owns a smartphone with an internet connection and access to app stores. For example, one of the main factors associated with more active usage in the Elixir study was that the person did not own a smartphone [228].

Although the median duration of the mobile app usage was rather high (i.e., four and a half hours) and the mobile app was well accepted, on average, the participants in the Face-to-face group were more exposed to the treatment (i.e., seven hours). It is also possible that although the content of the ACT interventions was similar, the participants may have applied the intervention differently because participating in the group sessions demanded intensive attention to the contents of the intervention and may have focused their attention on certain of its contents.

Our results are in line with the finding that technology alone may not be as effective as an intervention including human interaction [268]. In addition, human support has been found to enhance the impacts of technology-based interventions [269-271]. In addition, among Finnish adults with depressive symptoms, a web-based ACT intervention with contacts with a coach was found to be effective not only when compared to non-treatment control but it was also as effective as face-to-face intervention [272,273]. Thus, although digital solutions may in general be thought to replace human interaction, it may be more beneficial to consider combining human contact with e- and mHealth solutions.

6.4 STRENGTHS AND LIMITATIONS

6.4.1 Study population and study design

The population of the present thesis consisted of the volunteer participants of the Elixir lifestyle intervention study [224]. This study population does not represent the general Finnish adult population. For example, the proportions of females (83 – 85% vs 51%), university educated (43% vs 22%), and obesity (64% vs 28% in females and

26% in males) are higher in the study population than in the general Finnish population [10,274,275]. Furthermore, the gender distribution did not correspond to the distribution of overweight and obesity in the Finnish population, as being overweight is more prevalent in males than females although the prevalence of obesity is equal in both genders [10,276]. However, this is a unique study sample of working-aged adults with psychological distress and overweight/obesity seeking help for lifestyle changes. Thus, the study population represents treatment-seeking people with high risk of developing chronic non-communicable diseases, such as type 2 diabetes and cardiovascular diseases: people who are clients in general and occupational health care.

The large number of participants (n=297 in the cross-sectional and n=219 in the longitudinal analyses) is one strength of the study. Our intervention groups had 70-78 participants, and only a few previous ACT or mindfulness interventions have had more participants. The fact that the participants were from three different areas in Finland is also a strength. People living in the metropolian area of Helsinki may differ from people living in smaller cities in other parts of the country. Thus, the possible regional effect on the results is diminished, and the analyses were also adjusted for the study center. The proportion of females (83 – 85%) in the study was high. Most previous ACT and mindfulness intervention studies have had a similar proportion of females (80 – 98%) or all participants have been females. Because the number of male participants in our study was so low (9 – 13 per intervention group), females and males were analyzed as one group. There were no differences between the tertiles of perceived stress and recovery variables or intervention groups with regard to sex. Furthermore, adjusting the analyses for sex did not change the results. However, in the future, researchers should put more effort to recruit men into these kinds of studies so that we could gather more knowledge on eating behavior and the effects of ACT among men. Sex is also a factor affecting physiological stress responses [277]. Furthermore, because most participants were females and the participants' age ranged from 27 to 61 years (mean±SD was 49±8 years), a possible confounding factor not accounted for in the current analyses is the menstrual cycle and menopause. The phase of menstrual cycle and menopausal status affect HPA axis and ANS activity [278], and thus the hormonal status could be a factor to be taken into account in future analyses.

A randomized controlled study design makes it possible to compare the effects of ACT intervention with participants who did not receive any instructions but participated in the same measurements. An RCT is considered as the gold standard in investigating intervention effects [195]. Thus, the RCT setting is a major strength of this study. There are a very limited number of previous ACT-based RCT studies among non-clinical populations reporting effects on eating behavior, diet, and biomarkers of stress and inflammation, and thus this thesis adds valuable information to the previous literature. Due to practical reasons, the study was conducted in two phases: two seasonally different starting times of the study did, however, allow us to consider also the possible seasonal effect on the changes in measured variables.

The ACT intervention in the Elixir study was delivered by trained psychologists or via a mobile app created by the same research group. As this was a secondary data analysis, the intervention was not specifically designed for the present research questions and the analyses for intervention effects may be underpowered.

6.4.2 Assessment of stress and recovery

Several stress researchers have stated that stress is an ambiguously defined, complicated phenomenon [279] and requested researchers to rigorously define in their reports the "stress" they had studied. In this thesis, both subjective and objective measures were used for both psychological and physiological stress, and recovery, i.e. states which can be considered as a strength.

The 14-item Perceived Stress Scale, PSS-14 [230], was used as a subjective measure for psychological stress state concerning the previous month. It is a widely used questionnaire [231] to describe the level of stress that one experiences. For example, the assessment captures certain aspects of an individual's personality factors, coping resources, and all the previous events that still influence appraised stress, although it does not measure chronic stress as such [230]. The internal consistency (or internal reliability) of the questionnaire was high (Cronbach's alpha 0.88). The variation in PSS scores was rather large, although we had recruited participants with psychological distress. A different measure, the 12-item General Health Questionnaire, GHQ-12 [225], was used for screening because it has been shown to be a valid screening tool [229]. The internal consistency of also GHQ-12 was high (Cronbach's alpha 0.72 – 0.73).

In addition to the subjective stress, long-term recovery was measured in an objective manner. A sufficient recovery is crucial to avoid gaining allostatic load and minimizing the negative health effects of stress [3,4]. However, there are no uniform definition or measures for recovery [94]. In addition, the word recovery can be used to describe the situation of returning back to the initial level after several events (e.g., a single stress response, physical exercise, or a serious illness or injury). In the present thesis, the objective measure for physiological stress-recovery was based on HRV measured in real-life setting for several consecutive nights. HRV reflects the ANS activity and can thus inform whether parasympathetic activation is dominating [56,57,59,280], which should be the case during sleep. For example, the method is widely used among Finnish employees [71]. The use of a long-term HRV measurement during sleep is a strength compared to most of the previous studies in the field of eating behavior and diet, which have measured HRV in a short single recording period in laboratory [159,160,162,163,170].

In *Studies I-II*, perceived stress and HRV-based sleep-time recovery variables were analyzed in tertiles. This was conducted to compare participants with different levels of perceived stress or sleep-time recovery. For example, the association between parasympathetic activity and health may not be linear [281]. For Stress Balance, there is an interpretation present for the values (i.e., weak, moderate, and good recovery [66]), whereas for the PSS-14 scores and Recovery Index, there are no cut-off values for clinical or practical interpretation. Thus, these continuous variables were divided into tertiles. However, it can be debated whether some information is lost in categorizing a continuous variable or whether the cut-off points are optimal.

The objective measurement of physiological stress and inflammation biomarkers was the third level of stress assessment in the present thesis. Although this is a strength, evaluating the measured biomarker levels is challenging because in addition to hsCRP [282], there are no thresholds set to indicate a harmful level. In the exploratory PCA analyses (*Study IV*), cortisol levels were surprisingly not associated with subjective measures of distress or DHEAS levels and also no intervention effect was seen on cortisol concentration. The fact that we had only a single morning cortisol measurement is a limitation of our study [283]. For practical reasons, we were not able to have study participants visit the laboratory at precisely the same time after awakening at each study visit to control for the diurnal rhythm of cortisol [50]. Furthermore, it is challenging to interpret cortisol levels, because cortisol levels can be either increased or decreased in a chronic stress situation [46], and for example personal factors [46] and the amount of visceral fat [47] affect cortisol secretion.

Finally, it is noteworthy that although stress was studied in this thesis from a negative perspective, stressful periods of time include also positive psychological states [37] which also have an important role in the stress process [36]. The possible positive effects of stress, such as personal growth, reprioritization of life goals, increased feelings of self-esteem and self-efficacy, and strengthening of social networks [1], were not considered in this thesis.

6.4.3 Assessment of eating behavior

Eating behavior was measured with several self-reported questionnaires. The Three-Factor Eating Questionnaire, TFEQ-R18 [100], Health and Taste Attitude Scales, HTAS [116], Intuitive Eating Scale, IES [12], the preliminary Finnish translation of ecSatter Inventory 2.0™, ecSI 2.0™ [143,238,239], and the 24-item Regulation of Eating Behavior Scale, REBS [187] showed mostly high internal consistency based on the Cronbach's coefficient alphas. However, two subscales of the ecSI 2.0™ had rather low Cronbach's coefficient alphas (<0.6). This may reflect the small number of items in the subscales [284] (5 items in Eating Attitudes and 3 items in Internal Regulation), or suggest that these were not reliable measures in this population, or reflect the recent finding from confirmatory factor analysis among U.S. samples that one item should be relocated from the subscore Internal Regulation to Eating Attitudes [142]. In the current sample, conducting explorative or confirmatory factor analyses would have helped to increase the validity of the measures. In addition, although all of the questionnaires have been validated in their original language, all of the Finnish translations were not validated, especially among adults with overweight/obesity. Furthermore, although mindful eating was the only eating-related component in the ACT intervention, a specific questionnaire for mindful eating was not used. Although the Intuitive Eating Scale and ecSatter Inventory 2.0™ we used partly include the concept of mindful eating, it is still possible that we were not able to observe all of the possible effects of ACT on eating behavior because no specific mindful eating questionnaire was used.

6.4.4 Assessment of diet

The dietary assessments included self-reported questionnaires Index of Diet Quality, IDQ [240] and Alcohol Use Disorders Identification Test Consumption, AUDIT-C [241] in addition to 48-hour dietary recall via telephone. IDQ is a validated Finnish measure [240]. When needed, we checked from the participant about possibly unrealistic or outlier responses to the open-ended questions regarding the amounts of foods and drinks consumed to increase the reliability of the data.

Because the Elixir study participants were psychologically distressed and the study required effort from the participants (i.e., visiting the study clinic, using wearable devices, filling in a sleep diary, answering several questionnaires, in addition to participating in the intervention), the 48-h dietary recall telephone interviews were conducted instead of using food records to diminish their burden [285]. Furthermore, using this method allowed us to collect food consumption data in as free-living a situation as possible so that the measurement would not influence the participants' dietary choices and intake. This was particularly the case at baseline, however, at post-intervention and follow-up, the participants have quite likely expected the items that would be asked in the scheduled telephone interview because of their previous experience. Thus, the participants would have had the possibility to change their eating in order to be able to report it they felt that this would be more socially desirable (more healthy food items and less unhealthier food items) or write down their food consumption prospectively (as in a food record) to avoid burdensome recalling during the interview or as a way to please the interviewer with giving more accurate information. In addition, the accuracy of the reporting could have been higher at the post-intervention and follow-up in the intervention groups because of the possibly increased ACT skills, such as being present and mindful eating. Furthermore, although the method was chosen to be less burdensome for the participant, it required more from the research personnel. For practical reasons, interviews were mainly not conducted on weekends or Mondays, and thus Fridays and Saturdays are missing from the data. This is a limitation especially concerning stress-related eating at the weekend mentioned above.

The retrospective 48-h dietary recall method has also other limitations. The result depends on the participant's memory and his/her ability to describe the foods consumed. For example, the interview protocol was designed to address this limitation by giving the participants a clear structure, with repetition, and using an electronic picture book of food and drink portions [243]. To diminish variation between several interviewers, the interview protocol for the Elixir study was created and used by the three nutritionists who conducted all of the interviews. The interview protocol was based on the face-to-face 48-h dietary recall conducted in the national FINDIET 2012 survey [244]. The validity of the 48-hour recall has rarely been studied, and the results have been partly controversial [286-288]. However, compared to a single 24-h recall, a 48-h recall has been found to be superior [287].

Although alcohol was also included to the 48-h dietary recall, the data was not used because of the lack of consumption on Fridays and Saturdays. Thus, the information on long-term (i.e., previous six months) alcohol consumption was collected with a short questionnaire, AUDIT-C, which seems to be a valid measure in general Finnish population [242].

Finally, a special challenge in measuring dietary intake is the over- and underreporting which possibly have also affected the results of this thesis. People tend to overestimate the intake of health-beneficial foods and underestimate the non-beneficial foods. In particular, the underreporting among people with obesity affects the data collected on energy intake [260,289]. The possibility of misreporting was considered while creating the 48-h dietary recall protocol. It was emphasized to the participants that the interview was only for research purposes, and the interviewer would not make any comments on their responses or provide any feedback or dietary counseling. Participants were encouraged to be truthful and the situation was intended to be confidential and non-judgmental. Thus, it can be even hypothesized that the misreporting could be less prevalent in dietary recall when the participant was simultaneously encouraged to be truthful as compared to an independently self-filled food record.

In the present analyses, energy nutrient intake was handled as energy adjusted variables (E%, g/MJ) instead of pure amounts (g), although even this does not rule out the possibility of misreporting totally. The intakes of carbohydrates and dietary fiber were lower and the intake of saturated fatty acids was higher than recommended [290], a finding also in line with the general Finnish adult population at the time when the study was conducted [244].

High adherence (65%) to the health-promoting diet measured by the IDQ questionnaire suggests that there could have been some overreporting of health-beneficial foods in the questionnaire. On the contrary, using the cut-off value set in earlier studies [141], only a minority (20%) of the participants were competent eaters (*Study I*), a classification which has been associated with a higher intake of fiber, several vitamins and minerals, and Healthy Eating Index [149]. There are two potential explanations for this discrepancy between a high diet quality and a low eating competence. On the one hand, this could reflect the fact that the majority (89%) of the participants reported they were aiming to lose weight. On the other hand, this can indicate that there was misreporting about dietary intake but not in eating behavior questionnaire. The features of eating behavior were most likely not known by the general public, and thus participants did not have the socially desirable or ”the right” answers to the eating behavior questions whereas this is the reason for under- and overreporting in dietary assessments. This may also be one reason for not detecting statistically significant associations/changes in *Studies I* and *III* regarding diet, although associations and effects were seen regarding the features of eating behavior.

Finally, collecting dietary data via well-validated questionnaires [240,241] and 48-hour dietary recall protocol specifically developed for the Elixir study, are strengths of the study.

7 CONCLUSIONS AND FUTURE IMPLICATIONS

7.1 CONCLUSIONS

This thesis answers to the request in scientific literature to investigate stress and eating in a real-world context, outside of a laboratory. Furthermore, the thesis provides knowledge on the effects of a psychological ACT intervention on outcomes that have been rarely studied before in RCT settings. The main results of this thesis indicate that among working-age Finnish adults with psychological distress and overweight/obesity:

- perceived stress associated with unfavorable eating behavior but not with diet quality,
- sleep-time physiological recovery associated with better diet quality and lower intuitive eating,
- the ACT intervention used in this study improved eating behavior but not diet quality, and
- the ACT intervention did not have any effect on biomarkers of low-grade inflammation and stress as compared to a control group. However, a decrease in hsCRP in the face-to-face intervention group was observed.

This thesis integrated psychological and physiological measures with nutrition science. Especially, the adaptive features of eating behavior (i.e., intuitive eating and eating competence) and physiological sleep-time recovery are innovative features in the studied contexts. The investigated topics are important in this era in which there is a growing prevalence of psychological distress, obesity, and subjective feeling of not sleeping enough among Finnish working-age adults [9,10,291]. The results show that both perceived stress and sleep-time recovery are relevant factors in nutrition science. The unfavorable eating behavior associated with higher perceived stress may predispose an individual to higher BMI and unbeneficial food choices. Physiological sleep-time recovery was associated with better diet quality, lower alcohol consumption and lower intuitive eating, which may suggest that some self-regulation is associated with beneficial food choices among this population.

This thesis also extends the previous limited knowledge of the effectiveness of a psychological ACT intervention on eating behavior, diet, and biomarkers of low-grade inflammation and stress. This is the first study to investigate the effects of ACT also delivered via a mobile app. However, the effects of ACT were most pronounced in the group receiving the intervention in face-to-face group sessions. The positive effects of ACT on eating behavior indicate that ACT seems to be beneficial for health-promotion and chronic disease prevention among people with psychological distress and overweight/obesity. In line with its theory, ACT was able to influence eating behavior related to personal values, mindfulness, how one interacts with inner experiences, and acceptance. However, ACT did not affect diet quality or the levels of inflammation and stress biomarkers. This may be due to several facts related to the ACT intervention; (1) it was not designed to target these outcomes, (2) the intervention and/or follow-up period were too short, or (3) the methods used were not able to detect all possible changes. If there is an aim to improve diet quality or physiological biomarkers, it is suggested to specially design the ACT intervention to focus on that aim.

7.2 FUTURE IMPLICATIONS

In clinical practice, it would be important to take into consideration the perceived stress level of the patient requesting help for weight management. Because adults with overweight/obesity who have the highest perceived stress levels have less intentions to lose weight and report more and severe depressive symptoms, they may benefit most from psychological support. Providing ACT preceding or included as a part of nutritional counseling would be beneficial, irrespective of the initial level of perceived stress. Sleep-time recovery is also relevant to consider in clinical pratice, although it is not clear, whether better diet quality leads to higher sleep-time recovery or vice versa. Thus, it is recommended that psychological aspects and the consideration of stress and recovery should be emphasized in the education of nutrition students and in-service training of clinicians.

The results of this thesis show that ACT can increase inner motivation to eat in a more health-promoting way and improve stress-related eating behavior. However, the ACT intervention did not include nutrition counselling. It would be interesting to study further, whether adding the ACT mobile app to nutritional counselling in a health care setting could improve the patient's psychological wellbeing, eating behavior, diet quality, and metabolic syndrome risk factors.

The current results raises also several questions for future research. More research and methodological developments are needed concerning stress, recovery, and food intake as they are all challenging to measure accurately. Furthermore, longitudinal research and randomized controlled interventions are needed to understand the causality and mechanisms behind stress, recovery, eating behavior, and diet quality.

For example, investigating the effects of an intervention targeting improvements in sleep and recovery would represent a novel avenue of research in nutrition science.

Intuitive eating showed controversial associations with stress, recovery and diet quality. Thus, more research is needed on the concept of intuitive eating and its impact in general but also among people with overweight/obesity. Furthermore, the relationships between different features of eating behavior and their link to actual dietary intake need to be clarified more thoroughly. In particular, we need more knowledge on what kind of eating behavior (i.e., a mixture of different features of eating behavior) would be most beneficial and what should be guided to patients seeking help for weight management and improving diet.

It would be interesting to examine in a similar study population the effects of a more intensive ACT intervention emphazing also food choices and physical activity to determine whether dietary intake and physiological biomarkers could be influenced. Furthermore, in attempts to personalize the care provided, more research is needed to investigate which type of individual benefits most from which kind of intervention delivery: face-to-face group sessions, mobile app, or a combination of these forms. By utilizing the data of individual's socioeconomic position, features of eating behavior, diet quality, physiological state, etc., we should be able to provide the most effective support for people. In particular, individuals at high risk for non-communicable diseases should be considered. Instead of the traditional RCT settings, adaptive or SMART (Sequential Multiple Assignment Randomized Trial) [292] interventions may be utilized when investigating the most effective intervention for each person.

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APPENDICES

APPENDIX 1. SUPPLEMENTARY MATERIAL FOR *STUDY III*

Supplementary Table 1. Results of the moderation analyses.

Moderator: PSS (baseline)	**Outcome (from baseline to follow-up, Δ 36 weeks)**					
	IES Eating for Physical Rather Than Emotional Reasons	**ecSI 2.0™ Food Acceptance**	**TFEQ-R18 Uncontrolled Eating**	**HTAS Using Food as a Reward**	**REBS Integrated regulation**	**REBS Identified regulation**
Face-to-face	-0.03 (0.10) .798	-0.18 (0.10) .082	0.04 (0.09) .659	0.04 (0.09) .679	-0.09 (0.10) .368	-0.14 (0.12) .245
Mobile	-0.03 (0.10) .778	0.05 (0.10) .623	0.06 (0.11) .607	-0.10 (0.09) .277	0.01 (0.11) .930	-0.09 (0.13) .520

Values are standardized estimates (standard error) and p-values for moderated intervention effects. The ACT intervention groups (Face-to-face and Mobile) are compared separately to the Control group. PSS = Perceived Stress Scale; IES = Intuitive Eating Scale; ecSI 2.0 ™ = preliminary Finnish translation of Satter Eating Competence Inventory 2.0; TFEQ-R18 = The Three-Factor Eating Questionnaire-R18; HTAS = Health and Taste Attitude Scales; REBS = Regulation of Eating Behavior Scale.

ELINA JÄRVELÄ-REIJONEN

Chronic stress can lead to ill health via psychological, physiological, and behavioral processes. This thesis focused on stress, eating behavior and diet among Finnish working-age adults with psychological distress and overweight/obesity participating in a psychological lifestyle intervention study. The results show that perceived stress and poor sleep-time recovery are associated with unfavorable eating behavior and diet. The acceptance and commitment therapy (ACT) intervention improves eating behavior and is thus a promising method for chronic disease prevention.

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