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Individual differences in the dietary response to stress in ecological momentary assessment: Does the individual-difference model need expansion?

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Abstract

According to the individual-difference model, individuals differ in the way stress changes their eating behaviour. Research shows that some increase, some decrease, and others show no change in food intake. Despite numerous efforts to identify moderating variables that explain these individual (i.e., between-person) differences, evidence remains inconclusive. The present study aims at deepening the understanding of the stress and eating relationship by applying ecological momentary assessment to study (1) the influence of stress on whether and how much individuals eat and (2) the moderating role of gender, age, BMI, trait stress-eating, and eating styles. The APPetite-mobile-app was used for 3 days to capture actual food intake (event-contingent) and perceived stress (signal-contingent). Data of 154 healthy adults suggest that stress is not associated with whether but how much individuals eat. Only gender moderated the relationship between stress and the amount of food intake. Individual differences were small indicating that an individual's dietary response to stress might not be as stable as yet

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assumed. Moreover, a study suggests that time-varying factors (e.g., food availability) moderate the stress and eating relationship. Hence, intraindividual (i.e., within-person) variability may be relevant. Therefore, we propose an expansion of the individual-difference model, which accounts for time-varying factors.

KEYWORDS
diet, ecological momentary assessment, food intake, individual differences, stress, time-varying moderators

INTRODUCTION

Human health is substantially and directly influenced by diet and stress. Poor dietary habits and elevated levels of stress are linked to numerous negative health outcomes, such as cardiovascular diseases (Kivimäki & Steptoe, 2018; Micha et al., 2017). Beyond that, stress has an indirect impact on health through changes in health-related behaviours, including diet (O'Connor et al., 2021). A substantial body of research has shown that stress is associated with changes in dietary intake (for overviews, see Araiza & Lobel, 2018; Hill et al., 2021). Even though people commonly associate stress with overeating, studies assessing the link between diet and stress have produced mixed results. While some studies found that stress increases food intake (e.g., Wardle et al., 2000), others found decreases in food consumption (e.g., Stone & Brownell, 1994). The inconsistency in findings is highlighted by a recent meta-analysis, which found only a small positive effect size for the relationship between stress and overall food intake due to considerable heterogeneity across subgroup analyses and across the 54 studies overall (Hill et al., 2021). To some extent, differences in study design and in the measurement of stress and diet might have contributed to these heterogeneous findings. However, individual (i.e., between-person) differences in the dietary response to stress seem to be the primary cause of the observed heterogeneity. As early as 1994, a review concluded that there is strong evidence for the individual-difference model—as opposed to a general effect model (Greeno & Wing, 1994). The individual-difference model is based on the assumption that the effect of stress on eating is determined by individual differences in learning history, attitudes, or biology.

Individual differences in the dietary response to stress

Studies have shown that individuals differ in the way stress changes their eating behaviour. Some individuals increase, some decrease food intake, whereas others do not change food consumption when experiencing stress. Estimates derived from self-reports indicate that about 36–42% of individuals report eating more, 26–38% less and the remaining report no consistent change as a response to stress (Epel et al., 2004; Oliver & Wardle, 1999). Despite various efforts to identify person-level factors that underlie individual differences in the stress and eating relationship, the evidence is inconclusive. For instance, some studies found gender differences, with men decreasing food intake under stress and women showing some increases in eating

(Grunberg & Straub, 1992). However, other studies did not find gender differences (e.g., Conner et al., 1999). Weight and eating styles (e.g., dietary restraint and emotional eating) have also been studied widely as potential moderators of the stress and eating relationship. Some evidence suggests that individuals with higher body weight (e.g., Cotter & Kelly, 2018; O'Connor et al., 2008) and individuals higher in emotional eating and dietary restraint (e.g., O'Connor et al., 2008; Wallis & Hetherington, 2004; Wardle et al., 2000) are more likely to increase food intake when experiencing stress. Nevertheless, inconsistencies are also present here as other studies found no moderating effect of emotional eating (Conner et al., 1999) as well as restrained eating (Conner et al., 1999; Pollard et al., 1995). The impact of potential moderators of the stress and eating relationship, such as gender, age, BMI, and eating style (i.e., dietary restraint), was also explored in the meta-analysis by Hill et al. (2021). However, none of these variables significantly moderated the relationship between stress and overall food intake. Based on the findings from the meta-analysis, Hill et al. highlight the need for (1) more detailed measures of the nature of the stressors, (2) more accurate assessments of food consumption, such as energy intake, (3) more studies that test key moderating variables of the stress and eating relationship, (4) assessment of eating styles, and (5) accurate measures of weight, height and diet status. Furthermore, they emphasise the importance of taking dispositional stress-related eating (i.e., self-reported tendency to eat more, less or the same in response to stress) into account.

Ecological momentary assessment of the stress and eating relationship

The influence of stress on eating behaviour is highly complex (Hill et al., 2021). Ecological momentary assessment (EMA) allows studying complex psychological, behavioural, and physiological processes through the repeated assessment of behaviours (e.g., food intake), experiences (e.g., perceived stress), and physiological parameters multiple times a day in real life (Smyth & Stone, 2003). Given that eating is a repeated-occurrence health behaviour that is performed several times a day (Dunton, 2018), EMA seems particularly suited to study the complex relationship between stress and food intake when and where it naturally occurs. It circumvents disadvantages of traditional approaches (e.g., retrospective self-reports and laboratory tasks), by minimizing recall bias, maximizing ecological validity and capturing within-person processes and variation over time and across settings (Shiffman et al., 2008). Furthermore, Araiza and Lobel (2018) point out that a closer study of the stress and eating relationship could be achieved and reliability and validity could be increased through novel and sophisticated methodological approaches, such as EMA.

Despite its potential, the number of studies using EMA to investigate the stress and eating relationship is limited. One EMA study assessed the relationship between daily hassles and snack intake in African American women (Zenk et al., 2014). Participants were more likely to consume snack foods on days they experienced more daily hassles. However, no association between experiencing a stressful event and concurrent as well as subsequent snack food intake was identified on the momentary level (i.e., within-day level). Reichenberger et al. (2018) studied the effect of stress on taste- and hunger-driven eating in an EMA setting. While hunger-driven eating refers to eating in response to physiological feelings of hunger, taste-eating describes food intake that is driven by the anticipated pleasure associated with the taste of foods. They found that stress decreased taste-eating. This relationship was not moderated by gender, BMI, and eating styles (emotional, external, and restrained eating). Hunger-eating was not significantly influenced by stress. Again, gender, BMI, and eating styles did not moderate the relationship between stress and hunger-eating. A recent study by Reichenberger et al. (2021) used EMA to study the moderating role of trait stress-eating (i.e., an individual's self-reported tendency to eat more and less or the same in response to stress) in the relationship between stress and eating. When data collected throughout the day were aggregated (i.e., to the day level), they found that trait stress-eating moderated the relationship between stress and food intake. Individuals with high trait stress-eating reported more food intake on days with higher stress. No effect of stress on food intake was found in individuals with low trait stress-eating. Contrary to the day level, trait stress-eating did not moderate the stress and food intake relationship on the within-day level. There was also no main effect of stress on food intake. It should be noted, however, that only perceived food intake was assessed. That is, for each eating episode since the last prompt, participants reported how much they had eaten on a scale from 0 (eaten too little) to 100 (eaten too much). Even though the importance of assessing actual food intake, such as energy intake, has been highlighted (Araiza & Lobel, 2018; Hill et al., 2021), to the best of our knowledge, there are no EMA studies available that assess the association between stress and actual food intake in healthy adults. Only one small EMA study assessed stress and calorie intake in nine patients with type 2 diabetes and found a positive association between stress and calorie intake from snacks as well as a negative association between stress and calorie intake from lunch and dinner (Inada et al., 2019). Presumably, due to the small sample size, individual differences of the stress and food intake relationship were not taken into account.

Previous research has either studied if stress is associated with whether individuals eat (e.g., Zenk et al., 2014) or how much they eat (e.g., Reichenberger et al., 2021). What has been overlooked so far is that the occurrence and the amount of food intake are likely not independent. When the association between stress and the amount of food intake is studied, time intervals in which no eating is reported are excluded (e.g., Reichenberger et al., 2021: study 1—2318 out of 4656). This causes loss of important information (Tooze et al., 2002) and can cause bias in the parameter estimates (Liu et al., 2008; Su et al., 2009). However, including intervals in which participants did not consume any food yields a zero-inflated outcome (i.e., one considerable part of the outcome is equal to zero). This type of data can be challenging as traditional linear multilevel modelling cannot be applied. A promising statistical approach to analyse this type of data is multilevel two-part modelling, which accounts for the potential dependency between the occurrence and the amount of food intake (see Ruf, Neubauer, et al., 2021, for a detailed description of this approach).

The present study

The present study addresses the need for research that assesses the stress and eating relationship in an EMA setting based on accurate dietary assessments. Hence, the present study uses an EMA tool, which showed good validity to capture actual food intake (Ruf, Koch, et al., 2021). Following the recommendations by Hill et al. (2021), the present study assesses the moderating effect of gender, age, weight, eating styles, and trait stress-eating on the stress and eating relationship. It is examined (1) whether individuals differ in the stress and eating relationship, (2) whether individual differences in the stress and eating relationship can be explained by person characteristics (i.e., gender, age, BMI, trait stress-eating, and eating styles), and (3) whether these findings support the individual-difference model of stress-eating (Greeno & Wing, 1994). Furthermore, the present study is the first to use multilevel two-part modelling to assess the stress and eating relationship. This offers novel and distinct insights in terms of the occurrence as well as the amount of food intake.

Given the inconsistent body of evidence, we hope that the novel approach of our study—assessment of actual food intake in an EMA setting combined with sophisticated multilevel two-part modelling—will allow us to deepen the understanding of the stress and eating relationship. Understanding which individuals are more likely to eat or prone to overeating when experiencing stress in daily life is crucial in order to identify individuals at higher risk for diet-related negative health outcomes.

METHODS

Procedure

Data were collected within the Eat2beNICE-APPetite-study (parts of the data have been used to study different research questions, see Ruf, Koch, et al., 2021, and Ruf, Neubauer, et al., 2021). Participants completed two in-person sessions as well as an EMA period. Body weight and body height were measured in the first in-person session and were used to calculate BMI. Furthermore, participants completed questionnaires and received detailed training to familiarize with the APPetite-mobile-app used for the EMA assessment (for further details see Ruf, Koch, et al., 2021). The local ethics committee approved the study. All subjects declared that they understood the study procedure and signed a written informed consent.

EMA protocol

Participants received a study smartphone to complete the EMA protocol of the APPetite-mobile-app for three consecutive days (two weekdays and one weekend day). Between 8 a.m. and 10 p.m. participants received eight semirandom signal-contingent prompts (at least 1 h in-between prompts). Each prompt assessed stress and food availability. Food intake was captured event-contingent through the incorporated APPetite-food record. Hence, food intake could be recorded at any time. At 9 p.m. there was a time-contingent prompt asking if all foods and drinks of the day have been recorded. Further details on the APPetite-mobile-app are available in Ruf, Koch, et al. (2021).

Sample

Participants from the Longitudinal Resilience Assessment-study (inclusion criteria described in Chmitorz et al., 2021) were invited to the study ‘APPetite: the influence of diet and physical activity on impulsivity and resilience’. In total, 185 healthy adults participated in the study. Four participants dropped out before starting the EMA assessment due to personal reasons (e.g., spontaneous trip abroad) or because they realized they were unable to respond to prompts (e.g., due to work commitments). Data of one participant had to be excluded as they proved to be untrue. Data of 26 participants were excluded as dietary intake was recorded poorly (e.g., only breakfast recorded). The final sample includes 154 participants (112 female, 42 male) with an average age of 28.91 years ($SD = 7.75$). The sample has a mean BMI of 24.20 ($SD = 4.09$).

Measures

Food intake

The APPetite-mobile-app (Ruf, Koch, et al., 2021) was used to capture dietary intake. This mobile application comprises a food record. Participants were asked to enter all foods and drinks as soon as possible after consuming them. Foods and drinks were recorded through a six-step process: (1) Selection of meal type, (2) entry of time of intake, (3) selection of consumed foods and drinks, (4) specification of consumed amounts, (5) presentation of reminder for commonly forgotten foods, and (6) indication of predominant reason for eating or drinking. The obtained dietary data were transferred to myfood24-Germany, an online 24-h dietary recall (Koch et al., 2020), by trained staff in order to generate nutritional values, such as the exact energy intake in kilocalories (kcal), which is the outcome in the present study. The APPetite-mobile-app was subject to a feasibility, usability and validation study. Results indicated that the APPetite-mobile-app is a feasible EMA tool and a valid dietary assessment method that is is likely more precise than 24-h recalls (Ruf, Koch, et al., 2021).

Stress

Three items (adapted from Reichenberger et al., 2018) were used to capture perceived stress. The first item assessed how stressed participants felt since the last prompt. Responses were rated on a visual analogue scale from 0% (*not at all*) to 100% (*very stressed*). Two stress items, based on the Perceived Stress Scale (Cohen et al., 1983), assessed whether participants felt that they 'could not cope with all the things they had to do' and whether they were 'on top of things' since the last prompt on a visual analogue scale from 0 (*not at all*) to 100 (*very much*). In the first prompt per day, participants were instructed to rate stress since waking up instead of since the last prompt. McDonald's Omegas (Geldhof et al., 2014) for the three stress items were 0.648 (within) and 0.895 (between) in the present sample. Based on the three items (third item reversed), a mean stress score was calculated for each prompt.

Food availability

Because the effect of stress on food intake can only be reliably studied in time intervals in which food was actually available, food availability was assessed on a visual analogue scale from 0 (*not available at all*) to 100 (*easily available*) since the last prompt.

Trait stress-eating

The Salzburg Stress Eating Scale (SSES) (Meule et al., 2018) was used to capture trait stress-eating. Each of the 10 items describes a stressful situation. Participants were asked whether they eat a lot less (1), less (2), the same (3), more (4), or a lot more (5) than usual in this situation. A mean score was calculated. Mean SSES scores below 3 indicate an individual reports to decrease food intake when experiencing stress, above 3 that an individual reports to increase food intake under stress. A mean SSES score of 3 suggests that an individual reports to not change food intake when feeling stressed. Internal consistency was $\alpha = .86$ in the present sample.

Eating styles

The German version of the Three-Factor-Eating-Questionnaire (Stunkard & Messick, 1985), the questionnaire 'Fragebogen zum Ernährungsverhalten' (FEV; Pudel & Westenhöfer, 1989), was used to assess three eating styles: cognitive restraint of eating, disinhibition, and hunger. The questionnaire was chosen as its reliability and validity was evaluated in three large German samples (total $N > 80{,}000$; Pudel & Westenhöfer, 1989). The subscale cognitive restraint consists of 21 items, disinhibition of 16 items, and hunger of 14 items, all coded as 0 or 1. A sum score was calculated for each subscale. Higher subscale values indicate stronger cognitive restraint, greater disinhibition, and more pronounced feelings of hunger, respectively. In the present sample, internal consistency was $\alpha = .85$ for cognitive restraint, $\alpha = .81$ for disinhibition, and $\alpha = .70$ for hunger.

Data preprocessing

Due to poor or biased dietary data, single days of the EMA assessment of some participants had to be excluded (13 days in total).

Each time interval for which stress was assessed (i.e., time between current prompt and previous prompt/waking up) was paired with concurrent energy intake in kcal. Concurrent energy intake was defined as the sum of any intake of energy within the respective time interval.

The length of each time interval varied due to the semirandom sampling protocol. Furthermore, the assessment of stress 'since waking up' in the first prompt as well as the postponement of prompts yield either shorter time intervals than standardized (minimum time between two prompts = 1 h) or rather long time intervals. Time intervals shorter than 15 min ($n = 144$) and longer than 3 h ($n = 135$) were excluded. 314 time intervals were excluded as the stress items had not been completed. In addition, time intervals in which food availability was rated 10 or lower ($n = 191$) were excluded. However, the assessment of food availability was added to the study a few months after data collection started. Hence, we were unable to exclude time intervals of the first 33 participants based on this criterion. The final sample includes 2779 time intervals.

The Level-1 predictor stress was divided by 10 to avoid estimation problems (due to large differences in variance of the predictor and the outcome) and centred on the person-mean to generate unbiased estimates of the within-person effect (Wang & Maxwell, 2015). We centred the Level-2 predictor age around 30 years and BMI around 25 (i.e., the constant 30 or 25 were subtracted from participants' age or BMI respectively as recommended by Viechtbauer, 2022, to make the model intercept more interpretable). For the same reason, Level-2 predictor trait stress-eating was centred around 3. The Level-2 predictors dietary restraint, disinhibition, and hunger were centred on the grand-mean. Gender was coded as 0 (male) and 1 (female).

Data analysis

Due to the nested data structure (time intervals [Level 1] nested within individuals [Level 2]) and the zero-inflated, right-skewed outcome energy intake in kcal, multilevel two-part models were used for analysis. More specifically, the model we applied combines a multilevel logistic regression for the zero part of the outcome (to predict whether an individual eats in a given time interval) and a multilevel gamma regression for the continuous part of the outcome (to predict how much is eaten, if an individual eats in a given time interval), while accounting for the potential dependency between the two outcome components. This approach allows differentiating between stress influencing either the occurrence or the amount of food intake (or both). Therefore, findings are separately reported for the occurrence (zero part of the model) and the amount of food intake (continuous part of the model) in the results section. While logistic regressions typically predict the outcome to be 1, the multilevel logistic regression of our two-part model predicts no food intake (outcome = 0), that is, the probability not to eat for a given individual in a given time interval. These models were run using the R-package brms (Bürkner, 2017, 2018), which supports Bayesian multilevel modelling. Details on this type of analysis (e.g., implementation and interpretation) can be found in Ruf, Neubauer, et al. (2021).

To examine individual (i.e., between-person) differences in the within-person effect of stress on energy intake, a model with the Level-1 predictor stress in both parts of the model (i.e., the logistic regression as well as the gamma regression) was run. Next, seven separate models were run to test the association between the Level-1 predictor stress in interaction with the Level-2 predictor (1) gender, (2) age, (3) BMI, (4) trait stress-eating, (5) dietary restraint, (6) disinhibition, or (7) hunger (cross-level interaction), and energy intake in both model parts. If more than one of the cross-level interactions was significant, a combined model with all significant moderators was run. All models included a random intercept (i.e., we expect individuals to differ in their average probability not to eat and the average amount of energy intake) and a random slope for stress to examine whether the effect of stress differs between individuals.

Model parameters were estimated based on 4000 iterations. All other sampling and prior parameters were maintained as brms defaults. Analyses were performed using R version 4.0.5, RStudio version 1.4.1106 (RStudio Team, 2020), brms version 2.15, and rstan version 2.21.2 (Stan Development Team, 2020). The data and R code that support the findings of this study are available in Data S1 and S2 of this article.

RESULTS

Descriptive findings

Descriptive statistics of the variables can be found in Table 1. In the trait questionnaire, 27 participants reported not to change (SSES mean score = 3), 72 to decrease (SSES mean score <3), and 55 to increase (SSES mean score >3) food intake when experiencing stress.

In 1201 time intervals, no food intake was reported. Within time intervals in which participants ate (n = 1578), on average 466 kcal (SD = 381) were consumed. Mean compliance with the signal-contingent prompts (i.e., percentage of complete prompts within received prompts) was 89.3 (SD = 12.2) (not including participants and days that were excluded as a whole from final analyses due to poor or biased dietary data, but including time intervals that were excluded from final analyses based on interval length and food availability).

TABLE 1 Descriptive statistics of the Level-1 predictor stress ($N = 2779$) and Level-2 predictors trait stress-eating and eating styles ($N = 154$)

	M	SD	Range
Level-1			
Stress	18.65	12.38 (within) 12.35 (between)	0–100
Level-2			
Trait stress-eating	2.93	0.56	1.4–4.5
Cognitive restraint	6.91	4.53	0–19
Disinhibition	5.50	3.09	0–15
Hunger	5.09	2.92	1–12

Findings from the multilevel two-part models

Stress

Estimates of the zero part of the multilevel two-part model are modelled on the logit scale. The intercept of the zero part represents the average log-odds of no energy intake in time intervals with average stress (stress = 0). To transform the log-odds to the probability of no energy intake, we use the plogis-function in R. In model 1 (see Table 2), the mean probability of no energy intake in time intervals with an average stress level is 0.43. Credible intervals (95% CI) of fixed effects that do not include 0 indicate a significant effect. Hence, there is no significant fixed effect of stress on the probability not to eat. Note that nonpositive estimates for standard deviations (*SD*) are not allowed, and the lower limit of the CI for random effects will therefore always be positive. Accordingly, lower limit of the CI of random effects that are equal to 0.00 suggest that individual differences in the intercept or the effect of stress are small and possibly not statistically meaningful. Hence, as the lower limit of the 95% CI of the *SD* of the intercept is above 0.00, participants differ in the probability of no energy intake with an *SD* of 0.32. However, the random effect for stress in the zero part suggests that the effect of stress on the probability of no energy intake does not vary across participants. Consequently, individual/between-person differences in the within-person effect of stress on the probability of no energy intake are small and negligible (illustrated in Figure 1a).

Estimates of the continuous part are modelled on the log scale. The intercept of the continuous part represents the mean log energy intake in time intervals with average stress (stress = 0) in which eating occurred. To obtain the estimate of the intercept in the original metric (kcal), we calculate the exponential of the estimates. Participants consume on average 468.7 kcal in time intervals with average stress in which energy intake occurred. There is between-person variation in the log energy intake in time intervals with average stress in which energy intake occurred (see *SD* (intercept)). However, the effect of stress on the (log) energy intake does not vary across participants (see *SD* (stress)). This suggests that individual/between-person differences in the within-person effect of stress on the (log) energy intake are minor (illustrated in Figure 1b).

TABLE 2 Model estimates of the multilevel two-part model with the Level-1 predictor stress

	Zero part				Continuous part			
			95% CI				95% CI	
	Estimate	SE	LL	UL	Estimate	SE	LL	UL
	Model 1: Stress							
Fixed effects								
Intercept	−0.28	0.05	−0.38	−0.19	6.15	0.03	6.09	6.20
Stress	0.03	0.03	−0.04	0.09	−0.04	0.02	−0.08	0.00
Random effects								
SD (intercept)	0.32	0.06	0.19	0.44	0.11	0.04	0.04	0.19
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.09

Note: CI = credible interval; LL = lower limit; UL = upper limit.

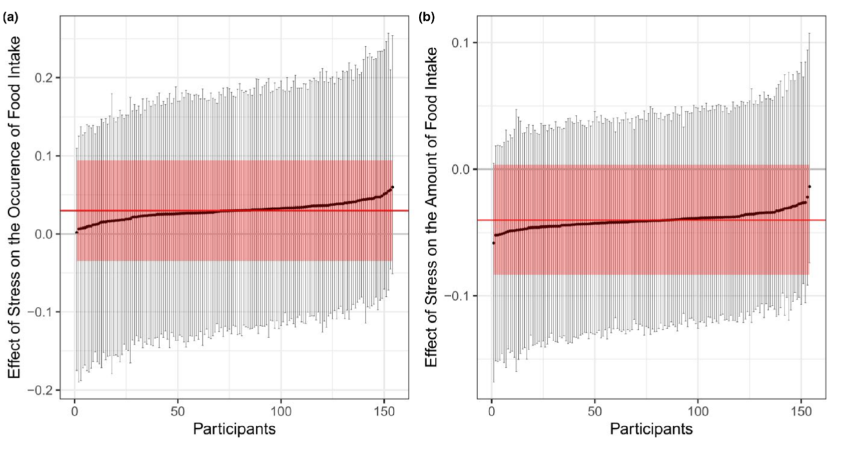

FIGURE 1 Individual/between-person differences in the within-person effect of stress on (a) the occurrence and (b) the amount of food intake. Note: Black dots represent estimates of the within-person effect for each participant. Vertical lines indicate the 95% credible interval of each within-person effect. The red horizontal line represents the average within-person effect. The shaded area around the red line indicates the 95% credible interval of the average within-person effect.

Gender, age, and BMI

Results of the three models assessing the effect of stress on energy intake as well as the moderating effect of gender, age, and BMI on the stress and food intake relationship in the zero and continuous part of the model are shown in Table 3.

There is no significant fixed effect of stress, gender, or their interaction in the zero part of the model. This suggests that (1) men and women do not differ in the probability not to eat, (2) stress is not associated with the likelihood that an individual eats, and (3) the relationship between stress and the probability not to eat is not moderated by gender.

The intercept of the continuous part represents the mean log energy intake for men (gender = 0) in time intervals with average stress (stress = 0) in which eating occurred. Male

TABLE 3 Model estimates of the multilevel two-part models of the moderating effect of gender, age, and BMI

	Zero part				**Continuous part**			
			95% CI				**95% CI**	
	Estimate	**SE**	**LL**	**UL**	**Estimate**	**SE**	**LL**	**UL**
	Model 2: Gender							
Fixed effects								
Intercept	−0.25	0.09	−0.43	−0.08	6.28	0.05	6.18	6.37
Stress	0.05	0.08	−0.10	0.21	−0.13	0.05	−0.23	−0.03
Gender	−0.03	0.10	−0.24	0.17	−0.18	0.06	−0.30	−0.07
Stress * gender	−0.03	0.09	−0.19	0.15	0.12	0.06	0.01	0.22
Random effects								
SD (intercept)	0.32	0.06	0.20	0.44	0.10	0.04	0.02	0.17
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.08
	Model 3: Age							
Fixed effects								
Intercept	−0.28	0.05	−0.37	−0.18	6.15	0.03	6.10	6.21
Stress	0.03	0.03	−0.04	0.10	−0.04	0.02	−0.08	0.00
Age	0.00	0.01	−0.01	0.01	0.00	0.00	−0.00	0.01
Stress * age	0.00	0.00	−0.00	0.01	0.00	0.00	−0.00	0.01
Random effects								
SD (intercept)	0.32	0.06	0.20	0.45	0.11	0.04	0.03	0.19
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.09
	Model 4: BMI							
Fixed effects								
Intercept	−0.27	0.05	−0.36	−0.18	6.16	0.03	6.11	6.21
Stress	0.03	0.04	−0.04	0.10	−0.04	0.02	−0.09	0.01
BMI	0.02	0.01	−0.01	0.04	0.01	0.01	0.00	0.03
Stress * BMI	0.00	0.01	−0.01	0.02	0.00	0.00	−0.01	0.01
Random effects								
SD (intercept)	0.31	0.06	0.18	0.43	0.10	0.04	0.02	0.18
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.09

Note: CI = credible interval; LL = lower limit; UL = upper limit.

participants consume on average 534 kcal in time intervals with average stress in which energy intake occurred. Gender has a fixed effect on the (log) energy intake. Through exponentiation, we get the rate decrease in the amount of energy intake associated with the female gender. Hence, women consume on average 16.5% less in time intervals in which energy intake occurred compared with men (e^{-18} = 83.5%). There is also a fixed effect of stress. On average 12.2% less energy is consumed in time intervals in which stress is one-unit higher than usual

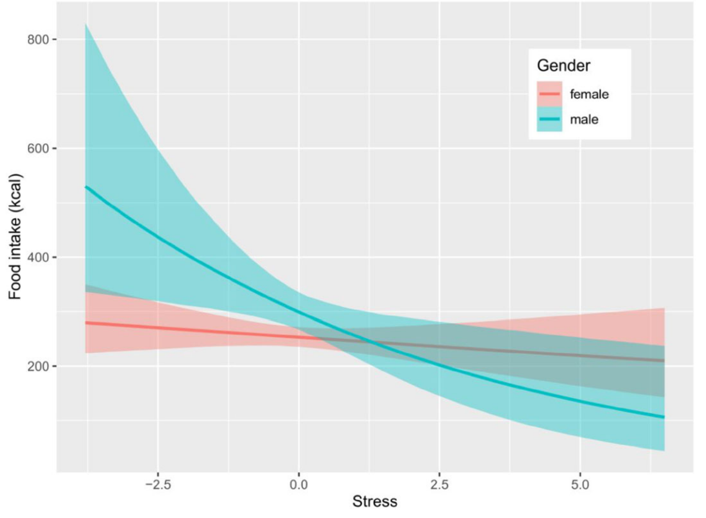

FIGURE 2 Relationship between stress and the amount of food intake moderated by gender. Note: The linear effect of stress on (log) food intake translates to an exponential effect of stress on food intake in the original metric kcal.

(10 points on the original 0 to 100 scale). The cross-level interaction between stress and gender is significant indicating that gender moderates the relationship between stress and the amount of energy intake as illustrated in Figure 2. Increased stress is associated with a decrease in the amount of energy intake in men, whereas no association between stress and the amount of energy intake is observed in women.

Age and BMI did not moderate the stress and eating relationship in either of the two model parts and did not have a statistically meaningful main effect on the probability not to eat. Only BMI, not age, had a small fixed effect on the (log) amount consumed in time intervals in which eating occurs (a one-unit increase in BMI is associated with a 1% increase in the amount of food intake).

Trait stress-eating

Trait stress-eating did not significantly moderate the relationship between stress and the probability not to eat as well as the (log) amount consumed in time intervals in which eating occurred (see Table 4). There was no fixed effect of trait stress-eating in either of the two model parts.

Eating styles

No eating style significantly moderated the relationship between stress and the probability not to eat as well as the (log) amount consumed in time intervals in which eating occurred (see Table 5). The three eating styles had no fixed effects in either of the two model parts.

TABLE 4 Model estimates of the multilevel two-part model of the moderating effect of trait stress-eating

	Zero part				Continuous part			
			95% CI				95% CI	
	Estimate	**SE**	**LL**	**UL**	**Estimate**	**SE**	**LL**	**UL**
	Model 5: SSES							
Fixed effects								
Intercept	−0.28	0.05	−0.38	−0.19	6.15	0.03	6.09	6.20
Stress	0.03	0.03	−0.04	0.09	−0.04	0.02	−0.08	0.00
SSES	−0.10	0.08	−0.26	0.07	−0.02	0.05	−0.12	0.07
Stress * SSES	−0.00	0.05	−0.11	0.10	0.01	0.04	−0.06	0.09
Random effects								
SD (intercept)	0.32	0.06	0.19	0.44	0.11	0.04	0.04	0.19
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.09

Note: CI = credible interval; LL = lower limit; UL = upper limit.

DISCUSSION

Following a novel approach—assessing actual food intake in an EMA setting combined with sophisticated multilevel two-part modelling—the present study assessed (1) whether individuals differ in the stress and eating relationship, (2) whether individual differences in the stress and eating relationship can be explained by person characteristics (i.e., gender, age, BMI, trait stress-eating, and eating styles), and (3) whether these findings support the individual-difference model.

The results of the present study indicate that stress was not related to whether individuals eat. The relationship between stress and the occurrence of eating was not moderated by gender, age, BMI, trait stress-eating, and eating styles. Stress had a significant effect on the amount of food intake in men, but not in women. That is, increased stress was associated with decreased amounts of food intake in men. BMI, age, trait stress-eating, and eating styles did not moderate the relationship between stress and the amount of food intake. Stress had no significant random effect. This indicates that individual differences in the stress and eating relationship were minor.

The present study provides first evidence that stress is not associated with whether individuals eat in daily life. The effect of stress seems to manifest primarily in the amount of food intake. Accordingly, stress may not be related to individuals being more or less likely to eat, whereas in men (but not in women), it may be associated with how much individuals eat when they eat. As this is the first study that differentiates between effects of stress on the occurrence and the amount of food intake, further studies are needed to verify these findings.

Given the large heterogeneity in findings across studies, which assess moderating effects of person characteristics in the stress and eating relationship, it is not surprising that our results are in line with some, but contradict others. For instance, contrary to O'Connor et al. (2008), Wallis and Hetherington (2004), and Wardle et al. (2000), who found that individuals higher in dietary restraint are more likely to increase food intake when experiencing stress, restrained eating did not moderate the stress and eating relationship in the present study as well as in

TABLE 5 Model estimates of the multilevel two-part models of the moderating effect of eating styles

	Zero part				Continuous part			
			95% CI				95% CI	
	Estimate	SE	LL	UL	Estimate	SE	LL	UL
	Model 6: Cognitive restraint							
Fixed effects								
Intercept	−0.28	0.05	−0.37	−0.19	6.15	0.03	6.10	6.20
Stress	0.02	0.03	−0.04	0.09	−0.04	0.02	−0.08	0.00
Restraint	0.02	0.01	−0.00	0.04	−0.00	0.01	−0.01	0.01
Stress * restraint	0.01	0.01	−0.01	0.02	0.00	0.00	−0.01	0.01
Random effects								
SD (intercept)	0.32	0.06	0.19	0.44	0.12	0.04	0.03	0.19
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.09
	Model 7: Disinhibition							
Fixed effects								
Intercept	−0.28	0.05	−0.37	−0.18	6.15	0.03	6.10	6.20
Stress	0.03	0.03	−0.04	0.09	−0.04	0.02	−0.08	0.00
Disinhibition	0.00	0.02	−0.03	0.03	−0.01	0.01	−0.02	0.01
Stress * disinhibition	0.00	0.01	−0.02	0.03	0.00	0.01	−0.01	0.02
Random effects								
SD (intercept)	0.33	0.06	0.21	0.45	0.12	0.04	0.03	0.19
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.02	0.00	0.09
	Model 8: Hunger							
Fixed effects								
Intercept	−0.28	0.05	−0.37	−0.18	6.15	0.03	6.10	6.20
Stress	0.03	0.03	−0.04	0.10	−0.03	0.02	−0.08	0.01
Hunger	−0.02	0.02	−0.05	0.01	−0.00	0.01	−0.02	0.01
Stress * hunger	−0.00	0.01	−0.02	0.02	−0.01	0.01	−0.02	0.01
Random effects								
SD (intercept)	0.31	0.06	0.19	0.43	0.11	0.04	0.03	0.19
SD (stress)	0.06	0.04	0.00	0.16	0.03	0.03	0.00	0.09

Note: CI = credible interval; LL = lower limit; UL = upper limit.

previous studies (Conner et al., 1999; Pollard et al., 1995). Furthermore, comparability of findings across studies is low due to differences in study design (e.g., daily diary—O'Connor et al., 2008; within-subject experimental design—Wallis & Hetherington, 2004; quasi-experimental approach—Pollard et al., 1995). Nevertheless, our findings are of importance as they provide novel evidence on the role of gender, age, BMI, trait stress-eating, and eating styles in the stress and eating relationship in daily life.

The results of the present study highlight the need to account for gender differences when studying the stress and eating relationship in daily life. Increased stress was associated with decreases in the amount of food intake in men, while stress was not related to changes in consumed amounts in women. Hence, men's eating behaviour seems to be affected by stress more intensely compared with women. While this is in line with a study by Grunberg and Straub (1992), which showed that men significantly decreased food consumption in the stress condition, it contradicts a study by Conner et al. (1999), which found no gender differences. Our finding could, to some extent, be explained by gender differences in compliance. Systematic noncompliance due to stress is a potential source of bias in EMA studies. Participants might be less likely to report all consumed foods when experiencing stress, whereby it appears as if food intake decreases as a response to stress. This effect might be particularly relevant in male participants as a recent meta-analysis indicates that women are more compliant compared with men, especially in EMA studies with many assessments (Wrzus & Neubauer, 2022). Even though the number of signal-contingent assessments was rather low in the present study, keeping record of food intake in daily life can be highly burdensome. However, to reduce the risk for bias due to systematic noncompliance in food recording when experiencing stress, we rigorously excluded participants and days with poor dietary records.

Reichenberger et al. (2021) found a relationship between stress and food intake (moderated by trait stress-eating) only on the day level, but not on the within-day level. They conclude that stress might have only prolonged or cumulative effects on food intake. A similar explanation was presented by Zenk et al. (2014), who outline that daily hassles might not influence snack food intake in small windows of time during a day, rather when daily hassles accumulate throughout the day. In contrast, the present study found that stress was associated with food intake on the within-day level in men, emphasizing the relevance of short-term effects of stress on food intake. This is in line with laboratory studies that found effects of stress during or shortly after stress-induction (e.g., Epel et al., 2001—within the subsequent 30 min; Grunberg & Straub, 1992—during a 14-min stress-inducing film). More EMA studies that assess actual food intake are needed to specify the time window in which stress affects food intake.

No moderating effect of trait stress-eating on the stress and food intake relationship was identified in the present study. Hence, trait stress-eating may not reliably predict if an individual eats more, less or the same in response to stress in daily life. This questions the ecological validity of self-reported trait stress-eating. Similar questions have been raised in the context of emotional eating (Adriaanse et al., 2011; Bongers & Jansen, 2016). Self-report emotional eating questionnaires seem not to measure what they intend to measure (i.e., increased food intake when experiencing negative emotions) and therefore lack predictive and discriminative validity (Bongers & Jansen, 2016). Further research is needed to assess the ecological validity of trait stress-eating questionnaires.

To our surprise, stress had no significant random effect indicating that individual differences in the stress and eating relationship were minor. This could be due to the fact that participants showed relatively low levels of stress. Only in 195 time intervals (out of 2779) stress was rated above 50 (with the highest score being 100). Again, systematic noncompliance could be a reason for this, as participants might be less likely to respond to prompts when experiencing stress and therefore higher levels of stress might be underrepresented in the data. However, this bias is most likely small in the present study given the high degree of compliance. Another explanation for the lack of individual differences in the dietary response to stress might be intraindividual (i.e., within-person) variability. Individuals might not always show the same dietary response to stress (as outlined below) and therefore intraindividual variability might mask individual differences.

We found fairly strong cross-part correlations in the multilevel two-part models indicating that individuals, who consume on average more energy when they eat, eat less often. Not accounting for this (i.e., running separate models) can cause bias particularly in the continuous part, as higher values of food intake will be underrepresented and smaller values overrepresented (see Ruf, Neubauer, et al., 2021, for a detailed description of this problem). This bias is still present when one is only interested in the continuous part and therefore choses to fit a single model (Su et al., 2009). This highlights the need for multilevel two-part modelling when studying the stress and eating relationship in an EMA setting.

Most research on stress-eating is based on the individual-difference model and thereby on the assumption that the dietary response to stress is stable within an individual (i.e., a trait). Hence, individuals are grouped into different stress-eater types. Even though research has been trying for decades to identify variables that moderate the stress and eating relationship and thereby explain individual differences in the dietary response to stress, no final conclusions can be drawn as findings are highly inconsistent. This poses the question whether stress-eating is as stable as yet assumed. While there is some evidence that the dietary response to stress is rather stable within individuals (Stone & Brownell, 1994), temporal and situational factors (e.g., location, social context, affective, and physical states) that change over short periods of time play an important role in shaping eating behaviour (Dunton, 2018). Instead of trying to understand between-person effects of time-invariant explanatory factors, such as traits and sociodemographic characteristics, on behaviour, there is a need to understand microtemporal processes underlying eating behaviour (Dunton, 2018). Furthermore, Huh et al. (2015) highlight the importance of taking time-varying relationship patterns into account in order to contribute to a deeper understanding of the effects of stress on eating behaviours. First evidence suggests that the stress and eating relationship might be influenced by time-varying factors, such as easy food availability (Zenk et al., 2014). Consequently, it may be time to expand the individual-difference model (Greeno & Wing, 1994) to a dynamic individual-difference model that accounts for dynamic, time-varying factors (external as well as internal) that may moderate the stress and eating relationship (see Figure 3). According to the extended model, time-varying factors might alter an individual's dominant dietary response to stress. Hence, the aim should not only be to identify individuals at greater risk for stress-related changes in food intake but also situations with increased risk for these changes. Research is needed to verify the relevance of the extended model.

Strengths and limitations

The present study has two main strengths: (1) The assessment of actual food intake based on a validated tool in an EMA setting and (2) the data analysis through multilevel two-part modelling, which prevents bias in parameter estimates (as outlined above) and allows new and distinct insights. EMA has great potential to advance the understanding of the stress and eating relationship. It provides more valid and more detailed data about real-world behaviour and experience and sheds light on the dynamics of behaviour in individuals' natural environments (Shiffman et al., 2008). Many authors have expressed the need for studies that assess food intake more accurately, such as energy intake (Araiza & Lobel, 2018; Hill et al., 2021). The present study used a validated EMA tool (Ruf, Koch, et al., 2021) for the assessment of complex dietary

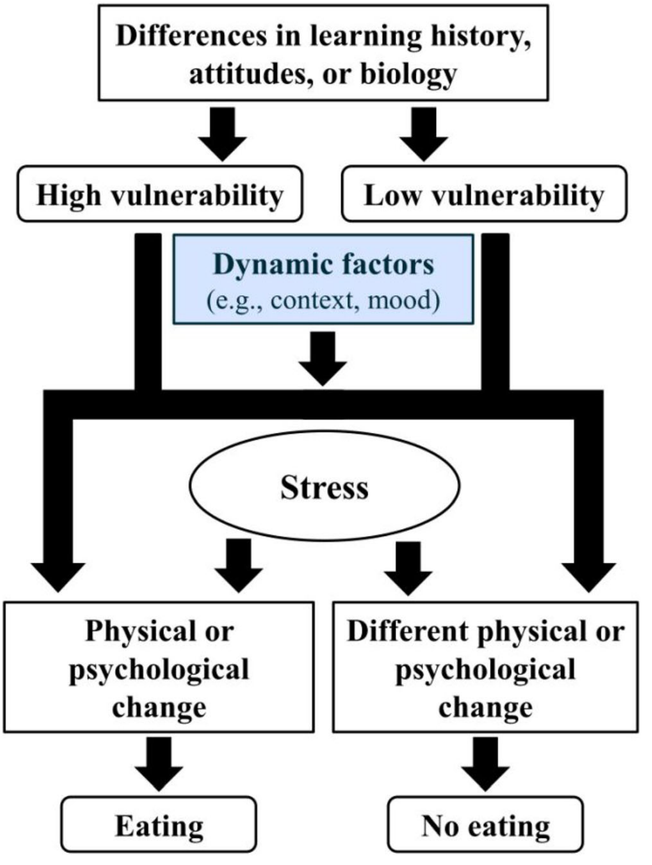

FIGURE 3 Expansion of the individual-difference model of stress-eating by Greeno and Wing (1994) to a dynamic individual-difference model

intake. In doing so, it is the first EMA study investigating the link between stress and actual food intake in daily life in a larger sample. Nevertheless, the food record relied on self-reports, which can cause bias (e.g., systematic noncompliance with reporting foods due to stress as described above). However, using EMA to capture food intake in real time or near real time instead of retrospectively as in traditional dietary assessment methods (e.g., 24-h recalls) seems to provide improved reporting accuracy (Ruf, Koch, et al., 2021).

Asking participants how stressed they were since the last prompt instead of momentarily while having semirandom prompts produced stress measurements for time intervals of different lengths. This is problematic given that it requires participants to average their level of stress over the duration of the time interval. Hence, shorter time intervals reflect more recent measurements of stress compared with longer intervals. For instance, a time interval of 1 h provides a more recent stress measure compared with a 2-h interval. As the recency of the stress assessment likely confounds the effect of stress on subsequent food intake, we decided to assess the effect of stress on concurrent food intake. This limits our findings as temporal associations cannot be established. A further limitation concerns the relatively low level of stress found in the present sample (as outlined above). The findings of the present study may therefore be limited to a restricted range of the stress continuum.

Recommendation for future studies

More studies of high methodological quality assessing intraindividual and interindividual processes in real time are needed to study the relationship between stress and actual food intake in daily life. However, studying stress and actual food intake in daily life can be challenging. Capturing actual food intake through self-reports is prone to bias and burdensome. Yet, only if compliance is high, the link between stress and food intake can be studied meaningfully. Additional to the event-contingent assessment of food intake, asking participants whether all eating occasions have been recorded since the last prompt within the signal-contingent prompts, could reduce the risk of food intake not being reported and thereby further improve the assessment of food intake. Beyond that, advances in the dietary assessment (e.g., passive detection of eating episodes and reliable photo-based dietary assessments) are needed in order to decrease participants' burden, particularly if studies plan to assess food intake over a longer period of time. Furthermore, systematic noncompliance as a response to stress (as outlined above) has to be carefully taken into account. Using passive sensing of physiological stress responses (e.g., heart rate variability) in addition to self-reports can help to circumvent this problem in future studies. Furthermore, individuals are less willing to take part in EMA studies during stressful times (e.g., when work is demanding) resulting in a selective sample. Targeted efforts are needed in order to include individuals into a study when the assessment period is representative.

The distinct findings regarding the occurrence and the amount of food intake as well as the strong cross-part correlations in the present study highlight the importance of multilevel two-part models when examining the stress and eating relationship in daily life. For this reason, future studies should incorporate multilevel-two part modelling (practical guidance on this type of analysis can be found in Ruf, Neubauer, et al., 2021).

CONCLUSION

Individual differences in the dietary response to stress might not be as stable as has been assumed so far. We suggest that the dietary response to stress might not only differ between individuals but also within individuals (i.e., between situations). First evidence indicates that time-varying factors (such as food availability) moderate the stress and eating relationship. For this reason, we propose an expansion of the individual-difference model: a dynamic individual-difference model that accounts for time-varying factors as potential moderators of the stress and eating relationship. Research is needed to verify the extended model.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

ETHICS STATEMENT

The local ethics committee of the faculty of medicine of the Goethe University Frankfurt (Ethikkommission des Fachbereichs Medizin der Goethe-Universität) approved the study (reference number: 192/18). All subjects declared that they understood the study procedure and signed a written informed consent.

DATA AVAILABILITY STATEMENT

The data and R code that support the findings of this study are available in the supporting information of this article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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