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Effects of stress on chewing and food intake in patients with anorexia nervosa

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Abstract

Objective: The present study investigates the impact of psychosocial stress on chewing and eating behavior in patients with anorexia nervosa (P_{AN}).

Method: The eating and chewing behavior of P_{AN} were examined in a standardized setting by means of a chewing sensor. These procedures encompassed n = 19 P_{AN}, age, and gender matched to n = 19 healthy controls (HC). Food intake and chewing frequency were assessed in two experimental conditions: rest versus stress (via Trier Social Stress Test). To verify stress induction, two appraisal scales were employed. In addition, chronic stress, psychological distress and eating disorder symptoms were assessed.

Results: In terms of food intake and chewing frequency, the results of the 2x2 ANOVA demonstrated a significant effect of *condition* and *group*. During stress, all participants demonstrated a higher chewing frequency and a decreased ingestion. In general, patients ate less at a lower chewing frequency (vs. HC). However, sample specific analyses demonstrated that the eating and chewing behavior of P_{AN} remained unchanged regardless of the condition, except for their drinking. Food choices were comparable between the groups, but appetite values significantly differed.

Discussion: The increase in chewing frequency in all participants during stress suggests that chewing might impact affect regulation, however, not specifically in P_{AN}. Future research should clarify to what extent the normalization of chewing behavior could ameliorate ED-symptoms (incl. food intake) in P_{AN}. The application of a chewing sensor could support this aim and future interventions.

KEYWORDS
anorexia nervosa, chewing frequency, chewing sensor, eating disorders, food intake, ingestion monitoring, laboratory eating behavior, psychology, stress induction, Trier Social Stress Test (TSST)

1 | INTRODUCTION

Anorexia nervosa (AN) has the highest mortality rate compared to other eating disorders (EDs; Arcelus, Mitchell, Wales, & Nielsen, 2011; Erskine, Whiteford, & Pike, 2016; Gosseaume, Dicembre, Bemer, Melchior, & Hanachi, 2019; Keshaviah et al., 2014; Papadopoulos, Ekbom, Brandt, & Ekselius, 2009; Smink, Hoeken, & Hoek, 2012) and is typically characterized by an extreme caloric restriction and an exaggerated fear of weight gain (DSM-V; APA, 2013; Seidel et al., 2018) in spite of being underweight (BMI < 17.5 kg/m^2). Additionally, patients with AN (P_{AN}) exhibit abnormal chewing behaviors (e.g., slow eating pace, chewing and spitting out food—CHSP; Aouad, Hay, Soh, & Touyz, 2016, 2019; Aouad et al., 2020; De Zwaan, 1997; Kovacs, Mahon, & Palmer, 2002; Makhzoumi et al., 2015). Besides other symptoms (e.g., low weight; DSM-V), some researchers considered CHSP as a marker of illness severity, since it is associated with a higher degree of severity in eating-related pathology (i.e., exacerbated ED-symptomatology: excessive weight control behaviors, for example, restrictive eating, diet pill and laxative abuse, exercise beyond the effects of behavioral subtype), poor (mental/physical) health, and impaired quality of life (Aouad et al., 2016, 2019; Kovacs et al., 2002; Makhzoumi et al., 2015).

Chewing plays a key role in ingestion, impacts appetite, cortisol, and it can be affected by stress (Miquel-Kergoat, Azais-Braesco, Burton-Freeman, & Hetherington, 2015; Tahara, Sakurai, & Ando, 2007). However, the empirical evidence on the impact of psychosocial stress (i.e., social evaluation, exclusion, performance/achievement context; Dickerson & Kemeny, 2004; Kirschbaum, Pirke, & Hellhammer, 1993; Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003) on the chewing behavior of healthy individuals is unclear (Gray et al., 2012; Herhaus, Päßler, & Petrowski, 2018; Johnson, Jenks, Miles, Albert, & Cox, 2011; Petrowski, Wintermann, Joraschky, & Päßler, 2014; Torney, Johnson, & Miles, 2009) and unknown in P_{AN}.

In contrast, it is well documented that compared to healthy controls (HC), P_{AN} consume less food (Rolls et al., 1992; Steinglass et al., 2010; Sysko, Walsh, Schebendach, & Wilson, 2005) and chew at a slower pace (Hadigan et al., 2000; Halmi & Sunday, 1991; Zandian, Ioakimidis, Bergh, & Södersten, 2007). Correlatively, it is known that the HPAA (Hypothalamic–Pituitary–Adrenal Axis) is activated in P_{AN} (Lo Sauro, Ravaldi, Cabras, Faravelli, & Ricca, 2008; Paszynska et al., 2020; Paszynska, Dmitrzak-Weglarz, Tyszkiewicz-Nwafor, & Slopien, 2016), suggesting that stress plays a role in eating and chewing behavior (Keys, Brožek, Henschel, Mickelsen, & Taylor, 1950; Peters et al., 2004; Peters, Kubera, Hubold, & Langemann, 2011; Zandian et al., 2007). For example, an earlier study reported that food-deprived participants consumed exaggerated amounts of chewing gum (40 packs/day; Keys et al., 1950), suggesting increased chewing. A similar behavior pattern of excessive jaw activity, as in bruxism (i.e., extreme chewing, teeth grinding/clenching) was also identified in ED-patients (Emodi-Perlman et al., 2008; Ximenes, Couto, & Sougey, 2010). Since starvation is a bodily stressor that activates the HPAA (Culbert, Racine, & Klump, 2016; Fichter & Pirke, 1986; Nakamura, Walker, & Ikuta, 2016; Stone, Harmatz, & Goosens, 2020) and bruxism is a stress-related disorder (dos Santos Chemelo et al., 2020; Foley, 2020) it is plausible to assume increased jaw activity in P_{AN} in the context of stress. However, the mentioned studies lack a standardized and experimentally induced stress intervention and avail themselves only as a point of reference. Hence, this assumption needs further examination.

Researchers highlighted the relevance of studying chewing behavior (e.g., chewing frequency/rate, eating pace) in order to understand the "eating style" that leads to an abnormal food intake. In this context, previous experimental research has been conducted with patients with a binge eating disorder (BED; Laessle & Schulz, 2009; Schulz & Laessle, 2012; Sysko, Devlin, Walsh, Zimmerli, & Kissileff, 2007) but not in $P_{AN.}$ In addition, a limitation of this research is the use of less appropriate measurement technology, addressed by the current study. Taking these aspects into consideration, it is pertinent to assess chewing in a P_{AN}-specific sample compared to HC. Therefore, the main purpose of the present study is to expand P_{AN}-specific data and investigate the impact of psychosocial stress on their eating and chewing behavior under controlled conditions. To this end, we applied a psychosocial standardized stressor (i.e., Trier Social Stress Test—TSST; Kirschbaum et al., 1993) and a high-tech chewing sensor (Päßler, Wolff, & Fischer, 2012). In line with previous research, we proposed the following hypotheses: (**H_1**) Based on data related to exaggerated chewing activity and food restriction, we expected a higher chewing frequency in P_{AN} during stress than at rest. (**H_2**) According to previous evidence, we hypothesized a reduced food intake in P_{AN} during stress than at rest. Consistent with the general criteria of AN and previous research, we assumed that (**H_3**) P_{AN} would exhibit a lower mean chewing frequency and (**H_4**) consume less food in comparison to HC in both experimental conditions.

2 | METHOD

2.1 | Participants

In the present study n = 19 P_{AN} (BMI: 17.80 ± 1.70 kg/m^2) and n = 19 HC (BMI: 22.12 ± 1.32 kg/m^2) were recruited to investigate the effects of psychosocial stress on eating and chewing behavior. Patients were admitted in the department of Psychotherapy and Psychosomatic at a German treatment clinic in Dresden, with a primary diagnosis of AN and were recruited during inpatient treatment. This clinic offers a program for all kinds of EDs and provides a multimodal therapy (e.g., psychodynamic elements, behavioral therapy approaches) with other treatment elements, such as art therapy (relationship-oriented, resource-oriented, perception-oriented) and relaxation techniques (autogenic training, PMR). During inpatient treatment some of the P_{AN} were artificially nourished and not open for participation. Consequently, these patients were not included in the study, but were invited for later participation (e.g., after termination of nasal gastric feeding). Hence, most of the P_{AN} who agreed to take part in our

TABLE 1 Characteristic of the participants

	P_{AN}	HC	t/x^2	*p*
Total (*N*)	19	19		
Female, *n* (%)	17 (89.5)	17 (89.5)		
Age *M* (*SD*)	25.26 (5.53)	24.16 (5.12)	.639	.527[a]
BMI *M* (*SD*)	17.80 (1.70)	22.12 (1.32)	−8.751	.001***[,a]
Contraceptives *n* (% females)	2 (10.5)	7 (36.8)	2.792	.095[b]
TICS (SSCS)	22.46 (8.27)	13.78 (6.65)	3.558	.001***[,a]
Smokers, *n* (%)	6 (31.58)	2 (10.53)	2.533	.111[b]
Cigarettes/day (of smokers)	10.83 (5.45)	1.75 (1.06)	2.225	.068[a]
Psychological variables	**Scores**	**Norm values**	**Interpretation**	
BDI	35.12 (17.03)	<14 = normal. 14–19 = mild. 20–28 = moderate. **29–63** = severe depression.	Severe depression	
SCL (GSI)	11.10 (6.09)	**Score 11** = percentile 92%. Score 15 = Percentile 95.2%	Pronounced psychological burden	
EDI	139.26 (53.07)	**Score 140–155** = Percentile = 85%.	Pronounced ED-symptoms	

Abbreviations: BDI, Beck Depression Inventory; EDI, Eating Disorder Inventory; HC, healthy controls; M, mean; P_{AN}, participants with anorexia nervosa; SD, standard deviation; SCL, Symptom-Checklist-GSI, Global Severity Index; TICS, Trier Inventory Chronic Stress.
[a]Independent *t*-test.
[b]Chi-square test.
***$p \leq .001$.

study were not severely malnourished and included after a positive re-examination of the inclusion criteria (18–65 years of age) and a confirmed diagnosed AN (based on the Structured Clinical Interview [SCID] of the Diagnostic and Statistical Manual of Mental Disorders [DSM-IV]; First, Gibbon, Spitzer, Williams, & Benjamin, 1997; Wittchen, Wunderlich, Gruschwitz, & Zaudig, 1997). P_{AN} with mental disorders other than depression, chronic diseases (e.g., autoimmune disorders), and any medication treatment were excluded. HC between 18–65 years of age were recruited through online media, newspapers and bulletin boards at several universities. Only individuals with a healthy weight (BMI = 18.5–25 kg/m^2) and the absence of a past, current eating or other mental disorder, medication treatment and dietary restrictions were included. HC with a chronic illness and stressful life events in the past 6 months were excluded. P_{AN} were age and gender matched to HC. Every participant received an expense allowance of 50 Euro after successful participation on two consecutive test days. A description of all *N* = 38 participants is displayed in Table 1. Ethical approval was obtained from the Ethics Committee of the Medical faculty of the Technical University of Dresden, Germany (No#EK25012013).

2.2 | Procedure

All participants were scheduled on two consecutive days for two different experimental conditions (*stress* and *rest*) on a certain weekday (2:00–4:00 p.m.) and were previously requested to refrain from eating, drinking, and smoking for at least 3 hr prior examination. Upon arrival, participants signed an informed consent form and filled out psychological questionnaires for around 30 min. After submission, the testing started with a resting period lasting 15 min. At the same time, participants were instructed to “test-eat” two bites for placement purposes and habituation to the chewing sensor. Immediately after, the participants were randomly assigned to the *stress* or to the *resting* condition: 19 participants took part in the resting condition, while the other 19 started with the stress condition. On the next day, all participants returned to participate on the remaining condition (see Figure 1). The *stress* condition consisted on the exposure to a standardized stressor (TSST; Kirschbaum et al., 1993) while the *resting* condition took part in a neutral and quiet environment. During the respective condition all participants were asked to complete the Primary Appraisal Secondary Appraisal questionnaire (PASA; Gaab, 2009). After either condition, participants rated their food preferences, appetite, and perceived stress by means of the visual analogue scale (VAS; Flint, Raben, Blundell, & Astrup, 2000). Both experimental conditions were followed by an eating phase. In this stage, participants were instructed to eat and drink at libidum, while wearing the sensor. An overview of the process is illustrated in Figure 1.

2.3 | Experimental conditions: Stress versus rest

Stress condition. The TSST is a validated and a standardized procedure, recognized for its effective stress induction (Kirschbaum et al., 1993; Mohammadi et al., 2019). This psychosocial stress test generally consists of a social-evaluation with a lack of feedback in the context of performance. The testing includes 5 min of public speaking in front of

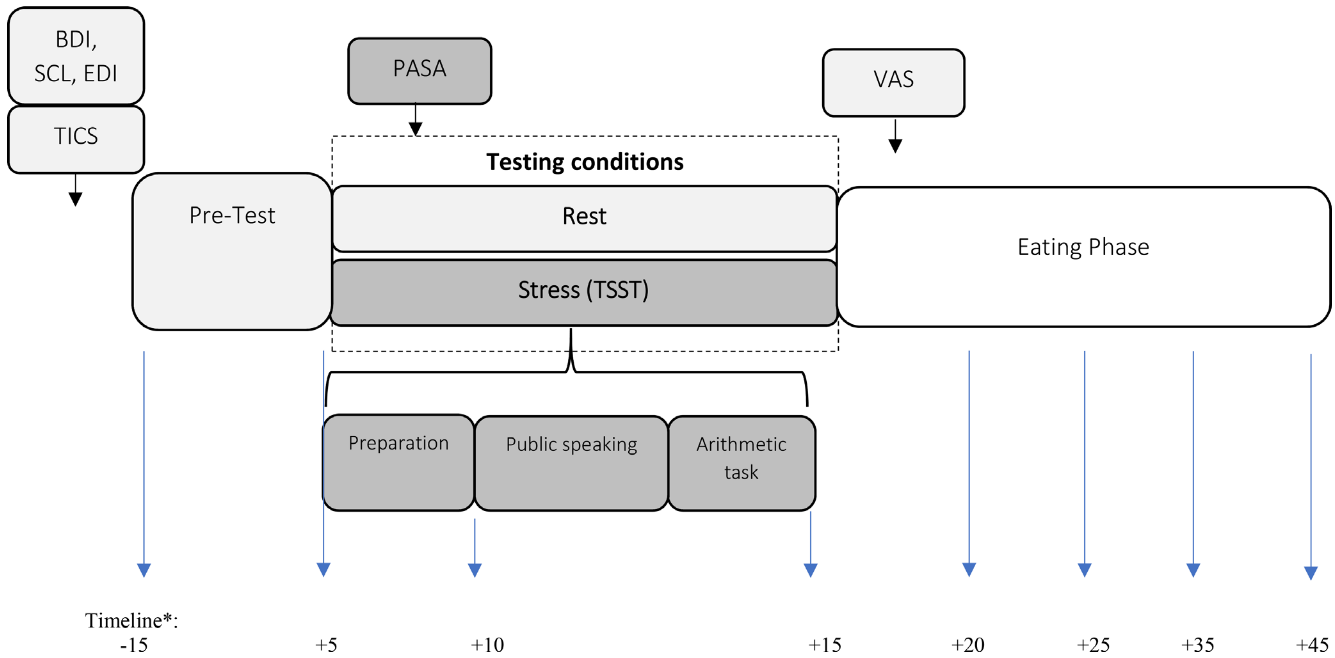

FIGURE 1 Timeline and design of experimental conditions. BDI, Beck Depression Inventory; SCL, Symptom Check List-K-9; EDI, Eating Disorder Inventory; PASA, Primary Appraisal Secondary Appraisal questionnaire; TICS, Trier Inventory for the assessment of Chronic Stress; TSST, Trier Social Stress Test; VAS, Visual Analogue Scale. * Timeline illustrated in minutes [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Subjective Stress Perception, Chewing Performance, and Food Intake

n =	P_{AN} (19)		HC (19)		ANOVA					
	Condition				Condition			Group		
	Rest	Stress	Rest	Stress	*F*	*p*	η^2	*F*	*p*	η^2
Stress perception	*M* (*SD*)									
PASA—Stress index	−1.46 (1.58)	.38 (1.43)	−2.43 (.75)	−.38 (.70)	77.887	<.001***	.68	7.564	.009**	.17
VAS	38.14 (12.56)	54.34 (14.85)	35.90 (14.16)	59.59 (11.52)	49.161	<.001***	.57	0.203	.655	.09
Chewing parameter										
Total ChF (Hz)	1.44 (.21)	1.47 (.21)	1.57 (.12)	1.61 (.14)	4.770	.036*	.12	5.807	.021*	.14
Food intake (g)										
Total beverage	169.97 (123.14)	185.32 (148.11)	295.47 (189.14)	289.21 (189.40)	.037	.848	.01	5.698	.022*	.14
	Rest	Stress	Rest	Stress	Condition			Group		
	Median				Wald-Test					
Non-parametric analyses					χ^2	*p*	OR*	χ^2	*p*	OR*
Eaten sandwich	7.8	8.0	109.7	85.0	7.00	<.001***	2	80.39	<.001***	18
Eaten cookie	27.1	21.0	28.5	28.30	.28	.590	0.8	1.65	.190	1.83
Total intake	42.0	36.7	149.0	116.0	6.87	.008	1.31	56.53	<.001***	18

Abbreviations: ChF, chewing frequency; g, grams; P_{AN}, individuals with anorexia nervosa; HC, healthy controls; M, Mean; PASA, Primary Appraisal Secondary Appraisal; SD, Standard Deviation; OR, Odds Ratio = Odds(Rest)/Odds(Stress); Odds(HC)/Odds(P_{AN}); VAS, Visual Analogue Scale.

*$p \le .05$;

**$p \le .01$;

***$p \le .001$.

TABLE 3 Baseline characteristics and appraisal of appetite in P_{AN} and HC at rest and after stress

Condition	P_{AN} Rest	P_{AN} Stress	HC Rest	HC Stress	Condition effect *F*	*p*
	Median (25–75% percentile				*Z*	
Total appetite	45.00 (15–60)	25.00 (0–40)	66.00 (52–73)	50.00 (42–78)	−3.230	.001***,a
Preference for …,						
Sweets	35.00 (6–75)	20.00 (2–55)	61.50 (34–76)	58.00 (28–65)	−1.883	.060[a]
Fruits	20.00 (5–50)	10.00 (0–50)	68.00 (45–84)	70.00 (51–85)	−.235	.814[a]
Starch	10.00 (0–35)	10.00 (0.0–35)	40.00 (23–70)	41.50 (22–62)	−.281	.778[a]
Salty	5.00 (0–15)	10.00 (0–20)	25.00 (5–70.5)	26.00 (6–61)	−.456	.649[a]
Vegetables	15.00 (5–45)	5.00 (0–35)	42.50 (25–66)	48.00 (28–65)	−.262	.793[a]
Meat	10.00 (0–25)	5.00 (0–35)	20.00 (6–55)	28.00 (5–66)	−.127	.899[a]
Milk food	20.00 (5–35)	10.00 (0–50)	57.50 (37–65)	44.00 (15–66)	−.759	.448[a]
Sour food	5 (3–20)	5.00 (0–10)	15.00 (4–60)	25.00 (14–44)	−.506	.613[a]
Fish	0.00 (0–5)	2.00 (0–5)	12.50 (4–60)	19.00 (2–58)	−1.093	.275[a]
Egg	00.00 (0–10)	2.00 (0–5)	14.50 (4–48)	12.50 (2–36)	−1.692	.091[a]

Abbreviations: HC, healthy controls; M, mean; min., minutes; P_{AN}, participants with anorexia nervosa; SD, standard deviation.
[a]Wilcoxon signed-rank test.
***$p \leq .001$.

a selected two-person panel and a mental arithmetic test. *Resting condition*. In this condition participants read fordable literature in a quiet and secluded room.

Chewing sensor. In general, chewing refers to the modus operandi related to mastication, eating speed or pace and related processes in the context of swallowing and digesting food. In the present study, chewing behavior was operationalized by chewing frequency (ChF).

The chewing behavior of all the participants was examined by a highly sensitive chewing sensor, which was placed in the external right ear canal of the participants. This device records sound sequences (Hz) during ingestion and determines mastication frequency based on the chewing sounds without observer bias and possesses a high accuracy (83%) in food intake detection (Päßler et al., 2012). In addition, it allows consistent specification of the types of foods consumed. The chewing events to measure ChF were detected with an algorithm in the recordings of an off-line procedure. The ChF was calculated as the mean value of five or more consecutive chewing events. A chewing event starts with the first bite and ends with the swallow. The collected data was subsequently assessed by trained scientific staff members. To increase measurement accuracy, a beginning, middle, and an end phase of each recording were determined and subsequently aggregated to a global mean value in terms of ChF (as presented in Table 2).

2.4 | Food intake

After each experimental condition, the eating phase began. All participants were told to drink and eat ad-lib. The snacks were representative of a typical western lunch and offered a sweet and a non-sweet type of food, these included = 4 halves of a cheese sandwich (from a local bakery), 7 milk-chocolate, and 7 dark-chocolate cookies (Schoko Keks, Griesson—de Beukelaer GmbH & Co.KG, Germany) apple juice (500 ml Solevita Apfel Nektar, Refresco Deutschland GmbH, Germany) water and mineral water (500 ml each). The food and beverages were measured in grams and weighed beforehand with a kitchen scale (accuracy = 0.01 g) in order to exactly determined the consumed amount of food. After the assigned condition, the participants filled out the scales on food preferences (see Table 3).

2.5 | Psychological questionnaires

Trier Inventory for the assessment of Chronic Stress (TICS-9; Petrowski, Kliem, Albani, Hinz, & Brähler, 2019; Schulz, Becker, & Schlotz, 2004). The TICS-9 measures perceived chronic stress during the last

3 months. Higher values indicate greater stress. Satisfactory psychometrics with a Cronbach's Alpha α = .88–.91 have been demonstrated in many studies (Petrowski et al., 2018; Petrowski, Kliem, et al., 2019; Petrowski, Paul, Albani, & Brähler, 2012).

Primary Appraisal Secondary Appraisal questionnaire (PASA; Gaab, 2009). This scale evaluates situational and disorder-specific cognitions. In the primary appraisal, specific situations are evaluated as *threatening* or *challenging*. The second appraisal records subjectively perceived coping skills (*self-concept and control expectancy*). Higher values mean greater stress perception. The PASA evinced reasonable psychometric properties and reliability (Cronbach's alpha = .61–.83; Carpenter, 2016).

Visual Analogue Scale (VAS; Flint et al., 2000). This measure was applied to assess the general appetite and special food preferences, such as sweet or salty food. Ratings were submitted on a 10-cm horizontal line between the items *no appetite* (0) and *extreme appetite* (100). Stress perception assessment of each experimental condition was also based on the VAS. Values ranged between *no stress* (0) to *severe stress* (100; Lesage, Berjot, & Deschamps, 2012).

Symptom-Check-List-9 (SCL-K-9; Klaghofer & Brähler, 2001). This scale assesses general psychopathology and provides a global severity index (GSI) as an indicator of overall psychological distress, with higher scores reflecting higher levels of distress as well as a greater symptom severity in nine psychopathological dimensions (e.g., *interpersonal sensitivity, anxiety and depressive symptoms, hostility*). For the purpose of the present study, we reported GSI-values. The psychometric properties are satisfactory showing good reliability (α = .83–.87). Normative percentile values specific to age and gender are provided by Petrowski, Schmalbach, Kliem, Hinz, & Brähler, 2019.

Beck Depression Inventory (BDI; Beck, Steer, & Brown, 1996; Hautzinger, Bailer, Worall, & Keller, 1994). The BDI records symptoms of depression, with higher scores demonstrating greater symptom severity. Cut-off values are established as follow: <14 = normal, 14–19 = mild depression, 20–28 = moderate depression, 29–63 = severe depression. The psychometric properties of the BDI are satisfactory and Cronbach's Alpha ranges from α = .89 to .94 (Beck et al., 1996; Hautzinger et al., 1994; Kühner, Bürger, Keller, & Hautzinger, 2007).

Eating Disorder Inventory (EDI; Garner, Olmstead, & Polivy, 1983; Thiel & Paul, 1988). The EDI measures symptoms and attitudes relevant to pathological eating behavior. The psychometric properties of the scale are satisfactory and reported Cronbach's Alpha range from α = .72 to .92 (Dinkel, Berth, Exner, Rief, & Balck, 2005; Garner et al., 1983; Thiel & Paul, 1988). In the present study, the evaluation of the EDI-score was based on the values provided by Kappel et al. (2012).

2.6 | Statistical analyses

The statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS version 24.0) and with *R* (R Core Team, 2013). The sphericity hypothesis was verified using the Mauchly test and the Greenhouse–Geisser correction was applied to adjust degrees of freedom when necessary. All data was normally distributed (except for the snack foods such as sandwiches and cookies). The optimum statistical sample size was calculated with the G*power program (version: 3.1.9.2.). Based on a medium effect size of Cohen's f = 0.25, two groups, n = 2 repetitions, a significant level of p = .05, power of 80% ($1 - \beta$ = 0.80), and after Bonferroni-correction, a total sample size of n = 19 for within-subjects factor and N = 38 for between-subjects factor was needed. Differences between both groups in terms of demographic characteristics (e.g., cigarette smoking), appraisal of appetite and psychological measures, were determined by means of independent t-tests and Chi-square tests. A two-way ANOVA for repeated measures with the between-factor *group* (P_{AN} vs. HC) and the within-factor for *condition* (rest vs. stress) was performed in order to determine main or interaction effects in ChF in response to stress. Additional paired sample t-tests were performed to specify differences within each experimental group. Food data were evaluated by means of non-parametric tests (i.e., Wald-test and Wilcoxon-test), due to their non-normal distribution.

3 | RESULTS

Table 1 illustrated no significant differences in the characteristics of the participants, except those resulting upon the diagnosis of AN (e.g., BMI, EDI-score). The elevated values in VAS and PASA demonstrated a successful stress induction in both groups (Table 2). No order of sequences effects was found (F [1, 36] = .276, p = .60, η^2 = .008).

A significant effect of condition indicated an increment in ChF and a decreased food intake in all participants. A significant group effect suggested a reduced ChF and ingestion (food/beverage) in P_{AN} compared to HC. This was also evident in the high effect sizes (see Table 2). Significant interaction effects were not observed. Besides the ANOVA, secondary analyses revealed the following results. (**H_1**) A higher ChF among P_{AN} during stress than at rest was not evinced (t [19] = −1.32, p = .20, d = .19). (**H_2**) Within analyses did not indicate a reduced ingestion in P_{AN} during stress than at rest (food: Z = −.63, p = .52, d = .29; beverage: t[18] = −.786, p = .44, d = .11). (**H_3**) P_{AN} ate significantly less than the HC in both conditions. Further, P_{AN} drank significantly less than HC during the *resting* condition (t[36] = −2.42, p = .02, d = .78). During *stress*, P_{AN} *increased* their drinking volume, but drank as much as the HC (t[36] = −1.88, p = .07, d = .61). (**H_4**) As opposed to HC, P_{AN} recorded a reduced ChF in both experimental conditions. For detailed results see Table 2, Figures 2 and 3.

Additional analyses. As demonstrated in Table 3, the appetite values of all participants are lower during stress than at rest. In terms of group differences, the appetite values in P_{AN} were consistently lower than in HC, however food preferences were comparable. HC ate *less* sandwiches, during *stress* than at rest (Table 2), while cookie consumption was not affected by stress. On the contrary, P_{AN} ate similar portions of cookies and sandwiches at rest and during stress. In contrast to healthy individuals, P_{AN} exhibited significantly higher means in chronic stress (TICS), stress appraisal (PASA) depression

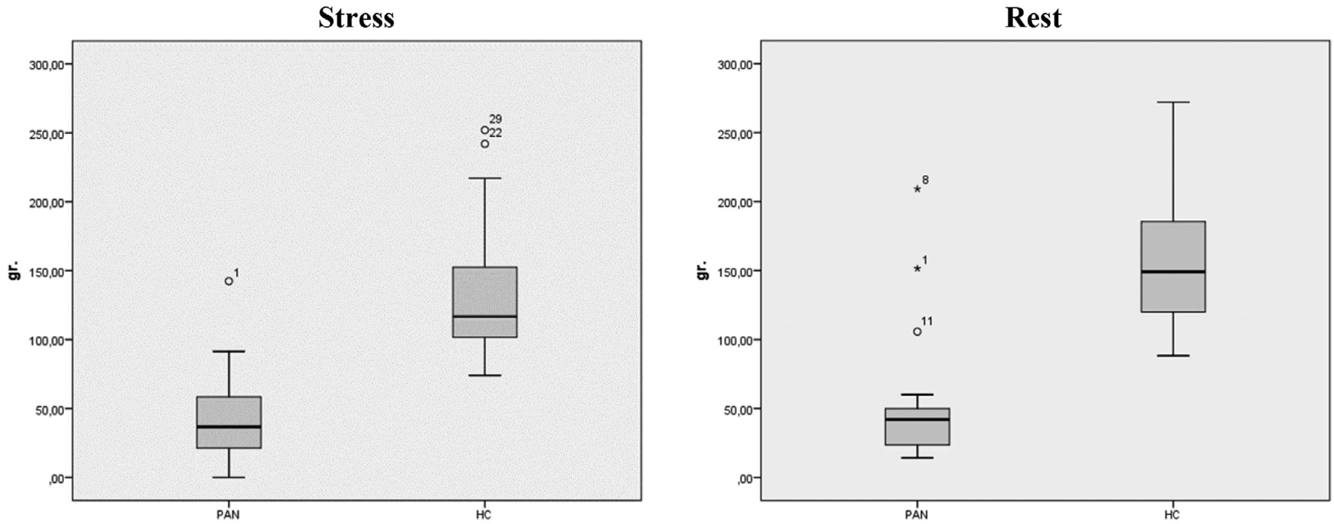

FIGURE 2 Total food intake during stress and at rest in P_{AN} and HC. HC, healthy controls; P_{AN}, patients with anorexia nervosa. * Outliers

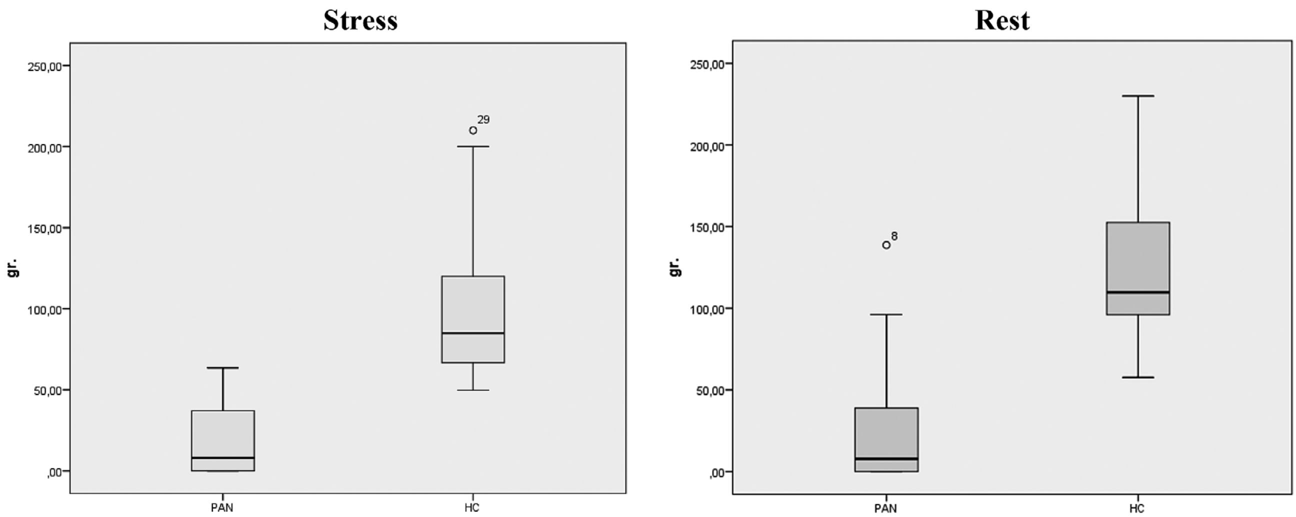

FIGURE 3 Eaten sandwich during stress and at rest. Non-parametric values (Wald-test) * Outliers. HC, healthy controls; P_{AN}, patients with anorexia nervosa

(BDI), ED-symptoms (EDI) and psychological distress (GSI)- see Tables 1 and 2.

4 | DISCUSSION

The aim of the present study was to investigate the influence of psychosocial stress exposure on the eating behavior (i.e., ingestion and mastication) in P_{AN} and analyze how these parameters differ from HC. Parameters like chewing frequency are relevant when discussing EDs, since symptoms related to mastication (e.g., CHSP) are correlated with pronounced illness severity and poor health outcomes. As far as we are aware, our study is the first to examine eating behavior parameters in a P_{AN}-specific sample under highly standardized conditions and by means of modern technology. In general, our research demonstrated an *increased* ChF in *all* participants, with a reduced food intake in HC and a preserved or unchanged ingestion in P_{AN} during stress. In terms of psychological measures, P_{AN} exhibited pronounced values of chronic and perceived stress relative to HC. In addition, they reported exacerbated ED-symptoms, depression, and psychological burden.

To some extent, the results of the present study broaden P_{AN}-specific data. Based on research related to exaggerated chewing/jaw activity and food restriction, (**H_1**) we expected a higher ChF in P_{AN} during stress than at rest. Contrary to this hypothesis, the mean ChF of P_{AN} was not affected by the stressor. At the same time contradicting previous related (Emodi-Perlman et al., 2008; Keys et al., 1950; Ximenes et al., 2010). Several aspects may explain the discrepancy between previous outcomes and our results: First, low statistical power in our analyses can be suspected, since the sample size for within-comparisons (n = 19) appears to be insufficient. An alternative explication lies in methodological differences (e.g., lack of stress induction) and in the quality of the sample (e.g., only men, mixed ED-groups, respectively). In opposition to our second hypothesis (**H_2** = reduced food intake in P_{AN} during stress vs. rest), our results indicated a preserved (i.e., unchanged) food intake in P_{AN} regardless of the experimental condition. A possible explanation proposes the presence of a dysregulated stress response, since the HPAA is already activated in P_{AN}. HPAA dysfunctionality is related to chronic stress, pronounced symptoms of depression and psychological distress, promoting ED-maintenance (Burke, Davis, Otte, & Mohr, 2005; Fiksdal et al., 2019; Fries, Hesse, Hellhammer, & Hellhammer, 2005; Het et al., 2015; McEwen & Wingfield, 2003). The former symptoms were indeed observed in our P_{AN}-sample. Thus, the preserved eating behavior can be interpreted as an adaptive response to the stress exposure. Moreover, we stated that (**H_3**) P_{AN} would exhibit a lower mean ChF and (**H_4**) consume less food in comparison to HC in both experimental conditions. In support of the **H_3**, patients notably exhibited a *lower* mean in ChF compared to HC. This observation underpins previous studies, stating a slow eating pace in AN (De Zwaan, 1997; Hadigan et al., 2000; Halmi & Sunday, 1991; Zandian et al., 2007). Even so, these studies merely represent a point of reference, since they lack a stress intervention and chewing was not systematically quantified. Our last hypothesis was verified by indicating that P_{AN} generally ingested less food than HC. This finding is in accordance with previous evidence on AN (DSM-V; Steinglass et al., 2010; Sysko et al., 2005; Rolls et al., 1992). Furthermore, additional analyses concerning appetite and food choices revealed that P_{AN} were less hungry than controls, but had similar food choices. In addition, it was evident that fatty and salty taste (sandwich) was rather affected by stress, than sweets (cookies). This corresponds with Wang's (2002) animal model, explaining that acute stress significantly suppresses fat consumption.

Overall, the stress induction in the present study was successful. A general increase in ChF and a tendency to reduce food consumption under stress was observed. Average food intake and mean ChF in P_{AN} was lower compared to HC. However, P_{AN}-specific (within) analysis revealed that food intake and chewing parameters were not significantly impacted by the acute stress intervention. In this regard, it should be noted that an activated HPAA is assumed in P_{AN}, but not in the healthy controls. Therefore, the acute stressor might have acted on two different states of the HPAA. Even if stressors obviously engage the HPAA in both groups, the relationship between increased chewing frequency and HPAA is not fully clear. Particularly, increased chewing is associated with stress regulation and decreased appetite (Hetherington & Boyland, 2007; Hetherington & Regan, 2011; Zibell & Madansky, 2009). This fits the results of Keys et al. (1950), whereby increased chewing/gum consumption helped regulate the psychological effects of starvation (e.g., distress, anxiety, depression) and food cravings, as suggested by more recent literature (Hetherington & Boyland, 2007; Hetherington & Regan, 2011; Zibell & Madansky, 2009). Increased chewing is also related to decreased cortisol levels (Tahara et al., 2007; Tasaka et al., 2018), stress perception, and anxiety in healthy individuals (Gray et al., 2012; Yaman-Sözbir, Ayaz-Alkaya, & Bayrak-Kahraman, 2019), suggesting a "relaxing" effect, as earlier evidenced (Hollingworth, 1939), and further confirmed (Nishigawa, Suzuki, & Matsuka, 2015; Tasaka et al., 2018) in research related to psychosocial stress (Gray et al., 2012; Sketchley-Kaye, Jenks, Miles, & Johnson, 2011; Yaman-Sözbir et al., 2019). Consequently, in the present study, we supposed a relationship between chewing and stress; whereby increased chewing might have acted as a stress regulatory mechanism, but not specific to P_{AN}. Notwithstanding, such findings refer to healthy individuals and it remains to investigate how increased ChF affects stress regulation in $P_{AN.}$

In general, the present study provided insights on the effects of stress on the eating and chewing behavior of P_{AN}. However, the results should be considered in light of the following limitations. A few weight-restored P_{AN} were included in the study. Hence, it cannot be discarded that some of them might have exhibited different eating and chewing patterns than those patients with a lower weight. Thus, this matter remains to be clarified. Furthermore, we acknowledge that the foods presented might have additionally stressed the patients. Thus, the possibility that P_{AN} could have chosen to eat a bit more at rest than during the stress condition, if presented with low-calorie food, cannot be excluded without additional research. Still, the food type we chose represented an average snack that people without an ED would "normally" pick. Additionally, it was also representative of a typical western lunch, offering one sweet and one non-sweet type of food. Besides, these food choices were selected based on similar studies that recommended this snack setting (Bellisle & Le Magnen, 1981; Epel, Lapidus, McEwen, & Brownell, 2001), eliciting a richer macronutrient profile than low-calorie food, allowing a more natural eating behavior. This can be advantageous since it allows comparability with other studies too. In any case, further studies could investigate the effects of stress in the chewing and eating behavior in P_{AN} and its subtypes when presented with other food choices (e.g., low-calorie snacks). Regardless of the significant effects reported, an evident limitation is the small sample size in our study. Therefore, larger studies with more robust samples are needed to back up the results and to shed light on to the non-significant trends. Additionally, future research could examine the relationship between regulation (i.e., normalization) of chewing behavior and further ED-symptoms (e.g., underweight). Additionally, researches could examine whether increased chewing is associated with functional stress coping in P_{AN}.

Overall, one of the major strengths of the present research is the application of novel and accurate technology for data collection on mastication without interfering in the natural process of food intake, which has been challenging in the past. A further strength is the novelty of our findings regarding the effects of psychosocial stress on ingestion and mastication of P_{AN}, since these outcomes were not represented in this field. Therefore, this is the first study that provides experimental data on the chewing and eating behavior in P_{AN} under a highly standardized setting (e.g., TSST, chewing sensor) including a control group. Considering all, our data are preliminary and further studies are still needed to validate these results.

In conclusion, the present study showed a general tendency in individuals toward a higher chewing frequency and decreased appetite and ingestion when confronted with a psychosocial stressor. Hence, a relationship between chewing, ingestion and affect regulation can be suggested. However, the extent of this effect and its consequences in P_{AN} require further examination. Future research could investigate to what extent the normalization of chewing behavior could ameliorate ED-symptoms (e.g., food intake) in P_{AN}. A chewing sensor could support this endeavor by providing consistent monitoring without observer bias and could possibly help prevent malnutrition.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of laboratory animals.

APPROVAL FOR HUMAN EXPERIMENTS

We provided an ethic vote from the licensing committee that approved the experiments, including any relevant details. (Please check the Section 2). We confirm that all experiments were performed in accordance with relevant named guidelines and regulations. We confirm that informed consent was obtained from all participants.

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