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How is variability in physiological responses to social stress related to punishment and reward sensitivities? Preliminary findings from the revised reinforcement sensitivity theory of personality perspective

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ABSTRACT

Objective: Although personality traits are assumed to have biological/physiological foundations, research has yielded mixed evidence regarding the relationship between personality and physiological stress responses. Moreover, the field has often overlooked the contemporary neuroscience-based personality approach, known as the Reinforcement Sensitivity Theory (RST) of Personality, in stress research.
Method: The present study examined the relationship between the revised RST's personality dimensions and heart rate and skin conductance level (SCL) in response to the Trier Social Stress Test in a sample of 61 healthy university students.
Results: Piecewise latent growth curve analysis controlling for the participants' current life stress, smoking use, and caffeine intake revealed that individuals with higher behavioral inhibition exhibited higher physiological reactivity, whereas those with high reward sensitivity showed smaller heart rate reactivity. The behavioral disengagement facet of the behavioral inhibition scale was associated with reduced sympathetic arousal during the stress task. Additionally, reward interest was associated with a larger recovery of SCL.
Conclusion: Results were generally in line with the revised theory. The study findings were discussed within the paradigm of the approach-avoidance conflict and highlighted the importance of reward sensitivity in stress resilience.

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reinforcement sensitivity; stress; personality; punishment; reward; behavioural inhibition

Stress is a well-established risk factor for both mental and physical diseases (Cleland et al., 2016; Whittaker et al., 2021). Stress reactivity encompasses the activation of various systems within the body and mind when exposed to stressors. For instance, stress triggers the sympathetic nervous system, resulting in the release of adrenaline into the bloodstream and an increase in heart rate. Furthermore, the perception of stress activates other systems, including the hypothalamic-pituitary-adrenocortical (HPA) axis, which releases cortisol, and the immune system (Kemeny, 2003; McEwen, 2017). Most of the rapid effects of stress are modulated by the sympathetic–adrenal–medullary (SAM) system, indexed by physiological responses such as increased heart rate and skin conductance level (SCL) (Allen et al., 2014). Stress can also evoke emotional responses (e.g., anxiety, fear, irritability) and cognitive changes (e.g., difficulty concentrating or hyper-vigilance). Nevertheless, stress responses are not uniform; individual differences play a significant role in how individuals react to stressors. Interindividual variations in

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stress reactions are prominent, and personality traits are among the most extensively studied factors contributing to this variability (Luo et al., 2023).

Personality traits are presumed to be relatively stable individual characteristics representing a person's emotional, behavioral, and cognitive makeup (Hampson, 2012). These traits are also believed to influence the perception of a situation (Carver & Connor-Smith, 2010), leading individuals to react to stressors in a highly personalized manner, even in physiological responses. However, little consensus exists on how personality traits relate to physiological stress responses. While some studies show significant associations, the relationships between personality traits and physiological stress responses are frequently inconsistent between studies. For instance, a meta-analysis revealed heterogeneous findings regarding diverse physiological outcomes. The study found that a composite measure of negative psychological states, consisting of anxiety, neuroticism, and negative affect, was negatively correlated with cardiovascular reactivity. However, this composite measure was not associated with HPA and sympathetic activity (Chida & Hamer, 2008).

Personality research heavily relies on the Five-Factor Model of Personality (McCrae & John, 1992) and Eysenck Personality Theory (Eysenck, 1967) generated by lexical and statistical methods, respectively. Although Eysenck primarily utilized factor analysis in describing trait dimensions, he proposed that personality traits reflect the sensitivities of specific systems in the brain. Nevertheless, studies have produced mixed results on the relationships between personality traits and physiological and biological stress reactivity. For instance, the neuroticism factor of both personality approaches has been associated with lower cortisol (Bibbey et al., 2013; Oswald et al., 2006) and cardiovascular responses (Bibbey et al., 2013; Higgins & Hughes, 2012; Hughes et al., 2011) while there have been positive relationships between neuroticism and cortisol elevation and cardiac activity in other studies (Evans et al., 2016; Zobel et al., 2004). Null findings have also been observed in many studies (e.g., Coyle et al., 2020).

Regarding extraversion, another shared personality trait, findings are not consistent either. Research on extraversion has generally produced null outcomes for both cortisol and cardiovascular stress responses (Bibbey et al., 2013; Coyle et al., 2020; Gallagher et al., 2018), although less physiological stress responses emerged in more extroverted participants in other studies (Evans et al., 2016; Jonassaint et al., 2009; O'Riordan et al., 2023).

Biologically based personality models propose hypothetical neuro-systems sensitive to specific conditions, eliciting distinct emotions and behavioral and cognitive reactions (Corr, 2004). Eysenck was among the first to propose a personality model emphasizing the biological foundation of neuroticism and extraversion. He believed individual differences are due to the arousability of the limbic and reticular activation systems (Corr & Perkins, 2006), although evidence for the arousal theory is highly mixed and complex (Corr, 2004; Matthews & Gilliland, 1999).

Gray (1970) proposed the different mechanisms underlying neuroticism and extraversion, suggesting that relative punishment and reward sensitivity are responsible for these traits. His alternative explanations gave birth to the new theory called the Reinforcement Sensitivity Theory (RST), which suggests that the relative sensitivity of the hypothetical neuropsychological systems to a given stimulus with a particular valence (rewarding or punishing) is responsible for appetitive or aversive motivation. Thus, experiencing any situation as stressful may depend on the degree to which these systems are activated.

In this study, we aimed to investigate the relationship between the personality traits proposed by the revised RST and physiological stress reactivity. We focused on social stress characterized by social-evaluative threat and demand, which requires an individual to produce a favorable impression on the evaluator.

Reinforcement sensitivity theory of personality

RST was first developed by Gray (1970) as an alternative to Eysenck's personality theory, and later, he revised the theory in accordance with the developments in neuroscience and data obtained from animal learning experiments (Gray & McNaughton, 2000). The revised RST postulates three motivational systems: The behavioral approach system (BAS), sensitive to appetitive or rewarding stimuli; the fight-flight-freeze system (FFFS), sensitive to all aversive or punishing stimuli; and the behavioral inhibition system (BIS), activated by conflicting stimuli (e.g., stimuli with both appetitive and aversive valence). In the original theory, BIS (original BIS) was responsible for mediating reactions to conditioned aversive stimuli, while it now takes on the role of conflict resolution. Conflict emerges from stimuli that activate both FFFS and BAS, as well as from FFFS-FFFS and BAS-BAS coactivation. The revised theory views fear (FFFS-mediated) and anxiety (BIS-mediated) as distinct phenomena, while the BAS remains unchanged mainly, mediating the approach behavior in the face of appetitive stimuli.

Most studies have examined the effect of reinforcement sensitivities on physiological responses to stress from the original perspective. Previous research demonstrated that in stress experiments requiring participants to acquire rewards, increased heart rate was associated with high BAS scores (Heponiemi et al., 2004). Conversely, high reward-sensitive individuals exhibited decreased heart rate reactions in experimental settings containing mental arithmetic stress with no evident rewarding stimuli (Knyazev et al., 2002). However, BIS showed no significant correlation with autonomic nervous system activity indicators in these studies, even when the situation involved loud noise punishment (Heponiemi et al., 2004; Knyazev et al., 2002).

In a recent study incorporating the revised version of the theory, exposure to the cold pressure (physical stress) task resulted in differential EEG activity in terms of wave type and location, depending on the sensitivities of BIS and FFFS. This study demonstrated the unique motivational outcomes of these two defensive systems (De Pascalis et al., 2019). These diverse outcomes may be more pronounced in human stress research incorporating social interaction.

Many social situations have the potential to generate approach-avoidance conflict (Corr, 2013). While social interactions are inherently rewarding for human beings, novel environments and ambiguous, unpredictable, or unfamiliar contexts activate the BIS, resulting in increased arousal (Barker et al., 2019). Unfamiliarity is a fundamental characteristic of any stressful event, and individuals with high BIS sensitivity are expected to be more responsive to these conditions. Therefore, when individuals approach an unfamiliar social context, particularly one involving social evaluation such as job interviews, approach (e.g., getting a new job) and avoidance (e.g., fear of failure) motivations would be in conflict. As mentioned, the BIS is responsible for detecting and resolving such conflict in the revised reinforcement sensitivity theory. Activation of the BIS triggers worrisome thoughts about the possible danger or loss (Corr & Cooper, 2016), thereby intensifying the perception of the situation as stressful.

Theoretical reformulation of BIS may provide insights into why the abovementioned study findings did not reveal a relationship between original BIS and cardiac autonomic indices. In human experimental settings, isolating the competing effects of appetitive and aversive stimuli can prove challenging (Corr, 2004). For instance, public speaking tests incorporating both appetitive and aversive stimuli can potentially elicit approach-avoidance conflicts. Likewise, mental arithmetic tests induce high levels of stress, particularly when participants are being evaluated in the presence of an experimenter. This situation often leads to performance anxiety, closely related to the experience of approach-avoidance conflict. For this reason, investigating the effect of revised BIS on stress reactivity could clarify the unexpected and conflicting findings regarding the relationship between personality traits and physiological stress responses.

On the other hand, the interpretation of the effect of BAS on physiological reactivity requires more careful attention. In studies where the reward is manipulated clearly, cardiac acceleration was observed (Fowles, 1980; Fowles et al., 1982), and individuals with high BAS show elevated heart rates in response to monetary incentives (Arnetta & Newman, 2000; Heponiemi et al., 2004). However, as found in a Knyazev et al. (2002) study, BAS was negatively related to heart rate increase when the subjects were required to perform a mental arithmetic task. The joint subsystem hypothesis proposes that "there are two effects of each reinforcement sensitivity: (a) facilitatory, and (b) antagonistic" (Corr, 2004, p. 325). Reward facilitates the responses to appetitive stimuli and antagonizes the punishment responses. Therefore, BAS sensitivity could inhibit the punishment responses, especially in a situation containing stimuli with mixed valence, resulting in decreased physiological reactivity.

The joint subsystem hypothesis has garnered support from recent experimental studies. In a study conducted by Mortensen et al. (2015), researchers found that activation of the BAS-related brain region (ventral striatum/nucleus accumbens) was highest in individuals with high BAS when controlling for the antagonistic effect of FFFS/BIS sensitivity. Similarly, Berghorst et al. (2013) discovered that acute stress exposure disrupted the reward sensitivity of subjects with high trait anxiety, suggesting an antagonizing effect of punishment induced by stress.

In addition, it is suggested that reward system activation not only boasts positive affectivity but also promotes resilience under stress through the brain's reward pathway projections to the stress-regulation regions (Dutcher & Creswell, 2018). In a recent study, participants' EEG waves, specifically indicating reward responses, were recorded before the experiment. Those with a higher degree of neural reward activity exhibited a decreased cortisol response during stress (Ethridge et al., 2020). In another study, participants with higher reward interest achieved a more desired result (pain relief) with optimum cardiac and EEG wave responses in a physical stress condition such as pain treatment (De Pascalis & Scacchia, 2019). Although these brain-based studies are promising, further studies are needed to explore the association between personality traits representing reward sensitivity and physiological stress responses, especially in a social stress condition.

Current study

In this study, our aim was to investigate the physiological stress reactivity and recovery of participants within the perspective of the revised RST. To achieve this, we measured two physiological indices: heart rate responses and SCL. Heart rate is the indirect measure of sympathetic nervous system activation because it depends on both sympathetic and parasympathetic branches of the autonomic nervous system. On the other hand, SCL provides a direct measure of sympathetic nervous system activity. For our stress manipulation, we employed the Trier Social Stress Test (TSST), widely accepted as a gold standard in stress research (Allen et al., 2017). This test was particularly suitable for our purpose as it can create approach-avoidance conflict, thereby activating the behavioral inhibition system (BIS). Consequently, we hypothesized that a high BIS score would be associated with heightened stress reactivity and prolonged recovery from stress.

As for the behavioral approach system (BAS), our hypothesis posited that it would be associated with diminished stress reactivity and immediate recovery from stress, indicating an antagonizing effect. This hypothesis was based on the joint subsystem hypothesis and recent notions suggesting that a robust reward system contributes to resilience under stress. Consequently, we anticipated that individuals with high BAS scores would react less to psychosocial stress.

Although the social stress test does not include the punishing stimuli that must actively be avoided, it is plausible that the Fight-Flight-Freeze System (FFFS), which mediates reactions to all aversive stimuli (Corr & Cooper, 2016), would be associated with higher stress responses. However, considering that the social stress test seems more relevant for evaluating the effect of the conflict-related system (BIS) than the fear-related system (FFFS), the association between FFFS and stress reactions might be less evident than the associations between BIS and stress responses. To ensure robustness in our predictions, we controlled for smoking use, caffeine intake, and current life stressors of participants, as these factors could impact the physiological regulation of the body (Barutcu et al., 2005; Green et al., 1996; Pardine & Napoli, 1983).

Method

Participant and measures

Sixty-one healthy participants (27 males and 34 females) with a mean age of 20.20 (range 18-26, standard deviation 1.16) were recruited from Aydın Adnan Menderes University. The sample size determination was based on the recommendation for conducting latent growth curve models (LGCM) (Curran et al., 2010). To reliably estimate the growth model (reactivity and recovery), it is required that the observed repeated data fit the hypothesized model. According to Curran et al. (2010), having at least 100 participants for model testing is preferable. The university students were informed about the experiment during regular class hours, and those interested in the study were registered on a list. The target sample initially consisted of 124 undergraduate students, but due to the COVID-19 pandemic, the study was stopped after 61 participants enrolled between October 2019 and March 2020. Despite the low involvement rate, a recent simulation study demonstrated that the growth model could still be applied with a small sample size (Shi et al. 2021.

Before the study, participants confirmed they had no physical or psychological health issues and were not taking any medication. They provided informed consent prior to the study and received a small monetary reward upon completion of the experimental procedure. The Ethics Committee of Aydın Adnan Menderes University approved the study protocol.

The Turkish version of the reinforcement theory personality questionnaire (RST-PQ)

This scale was developed by Corr and Cooper (2016) to assess the revised version of the RST. The scale comprises 65 items and is composed of six factors: two unitary defensive factors, the fight-flight-freeze system (FFFS; related to fear) and the behavioral inhibition system (BIS; related to anxiety), as well as four behavioral approach system (BAS) factors: Reward Interest, Goal-Drive Persistence, Reward Reactivity, and Impulsivity. The Turkish version of the scale was adapted by Sözer et al. (2022). Items are answered on a 4-point Likert scale that ranges from 1 (not at all) to 4 (highly), indicating the degree to which participants agree with the statements. In the current study, the internal consistency of the factors was assessed using Cronbach's alpha, yielding the following values: BIS = .90; FFFS = .79; Reward Interest = .83; Goal-Drive Persistence = .87; Reward Reactivity = .77; and Impulsivity = .69.

Although BIS is a unitary structure in terms of statistical output, researchers have developed this factor with theoretically grounded different thematic facets. These include Motor Planning Interruption, Worry, Obsessive Thoughts, and Behavioural Disengagement. The first three facets were identified considering the situations involving potentially both positive and negative outcomes that should be approached but, in principle, could be avoided. In these conditions, the organism starts a risk assessment process to weigh the possible benefits and risks of the outcome. However, behavioral disengagement was tentatively identified by McNaughton and Corr (2004) to describe the motivational state in situations where organisms feel that the aversive consequence is unavoidable and no effort could be helpful to resolve the conflict. According to McNaughton and Corr (2004), this is a possible explanation for depression. Thus, we separated this facet from the BIS factor and independently evaluated its effect on physiological responses. Behavioral disengagement reflects the demotivational state of an organism to reach a positive outcome in the face of a threat. Item examples of behavioral disengagement are as follows: "*I feel sad when I suffer even minor setbacks" and "When feeling down, I tend to stay away from people."* The Cronbach alpha value of this facet was .75.

Heart rate and skin conductance level (SCL)

Plethysmograph-based NeuLog Heart Rate& Pulse logger infrared LED transmitter/ receptor sensor was utilized to measure the heart rate, with the number of heartbeats per minute (bpm) serving as the unit of measurement within a range of 0-240. The sensor was attached to the little finger of the participant's non-dominant hand. To measure skin conductance, the Neulog GSR logger sensor NUL-217 was employed, recording skin conductance in micro siemens (range 0-50). The sensors were positioned at the base of the participant's non-dominant index and ring fingers. Throughout the entire experiment, both heart rate and skin conductance data were recorded, and these data were averaged for baseline, preparation, stress, and two recovery periods. Both the heart rate and skin conductance sensors were capable of collecting 100 samples per second.

Stressful life events measure

The 45-item life events list was created for the study. This scale comprised stressful life events that participants might encounter over a year. Items were mainly selected from the Social Readjustment Rating Scale (Holmes & Rahe, 1967), and additional items were added to broaden the list's scope, ensuring it represents events that could happen to university students. Furthermore, participants were allowed to add any event they had experienced which was not already included in the list. They rated the degree of the stressfulness of each event on a 10-point scale, ranging from "0" (none) to "10" (very high). They were also requested to point out when they encountered each event using five time intervals: "ongoing", "a month ago", "1-3 months ago", "3-6 months ago", and "6-12 months ago". Each time interval was assigned a value based on the event's proximity to the experiment day, with ongoing events receiving a value of 5 and events occurring six to twelve months ago assigned a value of 1. The values indicating the stressfulness of the event and time intervals were multiplied to calculate a stress score for each item.

Procedure-acute stress manipulation

The participants were contacted according to their order on the list, and those who expressed willingness and availability to participate in the study were scheduled for an appointment. Before the experiment, they were instructed to abstain from consuming cigarettes, alcohol, and caffeine for at least one and a half hours. Additionally, they were advised not to be excessively hungry or full during the experiment.

Upon arriving at the laboratory, the participants were requested to provide demographic information and complete paper-pencil questionnaires, which took approximately 5-10 min. Subsequently, they waited in the laboratory for 15 min to acclimate to the environment. Following this period, they were directed to the next laboratory room for the stress task.

In the stress task preparation, heart rate and SCL sensors were attached to the participants, and they were instructed to minimize gross movements and remain as still as possible. Once the physiological data reached a stable trend, which typically took about one minute, a five-minute baseline period was recorded. Following the baseline measurement, trier social stress test (Kirschbaum et al., 1993) procedures were initiated by providing participants with instructions for the tasks they were required to perform in the subsequent periods. The stress test consisted of two procedures. Firstly, participants were asked to deliver a five-minute speech on why they believe they are the best candidate for their dream job. Following the speech, they were given a five-minute mental arithmetic test to complete. All procedures were thoroughly explained to the participants by the first author of this manuscript.

The participants were informed that they would deliver a speech in front of a two-person jury, and their performance would be videotaped for evaluation by communication experts. They were given three minutes to prepare their speech using paper and pencil. After the preparation time, the paper was collected in a considerate manner, and the jury entered the room. The experimenter initiated the recording by clicking the start button on the camera, and a visible red light indicated that the participants were being recorded. However, during the debriefing, it was explicitly explained that the videotaping would not be evaluated, and all recorded data were deleted in front of the participants.

After completing the speech task, participants proceeded to a five-minute mental arithmetic task. This task involved counting backwards as fast as possible from 2023 in decrements of 17, requiring starting over from the beginning if they provided an incorrect answer. Subsequently, the jury left the room, and participants were instructed to remain seated quietly and avoid any movement during a five-minute recovery period. After the recovery period, sensors were detached, and participants were given a debriefing on the nature of the task.

Data analysis

We conducted latent growth curve models (LGCM) to analyze physiological changes over time. Change is modeled as a function of time in LGCM and is represented by the specification of latent (i.e., unobserved) variables known as growth factors. A latent intercept representing the initial time point or baseline and a latent slope representing the rate of change are estimated based on the individual trajectories. They provide an estimation of the mean trajectory over time, as well as the individual variations from that trajectory. When repeated data captures the distinct phase of the outcome variable, the overall trajectory could be divided into multiple segments, each with its own growth pattern (e.g., reactivity and recovery phases). These special types of growth models are known as multiphase or piecewise latent growth curve models (Curran et al., 2010), in which two or more modeled phases are analyzed simultaneously.

To test reactivity and recovery in heart rate and SCL, we used piecewise LGCM. Reactivity phases consist of baseline, preparation, and stress periods of the stress task, and recovery phases start with the stress period and consist of two recovery periods. Data obtained during the five-minute recovery period of the stress task were sectioned into two equal periods, resulting in separate two-and-a-half-minute recovery measures. Thus, both reactivity and recovery phases consist of three time points. The influence of the reinforcement sensitivity personality factors on stress reactivity and recovery was tested by directly letting them influence the latent growth factors (intercept and slopes).

To capture the true nature of the data, a free estimation procedure was selected for the factor loadings of the slope factors that represent the reactivity and recovery periods of the stress task (Burant, 2016). Time coding for parameter estimates was as follows: The baseline was set to 0, and the stress task was set to 1. Thus, the preparation period was allowed to be estimated freely. This procedure was applied again for the recovery phases: The factor loading of the stress period was set to 0 because it represents the baseline of the recovery period. The last time point, the second recovery period, was set to 1. Thus, the factor loading of the first recovery period was estimated freely. Figure 1. and Figure 2. show these time coding and freely estimated unstandardized factor loadings. The unstandardized coefficients can be interpreted as the magnitude of the physiological changes between time points. For example, across the reactivity phases, the greatest change in heart rate and SCL (78% and 76%, respectively) occurred between the baseline and stress task, that is, in the preparation period. We used SPSS and AMOS (Analysis of Moment Structures) 23 software for the statistical analysis and latent growth curve modeling.

Results

Preliminary analysis

Table 1 presents the characteristics of the participants. The percentages of life events encountered throughout the year and current events are presented separately. Additionally, smoking and caffeine use are indicated by the number of cigarettes and cups of coffee consumed daily. Means and standard deviations for personality factors and physiological indices obtained during the stress protocol are also presented.

The skewness and kurtosis values for physiological indices were within the range of −1 to +1, indicating a nearly symmetrical distribution. We also reported the zero-order correlations between the variables (see Table 2).

Modeling the heart rate and skin conductance responses to stress

Figure 1 and Figure 2 display the model structures and parameter estimates for the three latent growth factors representing the baseline, reactivity, and recovery of heart rate and SCL, respectively. The models demonstrated a very good fit to the data for heart rate ($x^2 = 6.79$, df = 6, $p = .34$; CFI

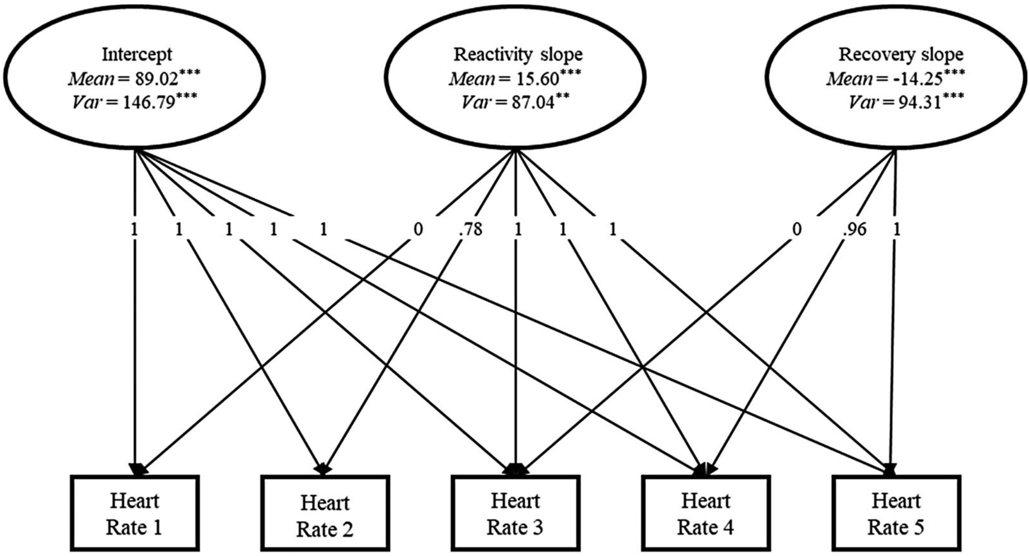

Figure 1. Piecewise growth curve model of individual heart rate responses to the stress task; loadings are shown as unstandardized coefficients; Var = variance; **$p \leq .01$; ***$p \leq .001$.

= .998; RMSEA = .047) and an extremely good fit data for SCL ($x^2 = 4.03$, df = 6, $p = .67$; CFI = 1.00; RMSEA = .00). Regarding heart rate, the model estimated 15.60 units increase in the reactivity period and 14.25 units decrease in the recovery period (see Figure 1).

Similarly, the model for SCL estimated 2.36 units increase in the reactivity period, and .38 units decrease in the recovery period (see Figure 2). Correlation coefficients between latent growth factors of heart rate showed nonsignificant associations between baseline and reactivity ($r = -.01$, $p = .98$) and between baseline and recovery ($r = -.10$, $p = .48$), meaning that on average, heart rate responses during stress task and recovery were independent of the baseline level. On the other

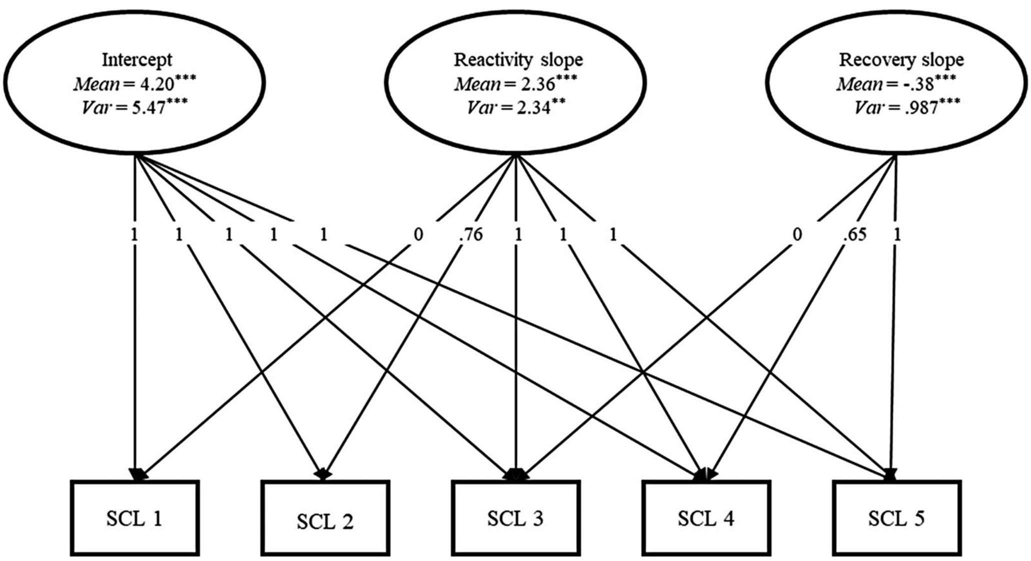

Figure 2. Piecewise growth curve model of individual SCL responses to the stress task; loadings are shown as unstandardized coefficients; Var = variance; **$p \leq .01$; ***$p \leq .001$.

Table 1. Descriptive statistics for all measures.

Variables	Mean	S.D	Variables	Mean	S.D	Ske.	Kur.
Life events (year)	116.79	86.32	Heart rate-baseline	89.02	12.29	−.068	−.619
Life events (Current)	14.28	15.02	Heart rate-preparation	101.26	14.45	.242	−.226
Smoking use (units)	3.44	6.30	Heart rate-task	104.52	17.34	.174	−.465
Caffeine (cup)	1.34	1.05	Heart rate-recovery 1	90.93	13.08	.166	−.193
FFFS	23.98	6.05	Heart rate-recovery 2	90.38	12.35	.047	.044
BIS(Total)	59.13	11.82	SCL-baseline	4.19	2.33	.985	.638
BIS(beh. diseng. excluded)	44.19	9.39	SCL-preparation	5.98	2.73	.399	−.735
Behavioral disengagement	14.93	3.52	SCL-task	6.53	2.95	.403	−.558
Reward interest	18.63	4.32	SCL-recovery 1	6.32	2.83	.463	−.438
Goal-drive persistence	22.03	3.75	SCL-recovery 2	6.14	2.91	.714	.244
Reward reactivity	29.95	4.72					
Impulsivity	20.34	3.94					

Note. FFFS, Fight-Flight-Freeze system; BIS, Behavioral inhibition system; beh. diseng., behavioral disengagement; Ske., Skewness; Kur., Kurtosis

hand, steeper heart rate reactivity was associated with steeper recovery ($r = -.83$, $p < .0001$). For SCL, there was no significant association between baseline and reactivity ($r = .08$, $p = .69$) and recovery ($r = -.24$, $p = .11$) and between reactivity and recovery ($r = -.02$, $p = .91$).

For both physiological indices, variances of reactivity and recovery slopes were significant, meaning there was inter-individual variability in stress responses. Thus, we tested the effect of the RST personality factors on stress responses by directly letting them estimate the latent factors of the models.

RST personality factors and physiological stress responses

To examine the impact of RST personality factors on heart rate and SCL trajectories in response to the stress test, we regressed the latent growth factors on the RST personality factors. As the personality factors were highly correlated, separate models were computed for each factor while controlling for current life stress, smoking use, and daily caffeine intake. Only the behavioral inhibition system and its facet of behavioral disengagement were simultaneously tested. We also reported the effect of the total BIS score to test whether the facet-specific evaluation would reveal a distinct pattern of physiological stress reactivity. Table 3 shows regression coefficients of personality factors in heart rate and SCL, respectively.

Consistent with the hypothesis, while BIS was associated with increased heart rate reactivity (Figure 3), goal-drive persistence and reward reactivity were negatively associated with heart rate reactivity (Figure 4). On the other hand, reward interest exhibited a marginal level of significance. Contrary to expectations, BIS was associated with a steeper heart rate recovery; that is, the heart rate goes down faster for higher BIS scores (Figure 3). In addition, reward interest, goal drive persistence, and reward reactivity were related to diminished heart rate recovery (see Figure 4 for the effect of reward sensitivity on heart rate). FFFS and behavioral disengagement were not significantly related to heart rate responses (Table 1). Despite not significantly affecting heart rate responses, behavioral disengagement exhibits a negative trend in relation to stress reactivity. Excluding it from the total scale amplifies the magnitude of the relationship between BIS and stress reactivity.

To test the robustness of the significant coefficients, the bootstrapping method was used to calculate 95% bias-corrected confidence intervals of standardized coefficients using 5000 bootstrap samples. For heart rate reactivity, the confidence intervals of personality factors were as follows: BIS (total score) = [.07 to .60], BIS (excluding behavioral disengagement) = [.02 to .68], reward interest = [−.49 to .10], goal drive persistence = [−.53 to .04], and reward reactivity = [−.74 to −.32]. As a result, both BIS factors and reward reactivity consistently emerged as robust predictors of heart rate reactivity. However, reward interest and goal-drive persistence displayed values that marginally crossed zero, suggesting a potential subtle association. Regarding the recovery pattern, confidence

Table 2. Zero-order correlations between main variables.

	1	2	3	4	5	6	7	8	9	10	11
1. Life events (year)	1										
2. Life (current)	.82***	1									
3. Smoking	−.10	−.03	1								
4. Caffeine	−.28*	−.35**	−.04	1							
5. FFFS	.26*	.13	−.36**	.14	1						
6. BIS (beh. diseng. excluded)	.05	.12	.04	.15	.49**	1					
7. Behavioral disengagement	.12	.17	.06	.15	.28*	.59**	1				
8. Reward interest	.07	.11	.07	−.24	−.24	−.32*	−.26*	1			
9. Goal-drive persistence	.16	.19	−.16	−.38**	−.21	−.35**	−.37**	.59***	1		
10. Reward reactivity	.13	.16	−.13	−.16	.05	−.05	−.21	.42**	.29*	1	
11. Impulsivity	.07	.08	.19	−.10	.02	.13	.10	.41**	−.11	.38**	1

Note. FFFS, Fight-Flight-Freeze System; BIS, Behavioral inhibition system; Beh. Diseng., Behavioral Disengagement. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 3. Unstandardized and standardized (in parentheses) regression coefficients of RST personality factors in heart rate and SCL responses to the TSST.

Heart rate	Baseline	Reactivity	Recovery
1. BIS (Total)	.36 (.35)**	.29 (.37)**	−.25 (−.30)*
2. BIS (Beh. Diseng. excluded)	.28 (.22)	.43 (.43)*	−.38 (−.36)*
Behavioral Disengagement	.62 (.18)	−.17 (−.06)	.20 (.07)
3. FFFS	.51 (.25)	.11 (.06)	−.22 (−.14)
4. Reward interest	−.80 (−.29)*	−.54 (−.25) $^{p = .08}$	.92 (.40)**
5. Goal-Drive persistence	−.90 (−.28)*	−.78 (−.31)*	.74 (.28) $^{p = .06}$
6. Reward reactivity	.60 (.24)	−1.15 (−.58)***	1.10 (.52)***
7. Impulsivity	.40 (.13)	−.32 (−14)	.41 (.17)
SCL			
1. BIS (Total)	−.04 (−.19)	.02 (.17)	.01 (.14)
2. BIS (Beh. Diseng. excluded)	−.04 (−.15)	.07 (.41)**	.002 (.02)
Behavioral Disengagement	−.04 (−.06)	−.14 (−.32)*	.05 (.16)
3. FFFS	−.11 (−.29)*	.06 (.23)	.05 (.27) $^{p = .06}$
4. Reward interest	.07 (.12)	−.02 (−.05)	−.08 (−.34)*
5. Goal-Drive persistence	.11(.18)	−.06 (−.14)	−.06 (−.23)
6. Reward reactivity	.06(.12)	.02 (.05)	−.02 (−.11)
7. Impulsivity	−.02(−.03)	.03 (.07)	−.02 (−07)

Note. BIS, Behavioral inhibition system; Beh. Diseng., Behavioral Disengagement; FFFS, Fight-Flight-Freeze system; SCL, Skin conductance level. *$p < .05$. **$p < .01$. ***$p < .001$.

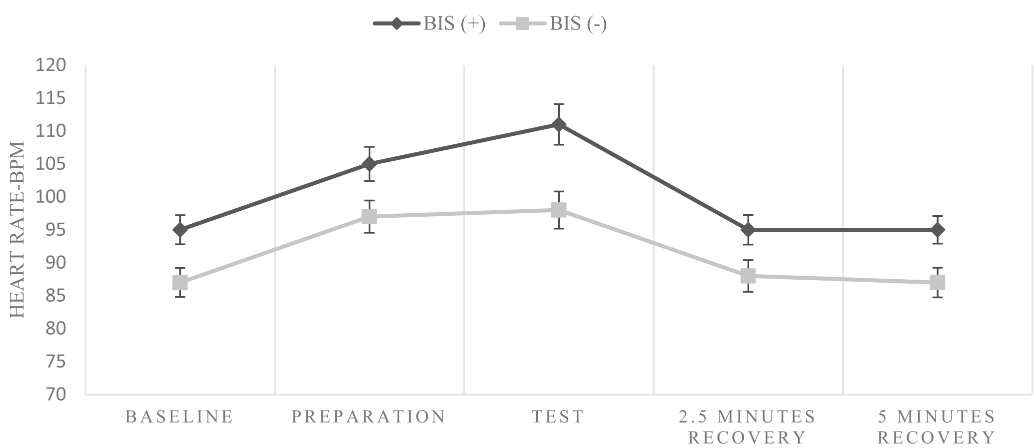

Figure 3. Illustrates the heart rate trajectories in participants with high (+) and low (−) BIS scores using median dichotomizations.

intervals are as follows: BIS (total score) = [−.58 to .01], BIS (excluding behavioral disengagement) = [−.68 to .09], reward interest = [.05 to .63], goal-drive persistence = [−.09 to .55], and reward reactivity = [27 to .73]. Therefore, reward interest and reward reactivity appeared to be more reliable predictors of heart rate recovery.

The increase in SCL from baseline to the test phase was more remarkable for individuals with higher BIS scores (excluding behavioral disengagement), aligning with expectations (see Figure 5). Additionally, behavioral disengagement showed an association with reduced SCL reactivity to stress. Upon bootstrapping analysis, the standardized estimate of BIS (excluding behavioral disengagement) was found to be robust, with a confidence interval of [0.12 to 0.75]. However, the confidence interval for behavioral disengagement slightly crossed zero, indicating a potential weak association, ranging from [−0.69–0.07]. Furthermore, FFFS demonstrated a marginal association with delayed SCL recovery, where the bootstrapped confidence interval slightly crossed zero, spanning [−0.02–0.64]. Individuals with higher reward interest exhibited heightened SCL recovery post-stress, supported by a confidence interval of [−0.63 to −0.09] (see Figure 6). None of the other RST factors were related to SCL reactivity and recovery (see Table 3).

Figure 4. Illustrates the heart rate trajectories in participants with high (+) and low (−) reward reactivity scores using median dichotomizations (for illustration, only the "reward reactivity" subfactor of BAS was shown).

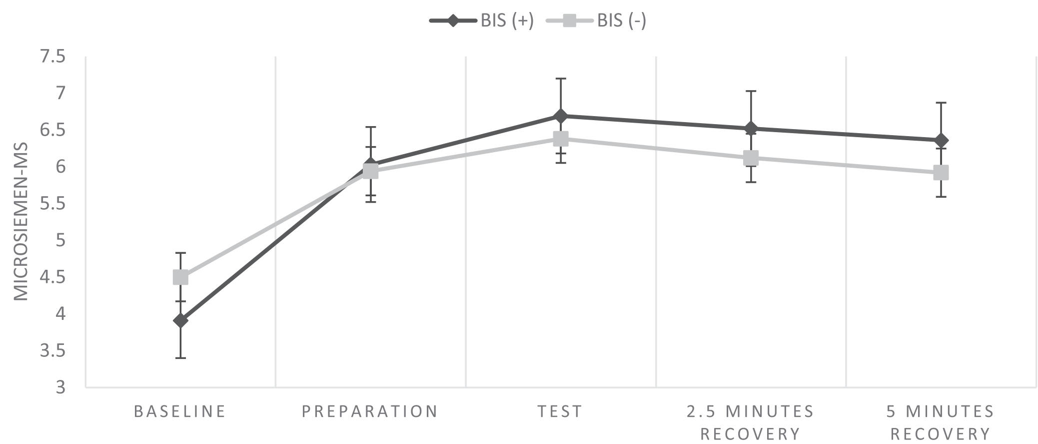

Figure 5. Illustrates the SCL trajectories in participants with high (+) and low (−) BIS scores using median dichotomizations.

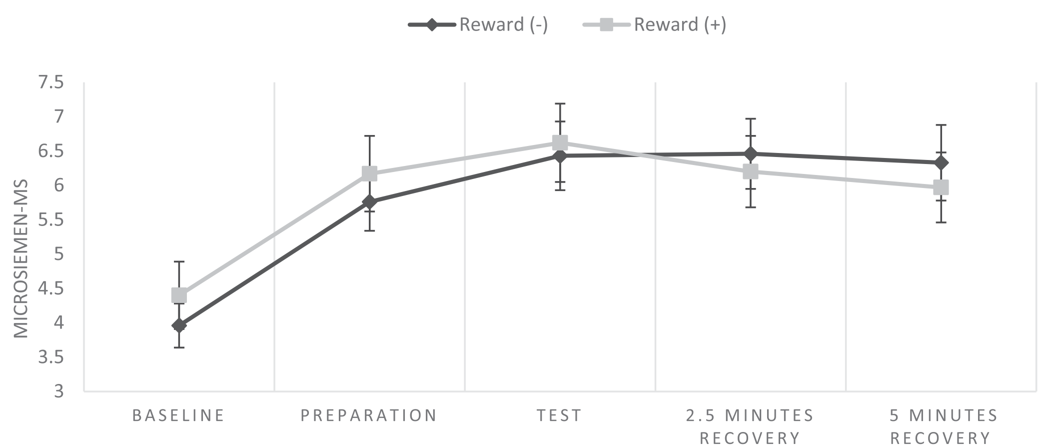

Figure 6. Illustrates the SCL trajectories in participants with high (+) and low (−) reward interest scores using median dichotomizations.

Discussion

In the current study, we aimed to assess the associations between RST personality traits and physiological stress responses during psychosocial stress manipulation. We found that r-RST factors were differentially associated with stress reactivity and recovery while controlling for smoking use, caffeine intake, and current life stress. Specifically, BIS is a robust predictor of heart rate and SCL reactivity. In addition, BAS factors, except impulsivity, were related to diminished heart rate reactivity. Behavioral disengagement, as its name implies, is related to diminished sympathetic arousal. Additionally, it was observed that the reward interest factor of the BAS seemed to accelerate SCL recovery, while the influence of FFFS appeared to delay the recovery process marginally.

Our findings regarding BIS align with the reformulation of the theory, suggesting that BIS is more sensitive to conflicting stimuli or conditions rather than the punishment itself. Social situations characterized by novelty, unpredictability, and uncertainty and requiring ego involvement may engender heightened conflict in individuals with high BIS. Consequently, these individuals may experience increased physiological and psychological demands while coping with such circumstances. Unlike the previous research that failed to demonstrate a positive correlation between original BIS and SCL (Hofmann & Kim, 2006) and heart rate (Heponiemi et al., 2004; Knyazev et al., 2002) under stress, the revised BIS yielded statistically significant results. We also tested the associations of the original BIS scale with the stress responses (not reported in this text) and did not find significant associations with both physiological indicators. Therefore, the revised BIS scale appears better to reflect the current understanding of the BIS function.

Although the BIS scale was developed as a unitary factor with different thematic facets, we specifically focused on the effect of BIS, excluding the facet of behavioral disengagement due to sound theoretical reasons. First, in their reformulation of the theory, Gray and McNaughton (2000) emphasized the approach behavior to the threat rather than behavioral disengagement in their analysis of BIS. Behavioral disengagement, introduced subsequently, signifies a demotivational state arising from the perception of unavoidable aversive consequences and unattainable positive outcomes. Consequently, it is often regarded as a temperament more aligned with depression rather than anxiety proneness (McNaughton & Corr, 2004). Our results were consistent with this explanation, as behavioral disengagement showed reverse associations with physiological reactions. Numerous cross-sectional and prospective studies have demonstrated that blunted or diminished reactivity to stress is associated with depressive symptoms (Brindle et al., 2017; Carroll et al., 2017; Ginty et al., 2020; Phillips et al., 2013).

Second, there is a wealth of inconsistent findings concerning the associations of the Big Five traits with stress responses in previous studies. A recent meta-analysis revealed weak to null correlations between physiological stress responses and Big Five traits (Luo et al., 2023). Notably, in a study, neuroticism, a risk factor for various psychological and health-related problems and stress vulnerability, had gender-dependent and facet-specific associations with physiological responses (Oswald et al., 2006). Facets reflect different characteristics of a person that align with higher-order traits but may manifest differently in various contexts. Global personality measures consist of heterogeneous items, which could attenuate the magnitude of associations between variables when evaluated in specific contexts (Schneider et al., 2012). In line with this perspective, our findings revealed that the association between a unified BIS score and heart rate was notably attenuated, and the influence of BIS on SCL became statistically insignificant when accounting for the effect of behavioral disengagement on both physiological indices.

As for the Fight-Flight-Freeze System (FFFS), considering the challenging nature of the stress task, we anticipated a positive correlation between this fear-proneness trait and heightened stress reactivity, albeit somewhat lower in comparison to the association of BIS with stress responses. Contrary to our hypothesis, however, no discernible associations between FFFS and stress reactivity were found. However, this finding does not entirely contradict the revised theory, which posits that the FFFS is activated in situations where the approach-avoidance conflict is absent and avoidance is possible (Corr & Perkins, 2006). The trier social stress paradigm appears ecologically comparable to everyday approach-avoidance conflicts, as it does not appear to pose a threat that the organisms should avoid. Therefore, the absence of positive associations may reflect the context-specific (eliciting anxiety but not fear) reactions and the affective specificity of the defensive direction.

The findings regarding reward sensitivity sustained the hypothesis that individuals with higher reward sensitivity would produce less heart rate reactivity. Our results align with those of an early study that induced stress through mental arithmetic but did not include any evident reward manipulation (Knyazev et al., 2002). Additionally, recent studies have found that reward anticipation mitigated the heart rate responses to psychosocial stress (Hu & Yang, 2021), and baseline reward sensitivity predicted lower cortisol responses in the stress condition (Ethridge et al., 2020). These findings imply that, even in the absence of immediate reward, individuals with higher trait reward sensitivity appear to exhibit greater cardiac stress resilience. In this sense, the robust reward system seems to mediate an antagonistic effect on the physiological stress response, leading to a more sustained resilience.

However, the heart rate recovery results were not consistent with our expectations. We anticipated that participants with high BIS and low BAS scores would display delayed recovery; however, our findings revealed the opposite trend. Despite higher heart rate reactivity observed in the same individuals, the steeper recovery can be attributed to the elevated response during stress. As the stressor subsides, their cardiovascular system gradually restores equilibrium, causing their heart rate to return to baseline. On the other hand, the average heart rate trajectories seen in Figures 3 and 4 show that their heart rates are still approximately 10 bpm units higher than those of participants with low BIS and high BAS during recovery. They had increased heart rate levels from the beginning to the end of the procedure, suggesting they may be at higher risk for physiological and psychological health problems (McEwen, 2006, 2017; Turner et al., 2020).

Findings on the recovery of SCL were more consistent with the hypothesis on reward sensitivity than with BIS. While the recovery rate of SCL did not significantly differ depending on the BIS scores, individuals with higher BIS sensitivity exhibited elevated SCL levels throughout the recovery period (Figure 5). On the other hand, the reward interest factor of BAS predicted more recovery of SCL after stress. In contrast to heart rate, the higher decline in SCL may be attributed to individual differences in reward sensitivity rather than regressing to the mean because reward factors did not produce higher skin conductance responses during the stress period (Figure 6). Cessation of stress could normally bring relief, and past studies have demonstrated that reduced SCL is associated with feeling relief (Kreibig, 2010). In addition, in a study in which the trier social stress test was a stress paradigm, increased positive emotions emerged in those more sensitive to reward after the experimental procedure (Corral-Frías et al., 2016). Relatedly, we also found that a heightened level of fear proneness was associated with heightened SCL after cessation of stress. Together, these findings suggest that sympathetic recovery after stress may partly depend on the reward system, which can more easily detect the signal of relief or non-punishment. Nevertheless, it may be suitable for future studies to incorporate other sympathetic stress indicators to provide further evidence for this suggestion.

The current study has certain limitations that should be considered when evaluating its outcomes. First, the study's sample size was relatively small, which poses limitations in statistical power and has the potential to inflate effect sizes. Hence, our findings should be regarded as preliminary, necessitating further replication studies.

Another limitation of the study pertains to data processing. Specifically, we did not apply any artifact correction for physiological measures, which may have resulted in distorted findings due to irrelevant arousal not directly associated with the stress induction. However, we conducted random checks on the outliers of individual data across the different phases of the stress task. Although the mean scores remained relatively stable and did not show significant changes, even when examining data with a wider range of data points, managing the artifacts remains crucial to ensuring the robustness of the study's findings.

Another interesting avenue for future research is to include various physiological indicators. Skin conductance level showed a relatively slower return toward the baseline compared to the heart rate during the five-minute recovery period. Although this pattern is similar to that observed in another study that used the same device, even though the recovery period lasted thirty minutes (Capobianco et al., 2018), the data display a dissociation between personality and physiological measures, highlighting the importance of evaluating multiple indicators of stress reactions, such as cortisol levels or heart-rate variability, to capture the diverse implications of stress outcomes.

In addition to these, our RST personality assessment relied upon self-report measurement, and accordingly, the ecological validity of dimensions is questionable. In other words, behavioral manifestations of purported sensitivities should be tested to determine whether they will map neatly onto the self-report answers. Although self-reported traits for other personality models have proved to be reliable predictors of actual behavior and have shown high correlations with personality ratings provided by external resources (McCrae & Costa, 1987), this implication has yet to be tested with regard to revised RST dimensions.

In conclusion, the current study was the first to investigate the relationships between the revised RST and physiological stress responses. Results indicate that physiologically based personality models may be able to provide an alternative perspective on how personality characteristics influence the various autonomic outputs in response to social stress exposure. We found that high BIS scores were positively associated with heart rate and SCL reactivity. The results also indicate that including facets in the analysis may result in more robust outcomes than those predicted by the higher-order traits. Finally, low heart rate reactivity and more remarkable recovery of SCL predicted by BAS support the notion that reward sensitivity may be a protective mechanism against the maladaptive effect of stress exposure.

Acknowledgment

This study was not preregistered. We report how we determined our sample size, all manipulations, and all measures in the study. All data, analysis code (templates), and research materials are available at https://osf.io/n8fky/

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statements

The data obtained for this study are openly available in OSF at https://osf.io/n8fky/

Ethical approval

The study protocol was approved by the Ethics Committee of Aydın Adnan Menderes University.

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Does not apply.

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