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ARTICLE

Control, anxiety and test performance: Self-reported and physiological indicators of anxiety as mediators

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Abstract

Background: This study investigated the role of different test anxiety components (affective, cognitive, motivational and physiological) as mediators between control and performance as proposed by Pekrun's control-value theory (CVT). While all components were assessed via self-report, the physiological component was additionally assessed via electrodermal activity (EDA).

Aims: We examined the relative impact of the self-reported anxiety components and EDA in this mediating mechanism to identify the most relevant assessment(s) (i.e., self-reported anxiety components and/or EDA) for predicting test performance.

Sample: The study comprised 50 eighth graders.

Methods: Data were collected during a mathematics test comprising six task blocks. State self-reports of control and anxiety components along with test performance and other test emotions were collected block-wise (i.e., repeated assessments within students). EDA was continuously recorded.

Results: Consistent with CVT, intra-individual mediation analysis with multiple mediators revealed that higher control predicted lower anxiety (i.e., all self-reported components). Unexpectedly, higher control was associated with increased EDA. Follow-up analyses taking other test emotions into account suggested this might reflect positive activation. Correlations between EDA and control and self-reported anxiety components differed depending on which test emotion was dominant in each situation. Regarding test performance, only the cognitive component was a significant mediator and thus seems to play a pivotal role in the relationship between control and performance.

Conclusions: Distinguishing between anxiety components and including unbiased physiological measures improve our understanding of the mechanisms behind the relationship between test anxiety and performance. Higher physiological arousal may be a sign of anxiety but can also be a sign of positive activation. When aiming to reduce negative effects of anxiety on performance, targeting the cognitive component seems crucial. Implications of these findings for educational and psychological practice are discussed.

KEYWORDS
control-value theory, electrodermal activity, skin conductance, test anxiety componentstest performance

INTRODUCTION

Students encounter numerous tests, examinations and evaluations during their academic life. These situations are often associated with the experience of anxiety (Putwain et al., 2010) – an emotion that is negatively related to information processing and retrieval, performance, self-esteem and well-being (e.g., Cassady, 2004; Hascher, 2007; Van Yperen, 2007). Against this background, knowledge about the antecedents and effects of anxiety is critical for the development of appropriate prevention and intervention programmes (von der Embse et al., 2018). In recent decades, there have been various studies investigating the antecedents and effects of anxiety in learning and achievement situations (Pekrun & Linnenbrink-Garcia, 2014). A prominent theory is the control-value theory (CVT; Pekrun, 2006), which characterizes control appraisals as central antecedents and lower performance as a major effect of anxiety. However, information is lacking regarding a component-specific assessment of anxiety which, next to differentiating among cognitive, affective and motivational components, also includes the physiological component. Aside from a more complete conceptualization and operationalization of test anxiety, including measures of sympathetic arousal (i.e., physiological measurement) would also extend usually applied self-report methodologies by providing a more objective and continuous measure (Caruelle et al., 2019; von der Embse et al., 2018). Ultimately, this could allow for more specific selections of interventions (Järvelä et al., 2019). For example, if the influence of the physiological anxiety component based on the physiological measurement on test performance is found to be underestimated, physiology-focused interventions could be more important in practice.

Therefore, to advance current knowledge, the present study followed an experience sampling approach and investigated the different anxiety components based on assumptions of CVT to examine the relative impact of control appraisal antecedents on the different components and to identify which of the components have the strongest impact on test performance. Specifically, and in addition to multiple state self-reports of control, and cognitive, affective, motivational and physiological anxiety components, measures of sympathetic arousal (i.e., EDA measurement) were used to investigate the physiological component of anxiety.

Conceptualizing and measuring anxiety

Anxiety and its components

An important aspect of measuring anxiety is taking its different components into account. In early research, test-related anxiety was conceptualized as a single, unidimensional construct (Mandler &

Sarason, 1952). Liebert and Morris (1967) were the first to introduce the distinction between 'worry' (cognitive) and 'emotionality' (affective) components. Later, researchers adopted a multi-component, rather than dichotomous, view of anxiety (Scherer, 1984, 2009). A commonly used distinction is the differentiation between four components: cognitive, affective, motivational and physiological (Scherer, 2009). These emotion components are theoretically distinct, yet related; regarding anxiety, they comprise intrusive thoughts (cognitive), feelings of nervousness (affective), an urge to withdraw from the situation (motivational) and increased physiological arousal such as higher heart rate or sweating (physiological component; Pekrun et al., 2004; Zeidner, 2014). The multi-component nature of anxiety is also reflected in emotion questionnaires, such as the Achievement Emotions Questionnaire (AEQ; Pekrun et al., 2011), but often neglected in empirical analyses, presumably for practical reasons. Consequently, anxiety is usually analysed as a relatively undifferentiated and one-dimensional construct, for example, by using sum scores or single items, which do not allow conclusions on which component(s) of anxiety are involved (Shuman et al., 2017). Regarding test anxiety, researchers often take a slightly more differentiated approach by distinguishing between 'worry' and 'emotionality' components, but usually only assessed them via self-reports (Zeidner, 2007).

Physiological measures

Self-report measures can be biased in various ways including memory biases or subjective beliefs (Robinson & Clore, 2002). They can be influenced by the willingness and capability to report about one's feelings and can only capture the conscious experience of a student. These limitations call for less biased susceptible measures that cannot be masked or controlled, such as physiological measures of arousal (e.g., electrodermal activity, heart rate or blood pressure), to obtain a more complete assessment of emotions (Harley, 2016). Interest in physiological indicators to complement traditional self-reports of emotions has grown immensely over the last decade (Järvelä et al., 2019; Scherer & Moors, 2019). However, applying these measures is work-intensive and expensive, and interpreting findings obtained from these measures in relation to existing educational research and theories remains a challenge in educational psychology (Kreibig & Gendolla, 2014). So far, only a few studies (e.g., Martin et al., 2021) have complemented self-report measures of anxiety with electrodermal measures (i.e., electrodermal activity). The present study aims to make a contribution to this.

Electrodermal activity (EDA) is one of the few readily available, non-invasive measures of sympathetic arousal. It is known to be controlled exclusively by the sympathetic nervous system and varies with the state of sweat glands in the skin (Setz et al., 2010). If the sympathetic branch of the autonomic nervous system is highly aroused, then sweat gland activity increases, which in turn increases EDA. EDA has been reported to be more closely related to emotion than heart rate, and thus is utilized in psychological research, particularly regarding scenarios and assessments of emotional arousal, stress and appraisal (Boucsein et al., 2012; Critchley, 2002). More specifically, it has been found to be significantly associated with generalized self-reports of anxiety (Betancourt et al., 2017). EDA can be most reliably and validly recorded with electrodes attached to the palm of the non-dominant hand in a lab setting (Boucsein et al., 2012). Some newly developed devices (e.g., Empatica E4, Shimmer3 GSR+, and Movisense EdaMove) allow for a continuous assessment of EDA directly in the classroom, such as during a test, and therefore can further elucidate the relationship among control, anxiety components and test performance.

The control–anxiety–performance relationship

The control–anxiety–performance relationship is described in Pekrun's control-value theory (CVT) which deals with the antecedents and effects of emotions including anxiety (Pekrun, 2006). CVT relates to control (appraisals) as a central antecedent and lower performance as a major effect of anxiety in achievement situations. Control can be described as the appraisal of being able to personally influence

activities and outcomes and may include perceptions such as competence beliefs and causal attributions (Goetz et al., 2006; Pekrun & Stephens, 2010). CVT proposes that increased anxiety arises especially in achievement situations that a student perceives to be important, such as a test (i.e., high value), and when the student experiences a loss of control or insufficient control over the achievement activities or outcomes (Pekrun, 2006). In turn, this increased anxiety is linked to decreased performance. In particular, increased anxiety resulting from a perceived lack of control reduces cognitive resources and the use of flexible strategies and self-regulation (Goetz et al., 2006) – which subsequently negatively affects performance (Pekrun et al., 2009). Thus, anxiety mediates the relationship between control and performance.

Consistent with Pekrun's (2006) assumptions, a series of empirical studies suggest that perceived lack of control (e.g., low self-concept of ability, self-efficacy and academic control beliefs) is closely related to increased (test) anxiety (e.g., Frenzel et al., 2007; Goetz et al., 2006) and that test anxiety can have detrimental effects on performance (meta-analysis by von der Embse et al., 2018). However, it remains unclear whether all anxiety components are equally important in this proposed mediating mechanism connecting control and academic performance via anxiety. Moreover, although CVT is primarily related to intra-individual relations, it is mainly tested on the between-person level (Murayama et al., 2017).

So far, only one study has examined all four anxiety components as mediators of the proposed relationship between control and performance using an intra-individual approach and found the cognitive component to be central (Roos, Goetz, Krannich, et al., 2021). This is in line with findings that worry showed stronger negative correlations with performance than emotionality (Cassady & Johnson, 2002; Deffenbacher, 1977; Seipp, 1991) as well as with recent meta-analytic findings that differentiated between the cognitive and affective/physiological components (von der Embse et al., 2018).

Research that (in addition to worry) also differentiated among test-irrelevant thinking, tension and bodily symptoms reported no clear patterns of associations between these components and performance (see Keogh et al., 2004; McIlroy et al., 2000; Putwain et al., 2010). Moreover, all of these studies were solely based on self-reports and, with the exception of the study by Roos, Goetz, Krannich, et al. (2021), all focused on some anxiety components in isolation.

Integrating physiological measures in the control–anxiety–performance relationship

Recent meta-analytic research examining the association between physiological arousal (as assessed with physiological measures) and self-reported test anxiety (i.e., often not differentiating between the anxiety components) suggests a medium-sized correlation (Roos, Goetz, Voracek, et al., 2021), meaning physiological arousal may capture similar aspects as self-reports of test anxiety. However, rather than viewing physiological arousal as a direct parallel measure to self-report, we propose that it is an important dimension of test anxiety, which is likely most associated with self-reports of the physiological anxiety component.

In linking anxiety components to control appraisal as antecedents and performance as consequence, it seems promising to use physiological measures (i.e., measures of sympathetic arousal) as an additional assessment of the physiological anxiety component because the experience of control is relevant in the CVT as well as in other appraisal theories which utilize physiological processes, such as the transactional stress model by Lazarus and Folkman (1984). They assume that in a situation that is meaningful for a person (e.g., an exam), the experience of loss of control causes a stress reaction and leads to increased physiological arousal. Scherer and Moors (2019) also present consistent evidence of stable correlates of appraisal criteria on physiological correlates. Regarding the association between physiological arousal and performance, there are conflicting results: Some studies suggest high physiological arousal has a negative impact on performance because high arousal may indicate stress, negative emotions and lead to impaired memory (Gagnon & Wagner, 2016; Oei et al., 2006). Other studies indicate a positive relationship between physiological arousal and performance in athletes, whereby increased physiological arousal can sometimes positively impact performance (Burton, 1988; Parfitt et al., 1995). These conflicting results are in line with recent

research by Martin et al. (2021) and with theories on challenge and threat in such a way that high physiological arousal may not only be associated with perceived anxiety or threat but also with perceived challenge depending on the appraisal of the situation, and that these appraisals, in turn, determine whether physiological arousal has a positive or negative effect on performance (Blascovich, 2008; Feldman-Barrett, 2006).

AIMS OF STUDY

The goal of this study was to investigate the importance of the different anxiety components as a link between control appraisals and students' performance based on assumptions of the CVT. Regarding a more complete assessment, in addition to self-reports of control and the cognitive, affective, motivational and physiological anxiety components, the physiological anxiety component was examined with physiological indicators (i.e., EDA). The use of both measures (i.e., self-report and EDA measurement) allows not only for a more complete assessment of anxiety and thus a better understanding of the relationship among control, anxiety and performance, but eventually also the selection of effective interventions based on the relative influence of the different anxiety components on performance. For example, as already outlined above, if the influence of the physiological anxiety component based on physiological data on performance is found to be underestimated, physiology-focused interventions could be more important in practice. Furthermore, as the CVT describes intra-individual processes, we aimed to extend findings from traditional inter-individual studies by applying an intra-individual approach (i.e., within-person measures; Murayama et al., 2017).

Hypothesis

Based on the described theoretical assumptions, we hypothesized that lower control is associated with higher anxiety (path a, see Figure 1) as reflected by higher ratings on all four anxiety components assessed

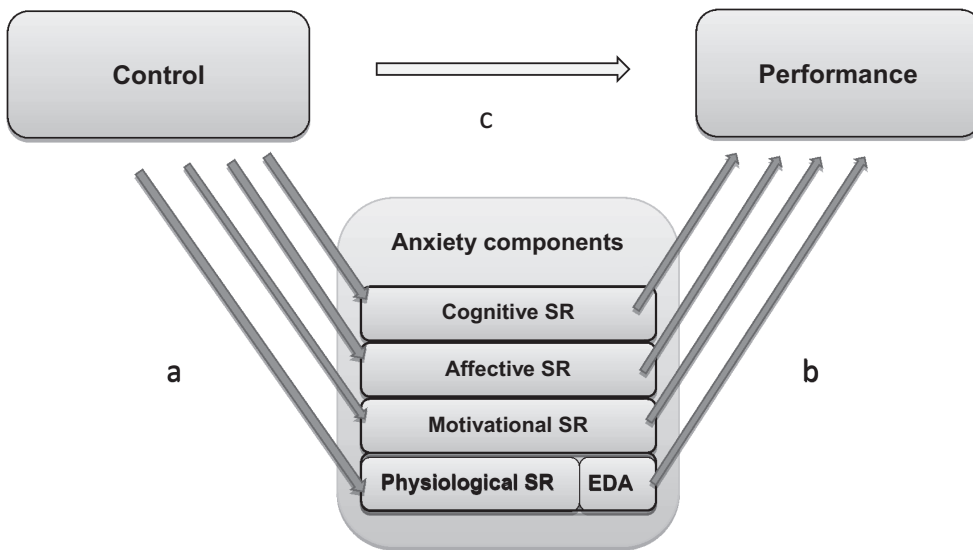

FIGURE 1 Hypothesized mediation. *Note*: It was hypothesized that lower control is associated with increased anxiety (i.e., all four components as assessed via self-report measures (SR) as well as higher electrodermal activity (EDA) as an additional assessment; path a) and that lower control is associated with worse performance (path c). Furthermore, it was expected that higher anxiety (i.e., all four components assessed via SR and EDA) is associated with worse performance (path b) in such a way that the anxiety components (i.e., SR and EDA) mediate the relationship between control and performance (path ab) and the components vary in the strength of their mediating effects.

via self-report (SR) measures and higher skin conductance (EDA, i.e., as an additional measure of the physiological anxiety component). Furthermore, we assumed that lower control is associated with lower performance (path c) and that higher anxiety (i.e., SR of the anxiety components and EDA) is associated with lower performance (path b) in such a way that the anxiety components (i.e., including SR and EDA assessments) mediate the relationship between control and performance (path ab). We also anticipated that the anxiety components vary in the strength of their mediating roles. As all appraisals, including control appraisals, are in essence cognitive processes, we expected that it has the strongest effect on the cognitive anxiety component, and based on findings on worry and emotionality, we further anticipated that it is also the cognitive component that has the strongest mediating effect. Given the inconsistent findings on the association between physiological arousal and performance, we did not have a clear assumption on the strength of the mediating effect via EDA. In all instances, mediation was expected to be partial rather than complete because other mediational processes, such as emotions other than anxiety (such as joy, boredom, pride, and anger), or study or test-taking strategies, are likely to influence the relationship between control and performance as well (Pekrun, 2006).

METHODS

Sample

High school eighth-grade students (i.e., from the top track of the German school system, 'Gymnasium') from six classes at schools in the Constance area participated in the current study. All students were participating in the mathematics test and questionnaire assessments (see procedure), but we only collected physiological data from 12 students in each class (since we only had 12 physiological measurement devices) which we randomly selected by drawing lots. Initially, the sample consisted of $N = 84$ German eighth graders from which physiological and self-report data were collected. Due to technical problems with some physiological measurement devices (e.g., the devices malfunctioned during data assessment, data could not be retrieved), we could not include all data assessed. The final sample consisted of $N = 50$ students ($M_{age} = 13.72$, $SD = .53$, 50% female; all right-handed). It has to be noted here that the sample of the current study was investigated within the same project as the study by Roos, Goetz, Krannich, et al. (2021), but a different data set was used.

Ethics statement

The study was conducted in compliance with ethical standards expressed in the WMA Declaration of Helsinki and all study procedures were deemed appropriate by the Institutional Review Board of the University of Konstanz. Students, parents, principals and teachers were informed about the study's purpose, duration and procedure. Participation was voluntary. Written informed consent was given by both students and parents. All data were anonymized.

Procedure

Self-report and physiological data were collected in students' regular classrooms during a written mathematics test, specifically created for the current study. It consisted of *six task blocks*, lasting approximately 60 min in total and included standardized tasks adapted from the VERA8 exam – a standardized exam all German eighth-grade students take at the same time of the school year (developed by the Institute for Educational Quality Improvement; IQB, Berlin, Germany). Task difficulty varied within the test to create variation in students' control appraisals (i.e., we induced the feeling of losing control by utilizing difficult tasks to examine whether loss of control is associated with increased anxiety). Each task block had to be

solved within 5 min. Afterwards, students were asked to hand in the task sheet and complete a short state questionnaire, which included the *state self-report measures*, before they started the next task block. *Students' performance* per task block served as the outcome measure. *Skin conductance* was continuously recorded with E4 wristbands (Empatica., 2016) and analysed per task block. Thus, there were six measurement points of all study variables (see state measures) per student.

Since for ethical considerations, the exam did not have an impact on students' grades; to incentivize students, a monetary prize was awarded to the class with the best performance (most points). Thus, the performance of each student, not just the high-performing students, contributed to the overall class performance and to win the prize. A similar procedure was used in a study by Bieleke et al. (2021).

Measures

State self-report measures (i.e., measures collected after each measurment point)

All items in the state questionnaire referred to the student's experience during the previous task (i.e., 'During this task I….'). Answers were given on a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

Control

Control was assessed with one item adapted from the Perceived Academic Control Scale (PAS; Perry et al., 2001; *'During this task I had a great deal of control'*). This single-item approach to assessing state appraisals of control is consistent with prior research (Goetz et al., 2007; Jarrell et al., 2016) and can be highly valid (Allen et al., 2022), especially with regard to state assessments (Gogol et al., 2014; Yang & Green, 2011).

Test anxiety components

The cognitive, affective, physiological and motivational anxiety components were assessed for each measurement point using three items each from the Achievement Emotions Questionnaire (AEQ; Pekrun et al., 2011). The AEQ is designed to represent the affective, cognitive, motivational and physiological components of anxiety, which was confirmed by CFA in research by Pekrun et al. (2011). Example items: 'During this task: …I worried whether I will receive a bad grade (cognitive); …I was very nervous (affective); …I was so anxious that I'd rather be anywhere else (motivational); …my heart was beating faster (physiological)'. The internal consistency across all six measurement points of these scales were $a = .85$ (cognitive), $a = .89$ (affective), $a = .87$ (motivational) and $a = .86$ (physiological component). All internal consistencies per measurement point were higher than .80.

Other test emotions

Since joy, anger, pride and boredom were found to occur frequently related to achievement and test taking (Finney et al., 2020; Raccanello et al., 2019), we wanted to consider if students may simultaneously experience multiple emotions and anxiety may not be the dominant emotion. Thus, while keeping the questionnaire short, for potential follow-up analyses, besides anxiety we assessed these emotions with a single item each for each measurement point (*'During this task I experienced (emotion)'*; see Goetz et al., 2007).

Perceived sweating

To understand students' perception of their physiological arousal reflected in increased EDA (i.e., increased sweating), we asked for each measurement point about *perceived sweating* with three items regarding the manifestation of anxiety in the form of sweating (on the hands; e.g., 'I had sweaty hands') from the Differential Test Anxiety Inventory (DAI, Rost & Schermer, 1997; $a = .79$ across all six tasks).

EDA measurement and analysis

EDA data were collected continuously with E4 wristbands (Empatica., 2016). The E4 collects EDA with a sampling frequency of 4 Hz, a dynamic range 0.01–100 μS and a resolution of 900 pS. Students wore them on their non-dominant hand to ensure data collection did not interfere with writing (i.e., hand movement), which could lead to data artefacts (Boucsein et al., 2012). The data were first visually inspected. All technically problematic datasets (e.g., in case of signal loss or if the device suddenly switched off) were excluded. Continuous decomposition analysis (CDA) using the Ledalab MATLAB toolbox, an analysis that is robust to lack of data quality (e.g., artefacts; Benedek & Kaernbach, 2010) was conducted. Due to our interest in sympathetic arousal in a high arousal situation, such as a test, we focused on the number of skin conductance responses (SCR) during the task blocks. These skin conductance responses can be described as peaks in sympathetic arousal, and they are considered evidence of the immediate response to stressful stimuli (Boucsein et al., 2012; Can et al., 2020; Iadarola et al., 2021). Calculating and analysing the number of SCR (i.e., peaks) as an indicator of stress and emotion is a common approach (for a review in the area of consumer emotions, see Caruelle et al., 2019) and similar methods and procedures were used in a number of previous studies (e.g., Bolls et al., 2001; Can et al., 2020; Groeppel-Klein, 2005).

Since students were given a fixed time (i.e., 5 min) for each task block, we used these 5 min for our analyses. Skin conductance responses significantly increase in frequency in high arousal situations (Braithwaite et al., 2013). The minimum value criterion for SCR amplitude is 0.01–0.05 μS (Cacioppo et al., 2000). Once the relevant events were identified in Ledalab, we extracted the total number of SCRs from the CDA results separately for each of the six 5-min task blocks (i.e., six measurement points of EDA per student).

Students' performance

The tasks in the exam were corrected by three independent raters following the recommendations of the IQB. Since the different tasks yielded different numbers of raw points, we used percentage correct per task block rather than raw points to allow for cross-task comparisons. As expected, our performance measure was significantly correlated with students' grades (last math exam $r = .56$, $p < .001$; last school report $r = .58$, $p < .01$), suggesting this is a valid indicator of performance.

Data analysis

Mediation analysis with multiple mediators was conducted with M*plus* 7.11 (Muthén & Muthén, 1998–2017) to examine the hypothesized mediation on the intra-individual level. As we had six measurement points for all study variables per student (control, anxiety components including EDA for the physiological component, and performance), we accounted for the nested data structure (multiple measurement points nested under students) with the 'type is complex' analysis. This analysis is used for complex (i.e., multilevel and hierarchical) survey data using the Hubert–White sandwich estimator without modelling the higher-level parameters directly (Muthén & Muthén, 1998–2017). Missing data were handled with full

information maximum likelihood procedures (Rubin, 1976). In our model, we tested direct and indirect effects as depicted in Figure 1.

RESULTS

Descriptive statistic and correlations across task blocks and persons

Table 1 shows correlations between the study variables across task blocks and persons, along with their means and standard deviations. All self-reported anxiety components were significantly positively correlated with each other and negatively correlated with control (all *ps* < .01). Only the cognitive component was significantly negatively correlated with performance. Correlation patterns between EDA and the self-reported anxiety components were less consistent and differed in direction. EDA was significantly negatively correlated with the cognitive and affective and positively correlated with the motivational component. Unexpectedly, the correlation with the physiological component was very small and non-significant. Surprisingly, EDA was significantly positively correlated with control and not significantly correlated with performance. Furthermore, control was significantly positively correlated with performance

Hypothesis: Anxiety components as mediators between control and performance

For an overview of all relations of this mediation model, see Table 2 and Figure 2. The intra-individual mediation model indicated a positive direct effect of control on performance ($b = .26$, $SE = .07$, $p < .001$). Control was significantly negatively related to all anxiety components as assessed via self-reports and as expected, the effect was strongest for the cognitive component ($b = -.45$; SE = .07; $p < .001$). However, higher control was associated with higher SC ($b = .17$, $SE = .08$, $p < .05$). There was a significant negative direct effect of the cognitive component on performance ($b = -.23$, $SE = .09$, $p < .01$). In contrast, the affective component showed a significant positive effect on performance ($b = .19$, $SE = .09$, $p < .05$). We did not find effects of motivational and physiological (self-report and EDA) components on performance. When analysing mediation effects, only the cognitive anxiety component significantly mediated the effect of the proposed relation (indirect effect, $b = .10$, $SE = .05$, $p < .05$).

TABLE 1 Mean scores, standard deviations and correlations between the study main variables across all tasks and persons

	1	2	3	4	5	6	7
1. Cognitive AC SR	–						
2. Affective AC SR	.75**	–					
3. Motivational AC SR	.41**	.53**	–				
4. Physiological AC SR	.60**	.75**	.62**	–			
5. Physiological AC EDA	−.16**	−.14*	.12*	.01	–		
6. Control	−.45**	−.34**	−.25**	−.36**	.17**	–	
7. Test performance (in %)	−.19**	−.05	−.06	−.07	.01	.29**	–
Mean	1.98	1.77	1.22	1.67	202.56	3.43	52.40
SD	1.00	0.91	0.51	0.88	97.49	1.14	30.95

Note: $N = 300$ (resulting from six measurement points per student and $N = 50$ students). Values do not take the nesting of data within persons into account (i.e., no 'type = complex').

Abbreviations: AC, anxiety component; EDA, electrodermal activity; SR, self-report.

*$p < .05$; **$p < .01$.

TABLE 2 Total, direct and indirect effects of the intra-individual mediation model

Paths and effects	Standardized coefficients	Standard errors
Path a		
Direct effect of control on cognitive AC SR	−.45***	.07
Direct effect of control on affective AC SR	−.34***	.10
Direct effect of control on motivational AC SR	−.25**	.08
Direct effect of control on physiological AC SR	−.36***	.09
Direct effect of control on physiological ac EDA	.17*	.08
Path b		
Direct effect of cognitive AC SR on performance	−.23***	.09
Direct effect of affective AC SR on performance	.19*	.09
Direct effect of motivational AC SR on performance	−.01	.06
Direct effect of physiological AC SR on performance	.03	.08
Direct effect of physiological AC EDA on performance	−.04	.04
Path c/c´		
Total effect of control on performance	.28***	.06
Direct effect of control on performance	.26***	.07
Path ab		
Total indirect effect of control on performance	.02	.03
Indirect effect of control on performance via cognitive AC SR	.10*	.05
Indirect effect of control on performance via affective AC SR	−.06	.04
Indirect effect of control on performance via motivational AC SR	.00	.01
Indirect effect of control on performance via physiological AC SR	−.01	.03
Indirect effect of control on performance via physiological AC EDA	−.01	.01

Note. All regression coefficients are standardized.

Abbreviations: AC, anxiety component; EDA, electrodermal activity; SR, self-report.

*$p < .05$; **$p < .01$; ***$p < .001$.

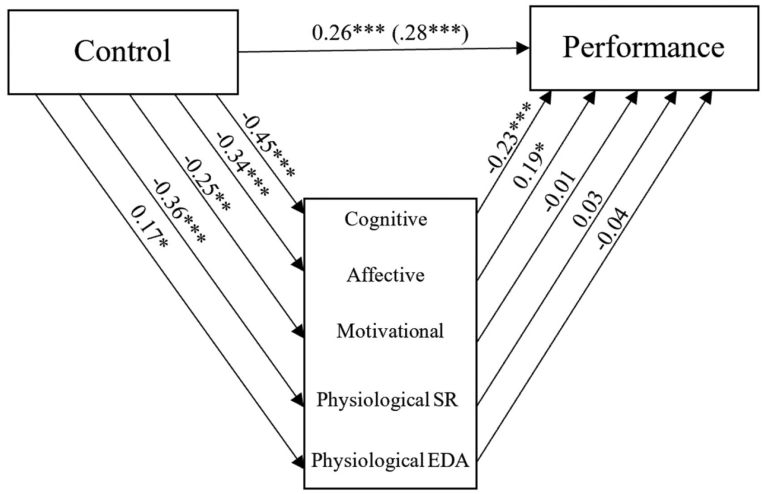

FIGURE 2 Results of the mediation analysis. *Note*: Standardized effects are presented. The effects on the direct path from control to performance depict the direct effect and the total effect, *$p < .05$; **$p < .01$; ***$p < .001$.

Follow-up analyses

To better understand correlation patterns with EDA and the positive relationship between control and EDA as found in the mediation analysis, we performed explorative follow-up analyses. We first took other emotions besides anxiety into account (joy, anger, pride, and boredom) and extracted the dominant emotion(s) (i.e., the highest rated emotion(s)) for each of the 300 measurement points across persons (six task-blocks × 50 students). This was done because students do not necessarily only experience one emotion at a time and the dominant emotion during a test is not always anxiety, which may have influenced our results. Since surprisingly joy and not anxiety was most often experienced as a dominant emotion (i.e., joy in $N = 107$ vs. anxiety in $N = 52$ of 300 measurement points) and research indicates that high arousal could also be a sign of feeling positively challenged (Feldman-Barrett, 2006), in a next step, we examined correlations between EDA and control and between EDA and the self-reported anxiety components separate for situations in which anxiety was dominant versus for situations in which joy was dominant. Results are presented in Table 3 and interpreted in the Discussion section. In short, we found that, when anxiety was dominant, EDA was marginally significantly correlated with control in a negative direction and significantly correlated with the physiological and motivational anxiety components in a positive direction. When joy was dominant, EDA was not significantly correlated with control and significantly negatively correlated with the cognitive anxiety components. In both cases, EDA was significantly positively correlated with perceived sweating.

DISCUSSION

The goal of the present intra-individual study was to investigate the relative impact of the anxiety components (cognitive, affective, motivational, and physiological) in the mediating mechanism linking control appraisal antecedents to students' test performance and to identify the component that is most central in this model (i.e., has the strongest impact on students' performance). For a more unbiased measurement, the physiological anxiety component was additionally examined with physiological measures (i.e., EDA).

Hypothesized mediation

As hypothesized, results from the intra-individual mediation model indicate that the anxiety components indeed differ with regard to their importance in the mediating mechanism linking control appraisals and test performance in such a way that the cognitive component was the only component for which we found a mediating effect: lower control was associated with an increase in the cognitive anxiety component, resulting in lower performance. These findings are in accordance with CVT and show that this

TABLE 3 Correlations between EDA and the main study variables in situations where anxiety and joy were the dominant emotion

Correlation between electrodermal activity and	Control	Performance	Cognitive AC SR	Affective AC SR	Physiological AC SR	Motivational AC SR	Perceived Sweating
Anxiety dominant ($N = 52$)	−.260#	.042	−.018	.011	.329*	.408**	.612**
p Value	.068	.770	.899	.939	.017	.003	.000
Joy dominant ($N = 107$)	.13	.045	−.183 #	−.157	−.025	.170	.297**
p Value	.201	.649	.059	.105	.801	.081	.002

Note: Due to the limited and varying number of measurement points in which anxiety was a dominant emotion, we could not conduct intra-individual analyses, and therefore, investigated simple correlations.

Abbreviations: AC, anxiety component; EDA, electrodermal activity; SR, self-report.

#Correlation marginally significant ($p < .10$); *$p < .05$; **$p < .01$; ***$p < .001$.

theory on intra-individual relations indeed also holds true when examining it on an intra-individual level. As the cognitive component is the only component for which we found such a mediating effect, our results suggest this component is likely central in the context of control and performance. Therefore, our findings are in line with the findings of Roos, Goetz, Krannich, et al. (2021) and suggest that this component should be the main focus of instructional techniques and anxiety interventions that are aimed at increasing students' performance. An example of this would be teaching students the so-called cognitive reappraisal strategies they can use prior to entering the testing situation to increase their control experience (e.g., by viewing the test as a challenge that can be met and overcome, rather than a threat) and decrease the cognitive component of anxiety (Denny & Ochsner, 2014; Gross & Thompson, 2007). Contrary to our expectations, we found a positive relationship between control and EDA, which was unexpected at first and warranted follow-up analyses. Furthermore, lower control was associated with increased anxiety on all four self-reported anxiety components, but the size of the effects differed. The control showed the strongest association with the cognitive component, while the strengths of the effects of control on the other components were rather similar. This is in line with our assumptions since appraisals of control are in essence cognitive processes, and are likely more closely related to the cognitive anxiety component (Goetz et al., 2006).

Moreover, in our mediation model that controlled for the influence of cognitive anxiety, although there was no significant indirect effect of control on performance via the affective component, a direct positive effect of the affective component on performance was found: higher affective anxiety was associated with increased performance. This implies that it might eventually be helpful to make students aware of how anxiety impacts performance and tell them that nervousness during a test is not always harmful to performance, but rather thoughts (i.e., cognitive component) about the consequences of failing are what can be associated with performance decrements (e.g., Jamieson et al., 2013; Martin et al., 2021).

Relationships among control, self-reported anxiety components and EDA

Aside from the positive effect of control on EDA in our intra-individual mediation model, correlations (across task blocks and persons) between EDA and anxiety components were also partly unexpected, since only the motivational component showed an expected significant positive correlation with EDA. This finding on the motivational component fits theoretical assumptions because the items assessing this component tap into the tendency to leave the situation which is part of the so-called 'fight or flight response' and which would entail increased physiological arousal (Lang et al., 1998). However, negative correlations were found between EDA and cognitive and affective components, and the correlation between EDA and the physiological component was non-significant and almost zero. An initial interpretation could be correlations between actual physiological arousal and self-reports of physiological arousal (i.e., as assessed with the physiological anxiety component) are not necessarily highly correlated (Hodges, 2015).

Follow-up analyses provided plausible alternative explanations of the divergence in our findings: Since research suggests several emotions are experienced in varying intensity during a test (Goetz et al., 2007), we wanted to investigate whether our unexpected findings (i.e., regarding control and EDA from our mediation model and correlation patterns) might be explained by high control also being associated with positive activating emotions, which may be experienced more intensely than anxiety during a task block (i.e., in the sense of feeling positively challenged), resulting in high arousal (i.e., EDA). Explorative follow-up analyses showed joy (i.e., positive activating emotion) was a dominant emotion in many task blocks and anxiety was less frequently experienced as a dominant emotion. Separate correlation analyses for situations in which anxiety was dominant versus situations in which joy was dominant indeed revealed two different pictures and confirmed our expectation that the positive relationship between EDA and control in our mediation model could be explained by positive activating emotions being dominant in specific situations: When anxiety was dominant, EDA was marginally significantly negatively correlated with control and significantly positively correlated with physiological and motivational components – this

is in line with arousal theories and our expectations. In joy dominant situations, EDA was not significantly but positively correlated with control and significantly negatively correlated with the cognitive component. This may be due to students' high control appraisal activating an adaptive 'fight' response, in addition to the feeling of being positively challenged, which is also associated with sympathetic arousal (Simonov, 1991), experiencing joy and low cognitive anxiety (Feldman-Barrett, 2006). In conclusion, depending on the situation and interplay of different emotions, increased EDA may be associated with high control experience and feeling positively challenged, or with low control experiences and feeling anxious. This is consistent with recent research on the challenge and threat by Martin et al. (2021).

Furthermore, regardless of the dominant emotion, EDA was significantly positively correlated with perceived sweating. This is not surprising, since EDA is a physiological measure based on sweating (i.e., sweat gland activation), and thus it is likely to be more closely related to self-reports of perceived sweating than other self-reports of the physiological component of anxiety, for example, a beating heart. It indicates that increased arousal was perceived by students but was not necessarily associated with a discrete emotional experience. This is in concurrence with Feldman-Barrett (2017), who argues that there is no specific physiological fingerprint of an emotion. Lastly, irrespective of the dominant emotion, we found no significant association between EDA and performance. Initial vague assumptions might be that increased EDA has no direct relationship with performance, but that the relationship between physiological arousal and performance emerges over time via poorer health, or that physiological arousal was positively interpreted as a challenge and therefore did not affect performance (e.g., as in Martin et al., 2021). However, both of these interpretations need further investigation.

Implications

In sum, our results suggest a high relevance of distinguishing between test anxiety components and focusing interventions on the cognitive component to increase students' performance. As stated above, this could be achieved by utilizing cognitive reappraisal strategies aimed at changing thinking about the situation or one's capacity to manage its demands (Gross & Thompson, 2007). However, although we did not find significant associations between the other components and performance, interventions and research should not only focus on the cognitive component, as we assume that other components including physiological arousal (e.g., EDA, heart rate, and blood pressure) might be more important when considering outcomes other than performance that may have consequences on mental and physical health (Diener, 2000). For example, the affective component can be seen as relevant for psychological well-being, and stress-related physical ailments (e.g., high heart rate and high blood pressure) can be associated with the physiological anxiety component (Damer & Melendres, 2011; Salend, 2012). Furthermore, follow-up analyses revealed anxiety is not always dominant in test situations and high arousal could be related to the experience of high control and positive emotions that are dominant at that moment. Thus, it seems that when investigating anxiety, it is also important to take other, also experienced emotions into account – first of all, the dominant emotion (if this is not anxiety). For example, enjoyment can be experienced even when there is a specific level of anxiety. Thus, even if students seem to enjoy the test this might not exclude that they also experience anxiety. Possibly a combination of enjoyment and anxiety indicates more a challenge/approach motivation than a threat. This could be further investigated with additional self-reports or specific physiological measures that can indicate challenge versus threat. In sum, it is therefore important to consider the context and more specifically test emotions other than anxiety, and also include them as covariates in the analyses in future research.

Limitations and future directions

Although this multi-method study was one of the first to examine antecedents and effects of the anxiety components, including measures of sympathetic arousal, on an intra-individual level, it also has some

limitations, which suggest a number of promising directions for future research. First, our sample of high school students was selective as we examined students in the top track of the German school system. Hence, the generalizability of our results may be limited in such a way that these students may not have been as anxious or that they used different test-taking strategies than students in other types of schools. Thus, it would be interesting to investigate these mediational effects in students from lower school tracks to check the robustness of these findings across different achievement levels. Besides physiological measurements being time-consuming and costly, in the progress of the current study, we noted that they can be challenging in other ways. For example, due to problems with some of the E4 devices, we excluded participants, resulting in a smaller sample size than initially intended. This negatively influenced the power of our study and options for follow-up analyses, potentially limiting its generalizability. In particular, the follow-up analysis can therefore only be seen as a first exploratory step. Such problems could be solved in the future by conducting multi-lab studies working on similar research questions to share data and expertise. Additionally, to examine the unexpected correlations, we found at the whole-sample level, in future research latent profile analyses are indicated to examine subgroups (i.e., some of whom may reflect the expected correlation) as was done, for example, in Martin et al. (2021). Moreover, we only examined EDA in our study, but it could prove promising to include other physiological measures to help triangulate our results, as well as to differentiate between positive and negative physiological reactions. Although a clear relationship is often absent for one specific measure (see Kreibig, 2010 for a review), using various measures might help to find patterns. Moreover, using physiological measures, such as cardiac output, has been shown to be promising to differentiate between challenge versus threat appraisals in lab settings (Blascovich, 2008; Scheepers & Ellemers, 2018; Scholl et al., 2017). Finally, although we assessed students' anxiety during a test situation, for ethical reasons students did not receive grades. Thus, it could be argued our test was a bit artificial. This may explain joy being a frequent dominant emotion experienced by students. On the other hand, the monetary prize we awarded to increase the relevance of participation and to resemble real-life test situations might have also created a heightened mean level of anxiety and might have been a possible confound. However, a similar procedure was used in a previous study (Bieleke et al., 2021) and since we analysed the data on an intra-individual level, we do not assume that this biased the results of the main analyses. Overall, future studies could assess students' anxiety in more realistic situations.

CONCLUSION

The current study proposes that extending research on the antecedents and effects of different anxiety components on an intra-individual level including physiological measures is promising, as it may contribute to a more complete picture of anxiety. Moreover, it may be important for future studies to recognize that in test situations there are more emotions than just anxiety – and that there appears to be a complex interplay between control experience, emotions, physiological arousal and performance that is worth investigating. In the future, this may help develop more effective anxiety interventions and thereby facilitate learning and academic achievement in the long run.

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AUTHOR CONTRIBUTIONS

Anna-Lena Roos: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; writing – original draft; writing – review and editing. **Thomas Goetz:** Conceptualization; funding acquisition; resources; writing – original draft; writing – review and editing. **Maike Krannich:** Conceptualization; formal analysis; methodology; writing – review and editing. **Monika Donker:** Methodology; writing – review and editing. **Maik Bieleke:** Writing – review and

editing. **Anna Caltabiano:** Writing – review and editing. **Tim Mainhard:** Conceptualization; methodology; writing – review and editing.

CONFLICT OF INTEREST

All authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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