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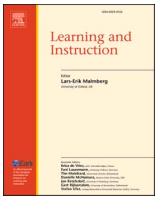

Potential classroom stressors of teachers: An audiovisual and physiological approach

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ABSTRACT

The number of teachers leaving their professions due to high levels of stress is a growing worldwide concern. Previous psychological and physiological research has already identified potential classroom stressors: low student engagement and motivation, negative teacher-student relationships and interactions, as well as teacher-centered activities. The current study extends this research by examining the frequency and intensity of these stressors during actual classroom teaching. The heart rates of 40 teachers were recorded throughout one real-life classroom lesson as a proxy for teacher stress. Heart rate measurements were used to select potentially stressful and non-stressful classroom situations. We transcribed the interactions during these situations and coded the stressors according to the previously mentioned stressor categories. Multilevel regression analyses were conducted to predict teachers' heart rates based on the occurrence of classroom stressors. Students' low engagement and motivation, as well as teacher-centered activities, significantly predicted an increased heart rate. However, pronounced differences were observed between teachers in what they experienced as stressful. This points to significant individual differences in teacher stress triggers and processes. Implications for research and practice are discussed.

1. Introduction

Elevated stress levels are a major problem for teachers around the world (e.g., Chaplain, 2008; Johnson & Birkeland, 2003; Kyriacou, 2001; Skaalvik & Skaalvik, 2015) as they are more likely to be affected by occupational stress than individuals in most other professions (Smith et al., 2000; Travers & Cooper, 1993). As a result, occupational stress and its influence on the number of teachers leaving the profession is a growing global concern (Brunsting et al., 2014; Ingersoll, 2001; Kyriacou, 2001; National Commission on Teaching and America's Future, 1996; Schlichte et al., 2005). In the US, around 40% of teachers change careers before the end of their fifth teaching year (Player et al., 2017; Reeves et al., 2017; Skaalvik & Skaalvik, 2017), while in China, the same percentage of teachers have at least considered leaving the profession (Liu & Onwuegbuzie, 2012).

In addition to factors outside the classroom, such as principal leadership (Newberry & Allsop, 2017; Tickle et al., 2011; Van Maele & Van Houtte, 2015) or conflicts with colleagues (Van Maele & Van Houtte, 2015), interactional processes inside the classroom play a major role in the development of teacher stress and burnout. Such processes include classroom management difficulties (Skaalvik & Skaalvik, 2015) and struggling with building positive and sustainable teacher-student relationships (O'Brennan et al., 2017; Richards et al., 2018; Skaalvik & Skaalvik, 2015; Van Maele & Van Houtte, 2015).

Previous research into the factors underlying teacher stress and burnout has largely relied on interviews and questionnaires (e.g., Aldrup et al., 2018; Klassen & Chiu, 2010; Montgomery & Rupp, 2005). Such studies focused on retrospective reports and subjective aspects of teacher stress, often evaluating stressors at a more general or habitual level. The most prominent types of stressors identified in these studies are low student engagement and negative teacher-student relationships due to both negative teacher and student behavior.

However, stress is also considered a biopsychosocial phenomenon (Blascovich et al., 2001) and thus includes, in addition to cognitive and motivational aspects, more implicit and physiological components (e.g., autonomic nervous system reactivity; Blascovich et al., 1999; Mendes et al., 2008, Mendes et al., 2003). The present study contributes to our understanding of teacher stress by examining classroom stressors and their association with physiological stress (i.e., heart rate) during actual teaching.

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1.1. Teacher stress and its assessment

Stress is defined as "certain types of experiences, as well as the body's responses to such experiences. The term generally refers to challenges, real or implied, to the homeostatic regulatory process of the organism" (McEwen & Mendelson, 1993, p. 101). Short-term or acute psychological stress triggers the hypothalamic-pituitary-adrenal axis (HPA; Hellhammer et al., 2009). Subsequently, the adrenal glands release glucocorticoids, which stimulate cardiovascular tissues and give feedback to the central nervous system to inhibit activation of the HPA axis. Under stress, the stimulation of cardiovascular tissues leads to an increased heart rate (Burford et al., 2017).

Repeated exposure to stressors that cannot be adequately managed may give rise to psychological symptoms of burnout (Maslach & Leiter, 2016) and a physiological effect called "allostatic overload" (McEwen, 2005). According to previous research, the main psychological symptoms of burnout are "overwhelming exhaustion, feelings of cynicism and detachment from the job, and a sense of ineffectiveness and lack of accomplishment" (Maslach & Leiter, 2016, p. 103). Many recent investigations on teacher stress, negative emotions, or burnout focused on the psychological experience of stress. Some studies evaluate this concept using single items such as "I find teaching to be very stressful" (Klassen & Chiu, 2010), whereas others applied more detailed questions referring to facets of stress such as "tension" or "discontent" (Clunies-Ross et al., 2008). Stress can be assessed as single (Aldrup et al., 2017; Dicke et al., 2014) or multi-dimensional concept (Aloe et al., 2014), comprising factors such as burnout or occupational well-being (Aldrup et al., 2018).

The few studies that used physiological indicators to investigate teacher stress have evaluated heart rate (Bönner & Walenzik, 1982; Donker et al., 2018, 2021; Scheuch & Knothe, 1997; Sperka & Kittler, 1995), electrodermal activity (Junker & Holodynski, 2021), cortisol levels (Susoliakova et al., 2014), or blood pressure (Bönner & Walenzik, 1982). While all of these are useful physiological indicators of stress, measures of heart rate and electrodermal activity provide an especially easy, inexpensive, and reliable method of recording stress reactivity (Lohani et al., 2019).

Sperka and Kittler (1995) assessed the heart rate of 16 student-teachers as they taught their first professional lessons. Following a situational analysis, the authors found that teachers' heart rate decreased throughout the lesson, likely because their regulatory necessities declined. Scheuch and Knothe (1997) examined the heart rate of 67 teachers and found these rates to be highest during teacher-centered activities like explaining concepts or giving directions and instruction. Junker and Holodynski (2021) analyzed the electrodermal activity and classroom interactions of eight teachers during a lesson. This study also showed that teacher-centered classroom activities produced more physiological stress than, for example, student-centered activities. Moreover, Donker et al. (2021) measured the heart rate of 80 teachers and rated video segments of their interpersonal behavior (agency and communion). Like the aforementioned studies, this investigation found that teachers showed an increased heart rate in situations where they had more interactional dominance.

1.2. Teaching stressors

A stressor is defined as a situation or stimulus "which produces stress" (Selye, 1976, p. 78), and conveys a certain personal demand or threat (Deckers, 2018). Much like the studies on teacher stress, most research on stressors in teaching has largely relied on self-report measures (e.g., Aldrup et al., 2018; Becker et al., 2015; Grayson & Alvarez, 2008). One of the most often used instruments in these studies is the Teacher Stress Inventory (Fimian, 1984, as cited in; Fimian & Fastenau, 1990), a self-report measure that identifies habitual stressors during teaching. Self-report studies provide important information on subjectively perceived negative mental states. Still, the external assessment of stressors through student reports or process-based data, such as observational records or ambulatory physiological monitoring, may provide additional situation-specific information to complement survey data (Lindahl et al., 2019). For example, Clunies-Ross and colleagues (2008) used the Observing Pupils and Teachers in Classrooms Schedule (OPTIC) by Merrett and Wheldall (1986) to record the percentage of time students spent engaging in task-related behavior (rather than disruptive-disrespectful behavior). Becker et al. (2015) used student ratings of class discipline collected with the following two items: "In this lesson, instruction was often disrupted" and "In this lesson, a lot of time was wasted."

Although at an individual level, stressors are perceived as such based on personal, internal appraisal processes (Demerouti & Bakker, 2011; Lazarus, 1984), previous psychological and physiological studies have been able to identify three general categories of stressors in teaching. The first category pertains to students' lack of motivation or effort (Becker et al., 2015; Benmansour, 1998; Buchanan, 2010; Geving, 2007; Grayson & Alvarez, 2008). Teachers may interpret this as a (potential) personal shortcoming due to an inability to provide engaging and interesting lessons.

The second category encompasses poor teacher-student relationships, which are often referred to as psychological stressors (Aldrup et al., 2017, 2018; Grayson & Alvarez, 2008; Klassen et al., 2012; Spilt et al., 2011). The quality of student-teacher relationships is influenced by fixed or external factors like student gender (Jerome et al., 2009) and parental involvement (Wyrick & Rudasill, 2009), as well as process-based classroom factors like student and teacher beliefs, attitudes, behaviors, and interactions with one another (Hamre & Pianta, 2006). Hamre and Pianta (2006) suggested that relationships include internal (e.g., beliefs and attitudes) and external (behavioral) aspects. In this study, we mainly focused on two conflict-related observable aspects of the teacher-student relationship: student behavior (i.e., disruptive-disrespectful behavior; Aloe et al., 2014; Becker et al., 2015; Benmansour, 1998; Clunies-Ross et al., 2008; Dicke et al., 2014; Harmsen et al., 2018; Klassen & Chiu, 2010; Paquette & Rieg, 2016) and teacher behavior (i.e., negative interpersonal teacher behavior; Aldrup et al., 2017; Aldrup et al., 2018; Grayson & Alvarez, 2008; Klassen et al., 2012; Spilt et al., 2011). Teachers may experience aversive student behavior as a stressor especially if they feel responsible for creating a positive classroom environment (Lewis & Sugai, 1999), establishing effective rules and routines, or conducting adequate monitoring (Colvin et al., 1993). Negative interpersonal teacher behavior may generate stress due to the emotional labor involved in bridging the gap between experienced and expressed emotion so as not to violate display rules (Donker et al., 2020; Wang et al., 2019).

Third, especially studies including physiological measures (see paragraph 1.1), discovered that teacher-centered episodes with increased regulatory necessities were associated with higher physiological stress (Donker et al., 2021; Junker & Holodynski, 2021; Scheuch & Knothe, 1997; Sperka & Kittler, 1995). Therefore, teacher-centered activities were included as a stressor in the present study.

1.3. The present study

The aim of the present study was to explore the extent to which classroom stressors identified by previous studies are predictive of heart rate as an indicator of physiological stress during actual teaching. We also aimed to determine which stressor had the strongest association with teachers' heart rate. We expected that low student engagement and motivation (Becker et al., 2015; Benmansour, 1998; Buchanan, 2010; Geving, 2007; Grayson & Alvarez, 2008), as well as disrespectful-disruptive student behavior (Aloe et al., 2014; Becker et al., 2015; Benmansour, 1998; Clunies-Ross et al., 2008; Dicke et al., 2014; Harmsen et al., 2018; Klassen & Chiu, 2010; Paquette & Rieg, 2016), would lead to an increased heart rate in teachers. Moreover, negative interpersonal teacher behavior was expected to be a predictor

of physiological teacher stress (Aldrup et al., 2017, 2018; Grayson & Alvarez, 2008; Klassen et al., 2012; Spilt et al., 2011). Finally, we hypothesized that teacher-centered activities like classroom instruction would be associated with a heightened heart rate, indicating higher stress (Donker et al., 2021; Junker & Holodynski, 2021; Scheuch & Knothe, 1997, Sperka & Kittler, 1995).

Most previous studies included only one or two categories of stressors. We could therefore not formulate an explicit hypothesis for the relative strength of their associations with teacher stress.

2. Methods

2.1. Procedure

We randomly selected data from 40 teachers that participated in the Dynamics of Emotional Processes in Teachers study (DEPTh; Donker et al., 2018). The study was approved by the ethical committee at the Faculty of Social and Behavioral Sciences of Utrecht University. Teachers were recruited via school newsletters, social media, and the authors' social networks. All participants provided active informed consent.

Data were collected for one lesson per teacher. There was no intervention during the lesson. Teachers were asked to select a class that was relatively challenging to them to increase the likelihood of exposure to stressors. Data collection lasted on average 42 min per lesson. Lessons were filmed with two cameras (both Panasonic HC-V110 Full HD). One camera was placed at the back of the classroom to capture teacher behavior, while the other camera was near the teacher and focused on the students. The teachers' physiological response was recorded throughout the lesson with real-time ambulatory monitoring of their heart rate.

2.2. Participants

Our sample consisted of 40 Dutch teachers (18 female, mean age 43.13 years, $SD = 12.33$). All teachers worked at secondary schools. In the Netherlands, students begin secondary school at around age 12. Participants taught the following grades: first (2.5%); second (10%); third (55%); fourth (20%); fifth (12.5%). Students were on average 14.93 years old ($SD = 1.17$), ranging between the ages of 13–18 years. Overall, students were equally distributed by gender (51.6% female) and there was an average of 23 students per class ($SD = 5$). Three types of schools were included in the sample: "vwo" (pre-university education: 11 teachers, 27.5%), "havo" (higher general education: 19 teachers, 47.5%), and "vmbo'' (lower general education: 10 teachers, 25%).

2.3. Measures

2.3.1. Teacher physiological stress

To measure teachers' physiological stress, we recorded teachers' heart rate continuously during the lesson. An increased heart rate indicates heightened sympathetic nervous system activity (Hellhammer et al., 2009). The teacher's heart rate was measured using the VU University Ambulatory Monitoring System (VU-AMS; De Geus et al., 1995). This system uses seven electrodes to measure both electrocardiographic signals and impedance cardiography. Electrodes were attached before the lesson and teachers wore the device on a belt around their waist to minimize reactivity to the physiological recording equipment. After the lesson, data was transferred to a computer and checked for abnormalities and outliers by two experienced assistants using the automated algorithm in the VU-AMS software and the VU-AMS manual. Corrections to the data, mostly due to the influence of physical movement, were made to less than 1% of the recordings. The heart rate signal was aggregated every 5 s. Moreover, to control for the influence of movement on heart rate measurements, we included body movement as a covariate in our analysis. This variable was also aggregated every 5 s.

This procedure was used to collect around 20.000 data points (i.e., 5 sec-periods). To increase our focus on potentially relevant time sequences, we first selected only the periods in which a teacher's heart rate was at least two standard deviations above their mean heart rate (controlling for physical activity; cf. Carroll et al., 2000; Linden, 1991; Myrtek, 2004). On average, six of these sequences were detected per teacher ($SD = 4$, min = 1, max = 26). To increase variability and reduce measurement error, thus broadening the empirical basis for this study, we also included the same number of equidistant sequences per teacher without referring to the video material. The exact time points and intervals depended on the number and length of stressful sequences as well as the duration of the lessons. In total 482 sequences were selected (241 stressful and 241 equidistant), with an average of 35 s.

2.3.2. Stressors in teaching

All events and teacher-student interactions during the sequences were transcribed from the video data. Two assistants were trained with the help of a situational transcription scheme, in which the assistants were asked to list the classroom activity and describe the tasks, rules, and goals involved. Moreover, during each situation, they provided verbatim transcriptions of what was said by teachers and students. To allow for a comprehensive assessment of the situation, nonverbal behavior (e.g., body positioning, posture, gestures, facial expressions, tone of voice, loudness of voice, viewing direction, or touch) was also described.

After the assistants transcribed the situations for five teachers each, the transcripts were inspected for accuracy. After a few minor adjustments and further instructions, all situations were transcribed. Fig. 1 is an example of such a transcription.

Deductive content analysis (Saldana, 2015; Schreier, 2016) was used to code the selected sequences. A key objective of our study was to enrich the established body of literature on teachers' psychological stressors with findings on physiological stress; as such, we constructed categories, definitions, and indicators based on self-report questionnaires that have been used to investigate classroom stressors in previous studies (see Table 1) and reflected the four general classes of stressors as discussed in section 1.2. Indicators of low engagement and motivation were compiled based on the work by Becker et al. (2015) and Grayson and Alvarez (2008). Concerning disruptive-disrespectful behavior, we referred to the student behaviors identified as most stressful by Clunies-Ross and colleagues (2008). Negative teacher interpersonal behavior, which also reflects aspects of the teacher-student relationship, was assessed based on the "conflict" facet of student-teacher relationships (Pianta, 2001). This dimension was selected because unlike closeness or dependency, the conflict has been considered a stressor in empirical studies. Due to the audio-visual nature of our study, relationship aspects like beliefs and attitudes (Hamre & Pianta, 2006) were not considered. Lesson phases in which the teacher was the focus of the class's attention (e.g., explaining concepts, giving directions or instructions) were coded as teacher-centered activities.

Deductive content analysis was performed by three additional assistants. They received 4 h of training which included explanations of the categories and indicators, examples from the transcripts, and opportunities for discussion and clarification of any additional questions. First, each of the three coders evaluated 60 situations for 10 teachers (i.e., 25% of the data set). Raters had no information on the teachers' heart rate during the situation. In each case, the rater decided whether a stressor category applied to that situation (0 = a category is not relevant to this situation; 1 = a category is relevant to this situation). Situations could be coded under multiple categories. Since dichotomous coding was used, Fleiss' Kappa (Fleiss, 1971) was calculated to evaluate the inter-rater reliability for each category. All four categories had good to excellent agreement (low engagement/motivation: Fleiss' $\kappa = 0.619$, disruptive-disrespectful behavior: Fleiss' $\kappa = 0.782$, negative interpersonal teacher behavior: Fleiss' $\kappa = 0.641$, teacher-centered activity: Fleiss' $\kappa = 0.881$; Landis & Koch, 1977). Because of the good reliability,

Grade/level: 4, vwo/gymnasium
Subject: Dutch language and literature
Classroom activity: Silent work
Tasks & rules: The teacher wants the students to work on the assignment she gave them.
Situational teacher goal: The teacher is checking how students are working on the assignment.
Interaction:
T: "End it." (calm tone of voice, moderate volume of voice, standing in central position in front of the class)
T to two students: "Boys, did it work out?" (calm tone of voice, moderate volume of voice, standing next to the table of the students)
S1: "I could not find a spelling mistake." (calm tone of voice, moderate volume of voice, sitting behind the table)
T to S1: "Well done. No mistake?"
S1: "I could seriously not find any."
T to S1: "Well, that is a compliment for [Name S2], right?"

Fig. 1. Example of a situational transcript.

Table 1
Situational coding scheme for potential micro-level stressors.

Category	Definition	Indicators	Examples
Low student engagement and motivation	Students show a lack of motivation or little interest in their tasks or what is happening in the classroom.	• Little interest/commitment/effort in the given tasks • Little participation • Little motivation • Little feedback on teacher's questions • Hardly any engagement with the given tasks • No completion of homework	• T: "Who did not do their homework? Thank you [name S], for your honesty." • T: "Okay uhm [name S1], please uhm [name S2], you came in late, I have already told you emphatically: take out your things and close your laptop."
Disruptive-disrespectful student behavior	Disruptive and disrespectful behavior of students against fellow students or the teacher.	• Teacher asks for silence and students keep being loud. • Students interrupt teacher or their classmates with disturbing or disrespectful remarks. • Students interrupt, mock, or chat with each other. • Students make faces behind the teacher's back or exchange objects or notes.	• S (some/all): (chatting) • S (some/all): (making noise) • T: "put it away" (shaking his head) • T: (looking at some students who make noise)
Negative interpersonal teacher behavior	Teacher acts in a way that indirectly interferes with their degree of cognitive and emotional detachment.	• Harsh criticism • Loud reprehension • Teacher exposing someone • Sarcasm • Derision • Verbal aggression • Teacher threatens students with punishment • Moaning • Impatience • Petulance	• S1: "Sir, are you a little tense?" (calm voice) T: "Kind of" (sarcastic tone of voice) • T: "Question 16" (impatient tone of voice, loud volume of voice) • T: "shut up"
Teacher-centered activity	A classroom activity that mostly focused on the teacher's actions.	Teacher … • explains concepts • gives directions or instructions • asks closed questions • gives a demonstration	• T: "And you see here, the sugar particles are triangles and the salt particles are circles. And if you have a mixture of sugar and salt …" (standing/walking in front of the class, pointing at the board)

the remaining situations were coded by only one rater.

2.4. Data analysis

All data analyses (i.e., descriptive statistics, correlations, and multilevel regression) were conducted with RStudio Version February 1, 5033. Statistical assumptions including linearity, homogeneity of variance, and normal distribution of residuals were tested and confirmed with RStudio (Palmeri, 2020).

In our multilevel regression, level 1 contained data on specific situations (the within-teacher level), and level 2 represented the individual teachers (the between-teacher level). The outcome variable was the situation-specific heart rate. The regression model was specified as follows (Fidell & Tabachnick, 2007):

$$Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + e_{ij}$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

where Y_{ij} represented the average heart rate of a given teacher *(j)* in a given situation *(i)*. β_{0j} referred to the intercept of stress levels for teacher *j* and consisted of the overall intercept (γ_{00}) as well as the error component for the deviation of the teacher's intercept (u_{0j}) from the grand mean (γ_{00}). β_{1j} represented the slope of the relationship between the level-1 predictor (X_{ij}, in our example: low engagement and motivation, disruptive-disrespectful behavior, negative interpersonal teacher behavior, teacher-centered activity, and physical movement) and heart rate for teacher *j*. β_{1j} consisted of the overall regression coefficient (or slope) based on the relationship between heart rate (Y_{ij}) and the level-1 predictor (γ_{10}) as well as u_{1j}, representing the error component for the individual slope. Finally, e_{ij} referred to the random prediction errors in the level-1 equation.

Since pure level-1 effects were of interest here (i.e., situation-specific correlations between heart rate and stressors), the independent variables (low engagement and motivation, disruptive-disrespectful behavior, negative interpersonal teacher behavior, and teacher-centered activity) were cluster-mean centered (Enders & Tofighi, 2007).

3. Results

3.1. Descriptive statistics

Teachers' average heart rate during the selected situations was approximately 89 bpm, with a standard deviation of 15 bpm. Table 2 shows the relative frequencies of low engagement and motivation, disruptive-disrespectful behavior, negative interpersonal teacher behavior, and teacher-centered activity during the situations examined. Around half of the situations were characterized by teacher-centered activity, whereas disruptive-disrespectful behavior and low engagement/motivation only occurred occasionally. Negative interpersonal teacher behavior was the least frequent category. Concerning level 1 (within) and 2 (between) stressors, we found that the within-teacher variance was smaller than between-teacher variance.

Multilevel analysis of within-person correlations showed that low engagement and motivation, disruptive-disrespectful behavior, as well as negative interpersonal teacher behavior were weakly correlated (r = 0.12*-0.15*). Teacher-centered activity was weakly correlated with low engagement and motivation only (r = −0.12*).

3.2. Multilevel regression

Table 3 contains the results of the multilevel regression analysis. Multilevel regression analysis was conducted to outline the fixed and random effects of each stressor. The two aspects of the teacher-student relationship (i.e., disruptive-disrespectful student behavior and negative interpersonal teacher behavior) were not significantly associated with teachers' heart rate. In contrast, low engagement and motivation by students as well as teacher-centered activity were related to an increase in teacher heart rate. Teacher-centered activities had the largest effect on heart rate, leading to an increase of nearly 3.5 bpm.

Table 2
Relative frequency and SD of potential stressors.

	Within-Level		*Between-Level*
Variable	Relative frequency	*SD*	*SD*
1. low engagement and motivation	11%	7%	14%
2. disruptive-disrespectful behavior	20%	9%	18%
3. negative interpersonal teacher behavior	6%	6%	8%
4. teacher-centered activity	53%	14%	24%

Table 3
Multilevel regression model with heart rate as outcome and physical movement as a covariate.

Predictor	b	95% CI	*SE*	*T*	p^a	random effects (*SD*)
(intercept)	91.32	[86.51, 96.52]	2.62	34.85	<.001	16.33
(physical movement)	0.11	[0.08, 0.14]	0.01	5.91	<.001	0.08
low engagement and motivation	1.61	[-0.21, 3.11]	0.89	1.80	.04	2.42
disruptive-disrespectful behavior	0.90	[-0.54, 2.11]	0.86	1.03	.15	3.89
negative interpersonal teacher behavior	−1.39	[-4.37, 0.01]	1.05	−1.32	.82	1.52
teacher-centered activity	3.49	[2.55, 3.74]	0.50	6.94	<.001	2.59

$p < .001$.
[a] p-values were calculated for a one-tailed test since all predictors were suggested to be associated with increased heart rate.

Random effects (see column on the right) were analyzed to get a clearer picture of inter-individual differences in the association between the stressors and heart rate. Random effects consisted of between-teacher variations in intercepts and slopes, as well as residual variance. Fixed effects had a coefficient of determination of $R^2_{marginal} = 0.05$, whereas fixed and random effects combined resulted in an $R^2_{conditional} = 0.93$, demonstrating the magnitude of random effects on heart rate. Teacher-specific intercepts were distributed with a standard deviation of 16.33 bpm. The standard deviations of predictor-specific slopes for each person ranged from 1.52 (negative interpersonal teacher behavior) to 3.89 (disruptive-disrespectful behavior). Overall, these findings suggest that negative interpersonal teacher behavior had a similar effect on heart rate across the entire sample, whereas disruptive-disrespectful behavior showed different effects between teachers. Fig. 2 shows the random individual differences in slopes for each of the four predictors. The third source of random error, residual variance of heart rate, showed a standard deviation of 5.52 bpm.

4. Discussion

The aim of this study was to contribute to our understanding of teaching stress by examining well-established classroom stressors and their association with physiological stress monitoring. Two out of the four stressors examined—namely students' disrespectful-disruptive behavior (e.g., Aloe et al., 2014) and negative interpersonal teacher behavior, which are indicators of a negative teacher-student relationship (e.g., Aldrup et al., 2017)—were not predictive of heart rate. However, low student engagement and motivation (e.g., Becker et al., 2015) as well as teacher-centered activities (e.g., Donker et al., 2021) were significantly associated with an increase in teachers' physiological stress.

As mentioned in previous psychological studies, students' low engagement and motivation are related to negative teaching experiences, especially if these behaviors are hard to cope with and undermine teachers' goals (Becker et al., 2015). The present study suggests that in addition to psychological effects, students' refusal to engage in classroom activities may have traceable physiological effects on teachers' heart rate. This, in turn, could have long-lasting effects on teacher well-being. In line with previous physiological studies (Donker et al.,

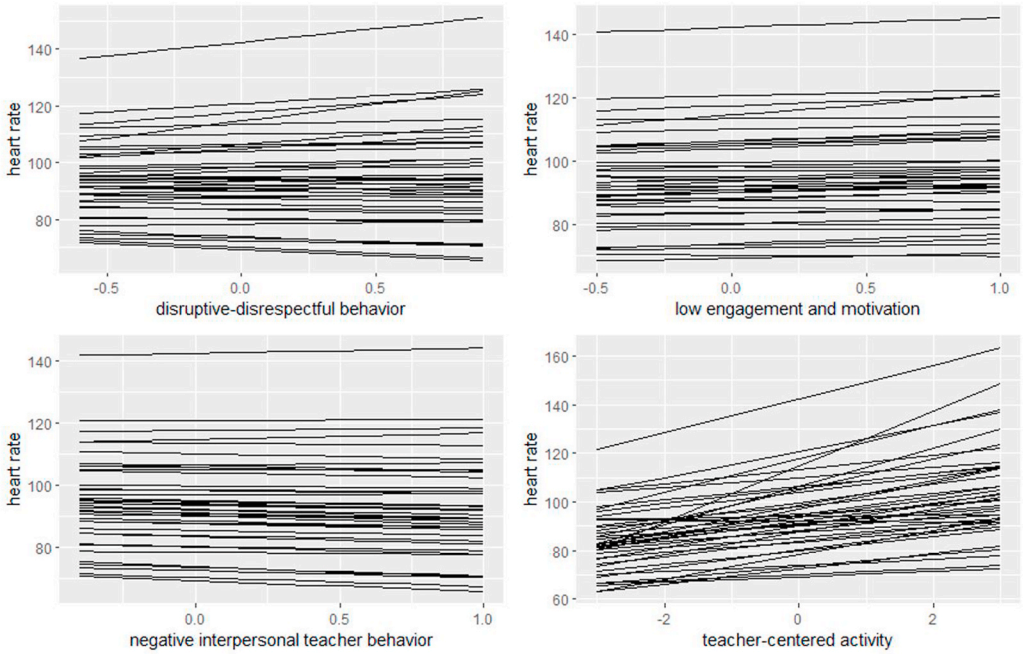

Fig. 2. Between-teacher variance of slopes for all four predictors.

2021; Junker & Holodynski, 2021; Scheuch & Knothe, 1997, Sperka & Kittler, 1995), teacher-centered activities, which have long been neglected in psychological stress research, showed the strongest effect on teacher stress. Being the center of attention seems to be stressful for many teachers and could have negative consequences on their physiological health.

Our results suggest that there is a difference between psychologically perceived and physiologically measured stress in teaching. It may seem reasonable to assume a degree of consistency between stress outcome systems (psychological vs. physiological), and this has been the traditional position in the literature (for a review see Mauss et al., 2005). However, in line with our findings, a meta-analysis of Campbell and Ehlert (2012) revealed that out of 49 studies of psychologically perceived and physiologically measured stress, only half observed significant positive correlations between the two measurement approaches. The authors attribute these moderate correlations to assessment features such as time, tools, frequency, and statistical approach, as well as to underlying psychological traits and physiological dispositions (p. 1131).

Our findings may be explained by the salience of stressors mentioned in studies of psychological stress. The salience of a stimulus (e.g., disruptive-disrespectful behavior) improves the ability to recall stimulus-related information (Daleiden, 1998). Attention, in turn, is associated with the intrusive salience of the stimulus and personal goal relevance, knowledge, and expectations (e.g., managing momentum; Sänger et al., 2014). Since teacher-centered activity is rather frequent and part of what is considered 'normal' in most classrooms, it may lack this salience. This may explain why teacher-centered activities have not been identified as stressors in previous psychological studies. Nonetheless, stress in these situations may be caused by the need for achievement and the fear of social evaluation as well as social exclusion (Dickerson & Kemeny, 2004; Pruessner et al., 2010).

Furthermore, some incidents where students are chatting or forget their homework may not have been so stressful as to cause a major heart rate response. Perhaps some teachers did not even notice some of the coded incidents or were not bothered by brief student chatter, which would point towards the role of individual appraisal processes (Lazarus, 1984) in stress. The large variations in the slope of the association between students' disruptive-disrespectful behavior and teacher heart rate support this possibility.

4.1. *Limitations and future directions*

A limitation of the current study is the purely behavioral-observational approach to student-teacher relationships. On the one hand, this can also be viewed as a strength, as it decreased dependence on self-report measures. On the other hand, personal experiences of the relationship and situation-specific interactions may have more impact on teacher stress than what can be externally observed (c.f. Donker et al., 2021). Experience sampling approaches as employed by Becker et al. (2015) tap into these momentary personal perceptions and could help assess more personally relevant stressors, but such an approach may also disrupt the naturally occurring classroom processes. Future studies may wish to include, in addition to physiological measurements, internal variables (appraisal, beliefs) evaluated using questionnaires or interviews to provide better mapping of student-teacher relationships (Hamre & Pianta, 2006; Pianta, 2001). Moreover, disruptive-disrespectful behavior as well as negative teacher behavior, which were used as indicators of negative teacher-student relationships, may also be affected by other factors. For example, disruptive-disrespectful behavior may be caused by students trying to impress each other, whereas negative interpersonal teacher behavior could be triggered by conflicts with colleagues. In this case, such behavior would probably have a smaller effect on teachers' heart rate in class.

Another limitation lies in the recording of actual lessons. The presence of physiological and audiovisual recording equipment during teacher-centered activities may increase the public speaking aspect of the situation (Ellis, 1995) and the fear of negative evaluation (Jibeen et al., 2019; Malini & Janakavalli, 2018). Conversely, teachers may have expected that students would show less (intense) maladaptive behavior or more productive behavior in the presence of the recording equipment, facilitating classroom management (Roethlisberger & Dickson, 1939).

Finally, a meta-analysis by Chida and Hamer (2008) revealed that habitual happiness, positive mood, self-esteem, and empathy can reduce HPA reactivity. Also, Jamieson et al. (2012) provided empirical evidence for how appraisal and emotion regulation styles can directly affect cardiovascular responses. Thus, it is also possible that a disproportionate number of participants in this study had adaptive traits and effective reappraisal strategies, resulting in smaller changes in heart rate in

response to classroom stressors. Including personal characteristics like empathy, general positive mood, or habitual appraisal styles as moderators could therefore provide a more comprehensive picture of teacher stress and stressors. Since teachers participated in this study voluntarily, a sample selection bias (Fadem, 2009) towards more positive and optimistic traits and appraisal strategies must also be considered. However, major differences in the heart-rate intercept and slopes between teachers indicate significant individual variability in the relationship between stressors and physiological stress.

5. Conclusion

The present study explored the extent to which classroom stressors, identified by previous surveys, interviews, and physiological studies, were predictive of situational heart rate as an indicator of stress. As suggested by previous psychological teacher stress studies, students' low engagement and motivation were associated with physiological stress. Moreover, as assumed based on earlier physiological teacher stress studies, teacher-centered activities often play an important role in the emergence of physiological stress.

As prolonged physiological reactivity has been associated with negative health outcomes (McEwen, 2005), it seems advisable to explore why teacher-centered activities are stressful in many cases and how this can be alleviated. Such findings could be used to enrich teacher education programs and interventions with more targeted advice, which could prevent and decrease teacher stress more effectively than currently available general interventions. For example, programs could help teachers improve their self-esteem, reduce negative attributions and optimize their classroom management skills to decrease their fear of social evaluation as well as social exclusion (Dickerson & Kemeny, 2004; Pruessner et al., 2010). Not only could this ultimately help decrease teacher stress and burnout, but also increase student engagement and well-being in the classroom.

CRediT authorship contribution statement

Robin Junker: Conceptualization, Methodology, Formal analysis, Writing – review & editing, Visualization, Formal analysis. **Monika H. Donker:** Conceptualization, Methodology, Validation, Writing – review & editing, Data curation. **Tim Mainhard:** Supervision, Methodology, Writing – review & editing.

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