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Handling Demanding Situations: Associations between Teachers' Interpersonal Behavior, Physiological Responses, and Emotions

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ABSTRACT

Teaching can be emotionally demanding. The current study investigated how teachers handle demanding situations in class, and how their behavioral and physiological reactions shape their emotions after the lesson. Interpersonal behaviors of 80 secondary school teachers were coded based on video recordings of one real-life lesson. During the lesson, heart rate and cardiac output were recorded continuously as indicator of relative challenge versus threat motivational states. Overall, teachers differed substantially in the number of demanding situations and how they changed their interpersonal behavior and physiological responses. Although teachers' behavioral and physiological changes were not a straightforward predictor of their emotional outcomes, especially teachers with dispositional low agency or communion were at risk of less positive and more negative emotions.

KEYWORDS

Cardiac output; challenge–threat; emotions; interpersonal behavior; teacher stress

Teaching is an emotion-loaded activity and both teachers and learners experience a broad range of emotions in the classroom. While research on student emotions has a longstanding tradition, the importance of teacher emotions has only been acknowledged relatively recently (Frenzel, 2014; Keller et al., 2014). This is surprising, because the available research shows that teachers' emotions are closely intertwined with their actions and cognitions (Hargreaves, 2000; Keller et al., 2014). Moreover, we know that teachers' actions and cognitions affect the relationship with their students and student outcomes (Frenzel et al., 2009; Hagenauer et al., 2015). Positive emotions in teachers are also associated with their own well-being and decreased stress, burnout, and teacher attrition (Chang, 2013).

Studying how teachers' emotions emerge in the classroom is thus highly relevant to optimize teacher and student outcomes. In particular, it has been proposed that specific stressful or demanding classroom events are associated with teachers' emotions (Becker et al., 2015; De Ruiter et al., 2019). We therefore investigated both the frequency and characteristics of demanding situations during real-life classroom teaching (i.e., RQ1). Emotional outcomes may, however,

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not only depend on the number of demanding events, but also on teachers' behavioral and physiological responses in such situations. We therefore examined how changes in teachers' interpersonal behavior during demanding situations were associated with their emotions (i.e., RQ2; Becker et al., 2015; Donker et al., 2020; Frenzel et al., 2015; Lazarus, 2006), and whether changes in physiology (as indicator of relative challenge versus threat motivational states) moderated the association between teacher behaviors and the emotions they elicit afterwards (i.e., RQ3; Blascovich, 2008; Seery, 2011a).

Teacher's evaluation of demanding classroom situations

Not all situations in the classroom can be classified as highly demanding. In his transactional model of stress and coping, Lazarus (2006) posed that a stress response occurs only when an individual evaluates the environment or a situation as taxing and potentially endangering their well-being. This process of evaluating whether a situation is relevant to one's well-being is referred to as *appraisal*. It should be noted that the appraisal process is not explicit and cognitive only; it can occur automatically and unconsciously (Scherer, 2009). The appraisal process is usually split in two phases: primary and secondary appraisal.

Primary appraisal – what constitutes a demanding situation for teachers

The first phase is primary appraisal, during which a person evaluates whether a situation is actually relevant for them and incongruent with their personal (lesson) goals (e.g., students are not paying attention during plenary instruction, and the teacher cannot execute the original lesson plan). Such situations demand a teacher's attention and need an action-oriented response (Behnke & Kaczmarek, 2018). Because teachers in these relevant, but goal-incongruent moments are motivated to minimize the discrepancy between the actual and desired situation, such situations are also referred to as 'motivated performance situations'. Motivated performance situations are demanding situations, that require an active, instrumental response from the person. Motivated performance situations are self-relevant and have a social-evaluative component as well. In that sense, performance during motivated performance has implications for one's well-being (e.g., self-esteem).

The working life of teachers is packed with motivated performance situations, throughout the day. Examples are teachers trying to get across a very difficult subject during plenary instructions, or keeping order by confronting disturbing students, or intervening during interpersonal conflicts. In the case of teaching, the whole lesson could be seen as important for teachers, but not all situations during a lesson constitute motivated performance situations, because not all situations are equally relevant to teachers' well-being or incongruent with their goals. Questionnaire studies have identified several potential classroom stressors, such as discipline problems, time pressure, and low student motivation (Skaalvik & Skaalvik, 2017) which may interfere with teachers' lesson goals, and thus need explicit attention. Also, whole class teaching settings (e.g., the lesson start or lecturing) have been argued to be demanding for many teachers (Junker et al., 2021; Pennings et al., 2018; Wubbels et al., 2006).

Importantly, and central to our study, teachers likely differ substantially regarding the situations in class they experience as demanding (De Ruiter et al., 2019). But also within a teacher there might be differences in how they evaluate situations over the course of a lesson, that is, dependent on the context and the current lesson goals. For example, disruptive student behavior may represent a demanding situation in some cases (a student talking during plenary instruction), but not in other contexts (students talking during individual seatwork). An intra-individual perspective using multiple assessments over time is thus essential to get insight into individual stressors during the lesson.

Secondary appraisal – teachers' resources to handle motivated performance situations

Once a situation has been evaluated as relevant and goal-incongruent, there is a need for action and responding to the situation. During secondary appraisal, the demands of the situation are weighed against personal resources and the ability to handle the situation. Examples of such personal resources are emotion regulation strategies (e.g., thinking that the student is just tired rather than genuinely uninterested) or classroom management actions that teachers are able to employ. When the teacher is very experienced, and has expertise (and is passionate about) the subject, it is likely that these resources are bigger than the task demands (difficult subjects, students not interested), resulting in challenge. When the teacher is just starting their job, has a low voice, and has a conflict-avoiding style, it is likely that these additional demands outweigh possible recourses, resulting in threat. When teachers experience more resources than demands, this will result in positive emotions, and vice versa (Lazarus, 2006).

The balance between individual resources and demands might affect the interpersonal behavior a teacher is able to show in the demanding situations. According to interpersonal theory, teacher behavior in the classroom can be described using the combination of two basic dimensions: interpersonal agency and communion (Horowitz & Strack, 2011). Agency captures the degree to which someone strives for a leading role and social influence. Communion reflects friendliness and the degree to which someone strives for interpersonal connection with others. Both students and teachers favor generally high levels of teacher agency and communion (Wubbels et al., 2006). Such interpersonal teacher behavior has been associated with higher student achievement and motivation (Becker et al., 2015; Mainhard et al., 2018) as well as teacher well-being (Chang, 2013; Spilt et al., 2011).

Remaining in a position of social influence (high agency) and positive connection with students (high communion), or even strengthening such behaviors, may however not be easy in demanding classroom situations. For example, when students are unfriendly or hostile, or try to adopt a leading and agentic role (Pennings et al., 2018). This is because teachers in such situations have to overrule the principles of interpersonal complementarity (Sadler et al., 2011), and thus actively need to refrain from responding to student hostility with equally hostile behaviors or from reacting subordinately to dominant student bids. Nonetheless, when teachers succeed in taking the lead or strengthening the connection with students during demanding situations, they might experience more positive emotions (De Ruiter et al., 2019).

Physiological measures as indices of motivation in real-life classroom settings

Teachers' appraisals can best be understood as being largely automatic and unconscious (Kappas, 2006; Scherer, 2009), which makes it hard to assess them with (retrospective) self-reports. Self-reports may fail to capture all relevant events and instead often focus on the most extreme, most recent, or otherwise most memorable events (Becker et al., 2015). Moreover, self-reported appraisals are likely to contain biases, because teachers are not aware of their automatic responses or because they are reluctant to disclose experiences of threat (Brose et al., 2013). Finally, asking teachers to reflect on their appraisal in-situ likely interrupts ongoing classroom processes (Becker et al., 2015).

Physiological measures might help to find out which events during a lesson are particularly demanding for teachers. According to the biopsychosocial model of challenge and threat (Blascovich, 2008), when a situation in class is relevant and goal-incongruent (i.e., a motivated performance situation), a teacher will show physiological activation associated with *task engagement* (i.e., an increased heart rate and increased ventricular contractility; Seery, 2011a). Because teachers typically feel responsible for providing structure and connecting with their students, high task engagement (and thus a relatively high heart rate) can be expected most of the time

during a lesson (Frenzel, 2014; Wubbels et al., 2006). However, each lesson will also contain particular moments that require extra teacher attention and/or have significant meaning for them (Shapira-Lishchinsky, 2011). In the current research we operationalize these peak moments of motivated performance as a heart rate of two standard deviations above teacher's individual average lesson heart rate, and consider such moments as the most demanding situations in the lesson.

Moreover, cardiovascular measures can offer insight into the motivation behind certain actions (in our case, interpersonal teacher behaviors) in demanding situations (Blascovich, 2008; Seery, 2011a). When an individual's resources are perceived as meeting the current demands, a motivated performance situation is viewed positively as a *challenge*. For example when teachers know classroom management strategies to maintain order. Physiological indicators of *challenge* consist of relatively high cardiac output along with low total peripheral resistance. This represents an efficient cardiovascular response pattern as the increased heart rate and ventricular contractility is accompanied by widening arteries which facilitates increased blood flow (Seery, 2011a). However, when demands are higher than resources, a motivated performance situation becomes *threatening* (Blascovich, 2008; Seery, 2011a). This might happen when teachers encounter a situation that is new for them or when their emotion regulation strategies are not sufficient to stay in control. *Threat* responses are indicated by low cardiac output along with high total peripheral resistance. This represents a maladaptive, inefficient cardiovascular response pattern, as the increased heart rate and ventricular contractility is not accompanied by vasodilation (i.e., heart and blood vessels work in opposition to each other; Seery, 2011a).

In general, challenge motivational states have been associated with positive affect, while threat is associated with negative affect (Blascovich & Mendes, 2000). The evidence for associations with discrete emotions is limited, but studies have associated pride with challenge and shame with threat, while anger has been associated with both challenge and threat motivational states (Herrald & Tomaka, 2002; Mendes et al., 2008). Moreover, in the current study, we will explore whether challenge vs. threat motivational states moderate the association between teachers' interpersonal behavior and emotions.

Dispositional teacher behavior

Teachers' agentic and communal behavior can be triggered by specific situational cues, such as a disruptive student behavior that requires a direct agentic response. However, teachers also differ substantially in their general dispositions regarding agency and communion (Wubbels et al., 2006), which will in turn also determine the affective consequences of these more incidental changes in agentic or communal behavior, as triggered by the social context. It may thus be necessary to take into account how a teacher generally behaves in class when investigating the association between behavioral and physiological responses in motivated performance situations and subsequent emotions of teachers.

Teachers with relatively high dispositional agency and communion levels are generally better able to change their behavior in demanding situations in line with professional standards (e.g., taking the lead or staying friendly; Pennings et al., 2018). It can thus be expected that the combination of high dispositional agency and communion levels, combined with increases in these behaviors *during* motivated performance, results in the most positive emotions.

Furthermore, a position of relatively high social power (Scheepers et al., 2012) or perceived control (Jones et al., 2009), which is characteristic for interpersonal agency, has been related to amplified challenge motivational states. In this vein, teachers who generally show high levels of agency might thus be more inclined to interpret demanding situations as a positive challenge. Power or agency, however, especially leads to challenge when it is perceived as an

opportunity rather than as a burden or obligation (Scholl et al., 2018). When teachers perceive classroom display rules (e.g., 'the teacher must be in charge') as such a burden (Chang & Davis, 2009; Donker et al., 2020), threat responses and negative emotions are likely (Rohrmann et al., 2011).

Finally, even the interaction between teacher behavior and challenge–threat responses during demanding situations in predicting emotions may depend on the behavior teachers usually exhibit (i.e., a three-way interaction). For teachers who generally display agency, the amplifying role of challenge responses might be smaller than for teachers who enter a demanding situation from a lower level of agency. For example, teachers with low overall agency levels might perceive demanding situations as a positively challenging opportunity for taking the lead (cf. Scheepers et al., 2015), and when they succeed in showing agency, experience feelings of mastery and accompanying positive emotions such as pride or enjoyment (Malmberg et al., 2014). Such mastery experiences might thus especially occur in teachers who depart from lower agency levels.

The present study

The present study aimed at better understanding the frequency and characteristics of demanding situations in classroom teaching (RQ1), and whether and how teachers' changes in interpersonal behavior during such situations are associated with their lesson-focused emotions afterwards (RQ2; see path A in Figure 1). Furthermore, we explored whether a relative challenge or threat motivational state (as marked by changes in cardiac output) moderated the association between interpersonal behavior and teacher emotions (RQ3; Path B in Figure 1). Finally, we explored whether the effect of behavioral and physiological adaptations on emotions was different in groups of teachers with distinct dispositional teacher behaviors (moderator analyses; grey arrows in Figure 1).

Although previous research using observational and physiological measures in real-life classroom settings is limited, and our study was thus largely exploratory, we specified the following research questions and hypotheses based on our literature review:

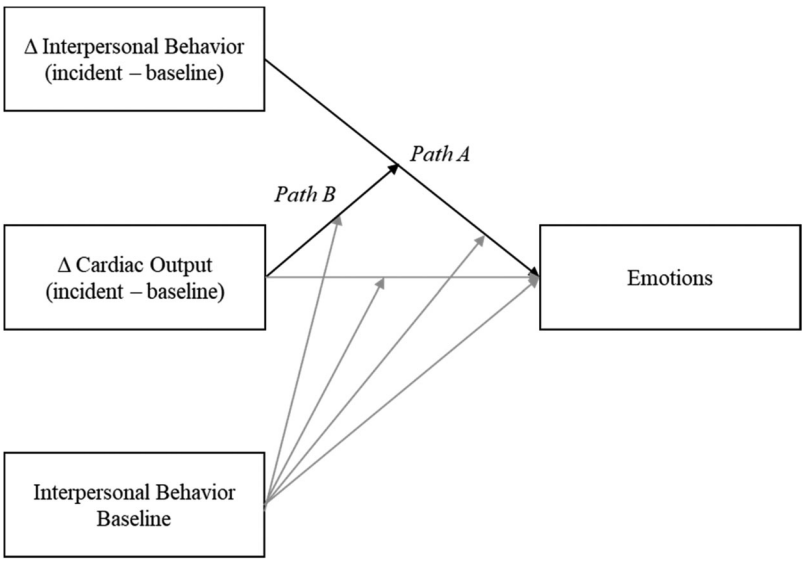

Figure 1. Schematic overview of the moderated moderation analyses.

1) What are the frequency and characteristics of demanding situations during teaching?
Overall, we expected large differences between teachers in the amount and duration of demanding situations. In general, we expected most demanding situations during the lesson start and whole classroom teaching (Junker et al., 2021).

2) Is there an association between teachers' changes in interpersonal behavior during demanding situations and their emotions after the lesson (Path a in Figure 1)?
We expected that an increase in agency or communion during demanding situations would lead to more positive and less negative emotions, because such a shift reflects generally more preferred interpersonal teacher behavior (Wubbels et al., 2006).

3) Do cardiovascular indices of challenge–threat motivational states moderate the association between teachers' interpersonal behavior during motivated performance situations and their lesson-focused emotions (Path B in Figure 1)?
We expected that the positive effects of an increase in agency or communion would be more pronounced when behavior during a motivated performance situation is accompanied by a challenge (relative increase in cardiac output) rather than a threat (relative decrease in cardiac output despite increased heart rate) physiological response (Seery, 2011a).

To explore whether the shift in interpersonal behavior and challenge–threat motivational state occurred from a position of already relatively high or low social influence (i.e., agency) and positive or negative contact with students (i.e., communion), we included average agency and communion levels during the lesson as a moderator in our analyses (see grey arrows in Figure 1). We expected that the positive effects of challenge might be especially present for teachers with relatively low agency and communion mean levels, because especially for them increasing their agency or communion levels might represent a mastery experience (Malmberg et al., 2014). Previous studies mainly found effects of power or teacher agency, and thus we expected stronger (moderating) effects for teacher agency as compared to effects of interpersonal communion.

Materials and methods

Participants

Teachers were recruited via social media and school networks. Participants were 80 Dutch secondary education teachers (51.3% female) with a mean age of 43.7 years ($SD = 11.5$) and 13.4 years of teaching experience ($SD = 9.7$). Teachers selected a lesson that could potentially be stressful, for example, due to the specific group or topic of the lesson. Lessons covered different subject areas: Science (35%), Social Studies (25%), Languages (23.75%), Mathematics (13.75%), and Arts (2.5%). Selected groups consisted on average of 22 students ($SD = 5$; 50.3% female; 15.1 years, $SD = 1.1$) in the third or fourth grade of all three tracks of Dutch secondary education.

Procedure

Data were collected as part of the Dynamics of Emotional Processes in Teachers project (DEPTh; Donker, 2020). Ethical approval by the Ethics Committee of the Faculty of Social and Behavioral Sciences of Utrecht University was present at the start of data collection (FETC16-074). Physiological and behavioral data were collected during one classroom lesson of on average 41 min 43 s ($SD = 13$ min 12 s). Teachers were instructed to teach as they would normally do. During the final 10 min of the lesson, teachers and students completed questionnaires. Teachers received a €15 gift card and a report with their questionnaire answers.

Physiological data were missing for one teacher and behavioral data were missing for four teachers due to technical failure. During data preparation, the cardiac output data of five teachers could not be scored reliably. The lessons of three additional teachers did not contain any situations with high heart rates (see Measures) and had thus to be excluded from further analyses. Finally, the data of two teachers were excluded because the physiological data contained outliers (z-score $>$ 6). For two teachers with a z-score for cardiac output during motivated performance between 3.29 and 6, we decided to keep their data, because these values were in line with their lesson average. The final sample used in the data analysis was thus $N = 65$. Sensitivity analyses using G*Power version 3.1.9.2 (Faul et al., 2009) showed that our final sample size of 65 teachers was sufficient to reliably detect medium effect sizes of $f^2 = .21$ (with an α of .05 and power of .95), which is in line with effect sizes found in previous research using teacher- and student-report of interpersonal behavior and emotions (Hagenauer et al., 2015; Mainhard et al., 2018).

Measures

Physiology

Teachers' physiological responses were recorded during the lesson at a 1000 Hz frequency with the 5fs version of the VU University—Ambulatory Monitoring System (VU-AMS; Willemsen et al., 1996). Three 55 mm hydrogel electrodes (Kendall^{TM} H98SG) were placed on the chest to capture the electrical activity associated with the cardiac cycle (electrocardiogram, ECG) in line with the VU-AMS protocol (www.vu-ams.nl). Two additional electrodes were placed on the chest and two on the back to capture the electrical impedance of the thorax (i.e., impedance cardiogram, ICG). This impedance changes as a function of the cardiac activity like the amount of blood pumped out by the heart per beat (which can be used to compute cardiac output; the volume of blood being pumped by the heart, in liter/min). Tri-axial accelerometry was recorded to control for physical activity in the analyses. Electrodes were attached before the lesson and teachers wore the device on their waist after signal inspection on a computer. After the lesson, data were transferred to a computer and automatically checked for potential artifacts using the VU-DAMS software. All identified artifacts were then manually checked by trained assistants to reduce noise in the signals. Corrections were made to less than 1% of the R peaks in the ECG signal. Small corrections to the automatic scoring of the ICG complex (based on morphology, intra-individual consistency, and physiological plausibility) were made to approximately 50% of the B-points, and 10% of the C- and X-points, which is in line with standard practice (cf. Nederend et al., 2017).

Heart rate. We exported teachers' heart rate (in beats per min) per 5 s to get an estimate that was robust to artifacts, as well as sensitive enough to small changes. We controlled for teachers' physical activity during the 5 s period using the Additional Heart Rate method with teacher-specific regression parameters (for more information, see Donker et al., 2018; Myrtek, 2004). A motivated performance situation was operationalized as a 5 s period in which a teacher's additional heart rate exceeded their individual lesson average heart rate by two standard deviations. Both visual inspection of the video and the accelerometry data confirmed that the heightened heart rate during the motivated performance situations was not only due to (an increase in) physical activity.

Cardiac output. Cardiac output is the volume of blood being pumped by the heart (in liter/min) and is calculated as the product of heart rate (in beats per minute, derived from the ECG) and stroke volume (i.e., the volume of blood per beat, derived from the ICG). We used 25 s intervals (i.e., included both the 10 s before and after the 5 s heart rate peak) as a reasonable balance between having enough datapoints to reliably score the ICG (Nederend et al., 2017) and taking

into account the dynamic, fast-changing nature of teaching (Donker et al., 2020). When motivated performance situations overlapped, we merged them into one situation.

To capture *changes* in cardiac output during the motivated performance situations, we calculated a difference score by subtracting the lesson average from cardiac output during the motivated performance situation (Llabre et al., 1991). A positive cardiac output difference score can be interpreted as a relative tendency toward higher challenge (and lower threat) compared to the lesson baseline (i.e., the increased heart rate is accommodated by widening arteries for increased blood flow), while a negative cardiac output difference score can be interpreted as a relative tendency toward higher threat (and lower challenge) compared to the lesson baseline (i.e., no change in artery contraction despite the increased heart rate). Although we could not correct for physical activity in the cardiac output scores, the correlation between cardiac output and physical activity during the demanding situations was not significant ($r = -0.05$, $p = .668$).

Interpersonal teacher behavior

Teachers' interpersonal behavior during the lesson was coded continuously in terms of agency and communion based on video recordings using Continuous Assessment of Interpersonal Dynamics (CAID; Sadler et al., 2009). Agency and communion were coded simultaneously as they can be represented in a circumplex, but both dimensions were analyzed separately. Each video was coded by three coders in a randomized order, and we used their average scoring in our analyses. There was strong to moderate agreement between coders (LeBreton & Senter, 2008): $ICC_{2,3} = .71$ (SD = .12) for teacher agency and $ICC_{2,3} = .63$ (SD = .13) for teacher communion. This is in line with other studies using CAID (Pennings et al., 2018; Sadler et al., 2009). In parallel to the physiological responses, we used the mean level of agency and communion during the lesson as a baseline. We used difference scores to compare teachers' behavior during the demanding situations to their baseline.

Characteristics of demanding situations

To describe the lesson segment and instructional setting during the demanding situations, we coded all motivated performance situations in line with coding categories from the Third International Mathematics and Science Study (TIMMS; Stigler et al., 1999), a large scale video survey study of eight-grade mathematics lessons in Germany, Japan, and the United States. The TIMMS coding scheme maps out the lessons along several dimensions. Here, for the lesson segment (in TIMMS: organization of class), we differentiated between pre-lesson activities and lesson activities. Pre-lesson activities included all activities before the lesson begins, such as greetings and teacher announcements. For instructional setting (in TIMMS: organization of interaction), we differentiated between classwork (i.e., teacher is working with all or most students in a whole-class situation), seatwork (i.e., students working independently on tasks, alone or in small groups), and transition moments from one instructional setting to the other.

Teacher emotions

Nine discrete emotions were assessed at the end of the lesson with a self-report questionnaire consisting of 3 or 4 items per emotion (31 in total) based on the Achievement Emotions Questionnaire (AEQ; Pekrun et al., 2011) and the Teacher Emotions Scales (TES; Frenzel et al., 2016). All scales had sufficient reliability (see Donker et al., 2020). For the main analyses, we grouped the emotions in a positive and negative factor. Based on Confirmatory Factor Analyses, we left out Relaxation and Boredom from respectively the positive and negative emotion factor scores. The low model fit could possibly be explained by the low arousal nature of both emotions. The updated two-factor model fitted the data reasonably well, $\chi^2(13) = 27.279$, $p = 0.01$, RMSEA

= .12, CFI = .96, SRMR = .04. An example item for positive emotions is 'During this lesson, I was enthusiastic' (enjoyment; $\alpha = .77$) and for negative emotions 'When I look back at the past lesson, I am disappointed in myself' (disappointment; $\alpha = .89$). Post-hoc analyses for all nine discrete emotions are presented in Supporting file A.

Data analysis

Because most teachers encountered only a few demanding situations and because we were mainly interested in their overall effect on teachers' emotions after the lesson, we aggregated teachers' interpersonal behavior as well as their physiological responses during the motivated performance situations to the teacher level. The relatively high ICC-values (see Table 1) supported the reliability of these aggregated measures and indicated that teachers tended to react in rather similar ways to the demanding situations they encountered during their lesson.

For our first research question, we explored the frequency and characteristics of the demanding situations. We also compared the level of teacher agency and communion during the demanding situations with teachers' average behavior during the lesson with a paired-samples *t*-test. To answer our second and third research question, we conducted a moderated moderation analysis using PROCESS v3.3 in SPSS version 25.0 (i.e., model 3; see Figure 1). We investigated whether changes in agency and communion during demanding situations predicted teachers' post-lesson emotions (Path A; RQ2). Furthermore, we explored whether teachers' relative challenge (i.e., increase in cardiac output compared to their lesson baseline) versus threat (i.e., decrease in cardiac output compared to lesson baseline) motivational states moderated the association between behavioral changes and teacher emotions (Path B; RQ3). We further explored the moderating effect of dispositional agency and communion levels during the lesson on these associations (light grey arrows in Figure 1).

Results

RQ 1: Frequency and characteristics of demanding situations

Descriptive statistics are presented in Table 1. Regarding our first research question, we found that teachers had on average 5.17 motivated performance situations per lesson ($SD = 3.66$, range 1–26). These situations lasted on average 39.95 s ($SD = 14.76$, range 25–125 s). Most motivated performance situations occurred during lesson activities (57.9%) rather than pre-lesson activities (42.1%). However, taking into account that pre-lesson activities usually only span the first 5 to 10 min of the lesson (i.e., max. 20%), a considerable number of situations occurred before the actual lesson started. During most motivated performance situations teachers conducted plenary classroom teaching (59.5%) while 18.9% of the situations occurred during seatwork (i.e., individual or in small groups), and 3.9% of the situations contained transitions from one instructional setting to the other. The remaining 17.7% of the situations were coded as 'other'.

Teachers' average cardiac output during the lesson was 11.58 liter/min ($SD = 5.28$). Compared to the average cardiac output of adults in rest (i.e., 4–5 liter/min; Bronzwaer et al., 2017), a teacher's heart is working hard during teaching, comparable to exercising. The non-significant association between teachers' average cardiac output and their physical activity level during the lesson ($r = .03$, $p = .82$) confirmed that the increased cardiac output was however not due to teachers' physical activity alone. Cardiac output was significantly higher during the motivated performance situations compared to the lesson average, $t(64) = -5.02$, $p < .001$, Cohen's $d = .62$, indicating that, overall, teachers showed physiological responses that are in line with relative challenge (vs. relative threat). There was, however, substantial variability among teachers regarding their cardiac output reactivity (i.e., difference scores ranging from −4.07 to 10.54), making this potentially a

Table 1. Means, standard deviations, and pearson correlations ($N = 65$).

	M	*SD*	ICC1	ICC2	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cardiac output																		
Lesson baseline	11.59	5.28			–													
Demanding situations	13.21	5.09	.77	.94	**.88**	–												
Difference score	1.62	2.60			**−.32**	.18	–											
Agency																		
Lesson baseline	282.97	135.07			−.03	−.01	.05	–										
Demanding situations	301.48	177.35	.29	.67	.08	.10	.04	**.46**	–									
Difference score	18.50	165.87			.11	.12	.00	**−.32**	**.69**	–								
Communion																		
Lesson baseline	342.59	90.33			**−.26**	**−.27**	.01	−.07	−.10	−.05	–							
Demanding situations	326.35	106.42	.38	.76	−.20	−.21	−.02	.03	−.16	−.20	**.73**	–						
Difference score	−16.24	73.57			.03	.02	−.03	.13	−.11	−.23	−.17	**.55**	–					
Emotions																		
Positive	3.73	0.60			**−.25**	**−.26**	.01	**.28**	**.26**	.05	**.25**	.16	−.08	–				
Negative	1.77	0.62			.20	.24	.06	**−.33**	−.15	.11	**−.29**	−.16	.12	**−.58**	–			
Teacher characteristics																		
Nr of demanding situations	5.17	3.66			−.09	−.16	−.13	−.11	−.10	−.01	.11	.09	−.01	−.06	.14	–		
Gender[a]	.52	.50			.21	.22	.00	.09	.12	.06	−.23	**−.26**	−.09	−.16	−.06	−.10	–	
Years of experience	13.34	9.83			−.02	−.08	−.13	.07	.24	.20	−.17	.03	**.25**	−.16	−.03	**.27**	.02	–

Note. Bold coefficients were significant at $p < .05$.
[a]0 = male, 1 = female.

Table 2. Results from moderated moderation analyses with standardized and mean-centered predictors ($N = 65$).

	Agency						Communion					
	Positive emotions			Negative emotions			Positive emotions			Negative emotions		
	b	*t*	*p*	*b*	*t*	*p*	*b*	*t*	*p*	*b*	*t*	*p*
R^2	.26			.25			.14			.20		
Constant	−.05	−0.45	.65	−.05	−0.45	.65	.01	0.10	.92	−.07	−0.59	.56
Δ Behavior (*Path A*)	.09	0.70	.49	.02	0.16	.88	.03	0.19	.85	.01	0.05	.96
Δ Cardiac Output	−.10	−0.80	.43	.14	1.10	.28	.09	0.54	.59	−.23	−1.42	.16
Δ Behavior * Δ Cardiac Output (*Path B*)	.21	2.13	.04	−.10	−1.00	.32	−.14	−0.78	.44	.07	0.38	.70
Behavior Baseline	.34	2.64	.01	−.34	−2.63	.01	.17	1.19	.24	−.20	−1.46	.15
Δ Behavior * Behavior Baseline	−.19	−1.66	.10	−.16	−1.35	.18	.11	0.67	.50	−.02	−0.12	.91
Δ Cardiac Output * Behavior Baseline	.08	0.58	.56	−.24	−1.68	.10	−.03	−0.19	.85	.25	1.67	.10
Δ Behavior * Δ Cardiac Output * Behavior Baseline	−.11	0.11	.32	.16	1.54	.13	−.00	−0.04	.97	−.13	−1.45	.15

relevant and valuable source of information to examine how individual differences in motivational states shape emotions after the lesson.

Teachers also differed largely in their behavioral changes during the demanding situations. On average, teachers conveyed slightly more agency and less communion (i.e., teachers tended to become more strict or imposing toward students) compared to the lesson average, but these differences were not significant at the sample level, $t(64) = -0.90$, $p = .37$, Cohen's $d = .11$ for agency and $t(64) = 1.78$, $p = .08$, Cohen's $d = .22$ for communion. Correlations indicated that a higher mean level of agency and communion during the lesson was associated with more positive self-reported emotions and less negative emotions at the end of a lesson (see Table 1). Table 1 further indicates that more experienced teachers had more motivated performance situations and overall increased their communion during these situations. Female teachers showed on average lower communion during the demanding situations. It should be noted that the teachers' lesson average for cardiac output, agency, and communion was positively associated with the absolute value during the demanding situations and negatively with the difference score for each of these variables, thus possibly indicating a ceiling effect for teachers with higher baseline levels.

RQ2 and RQ3: the association between interpersonal behavior, physiological responses, and post-lesson emotions

Results of the moderated moderation analysis are reported in Table 2. In line with the correlational analyses (Table 1), we found that higher agency mean levels during the lesson were associated with more positive emotions ($b = .34$, $p = .01$) and fewer negative emotions ($b = -.34$, $p = .01$). Post-hoc analyses with discrete emotions as outcome variables (see Supporting file A) showed that higher baseline agency was associated specifically with more enjoyment ($b = .31$, $p = .03$) and pride ($b = .30$, $p = .02$), as well as less anxiety ($b = -.28$, $p = .04$), disappointment ($b = -.43$, $p < .001$), and shame ($b = -.37$, $p = .01$).

Overall, there were few significant (interaction) effects, see Table 2. There was no significant main effect of teachers' change in agency or communion during motivated performance situations on their emotions (i.e., RQ2, Path A), and there was only one significant interaction effect between teachers' behavioral change and their change in cardiac output (i.e., RQ3, Path B). That is, when teachers decreased their agency during motivated performance situations, this resulted in significantly less positive emotions (and specifically less pride, see Supporting file A) when this co-occurred with a relative increase in teachers' cardiac output (i.e., a stronger tendency toward relative challenge vs. threat).

Although the overall interaction effect between teachers' change in agency and their change in cardiac output on *negative* emotions was not significant, we found a significant interaction effect

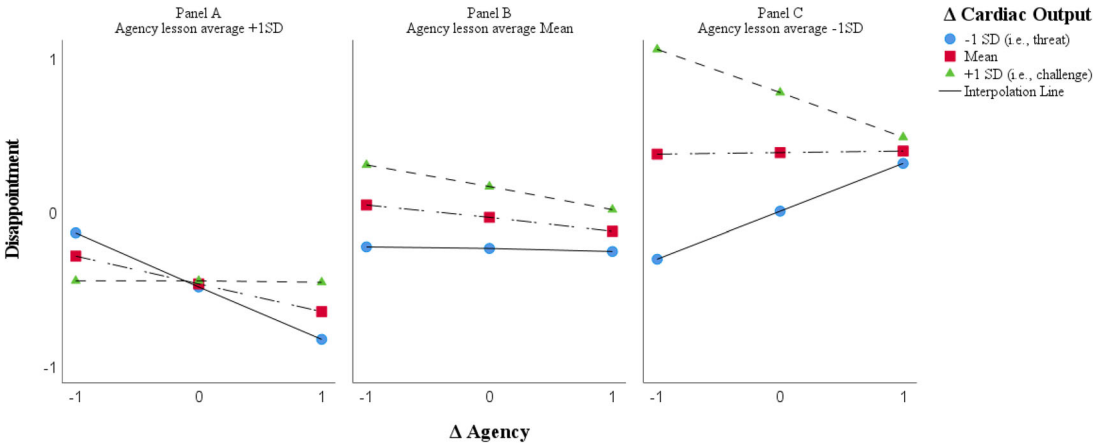

Figure 2. Visualization of the moderating effect of changes (δ) in cardiac output on the association between teachers change in agency during demanding situations and their self-reported disappointment for different agency lesson averages.

for boredom specifically. This interaction indicated that teachers experienced less boredom when decreases in agency during peak moments of motivated performance went together with lower levels of cardiac output (i.e., a stronger tendency toward relative threat vs. challenge). Thus, when teachers were relatively threatened while decreasing agency, there were less bored, which makes sense when one considers that they were then probably working hard to manage the situation.

The three-way interaction between changes in agency, changes in cardiac output, and baseline agency was not significant for the positive or negative emotion scales. However, this interaction was significant for disappointment specifically (see Supporting file A). The Johnson-Neyman test for significance regions showed that for disappointment the interaction effect (i.e., path B) was significant for the 30.8% teachers with relatively low agency levels during their lesson (i.e., *z*-scores below −0.44). That is, especially among teachers with low dispositional agency, a further decrease in agency during motivated performance, coupled with an increase in cardiac output (i.e., relative challenge) was related to higher levels of disappointment. This effect is visualized in Figure 2. The three panels in Figure 2 represent groups of teachers with different baseline agency levels (+1SD, mean, -1SD). For each group of teachers, the plot depicts the interaction between changes in agency (on the x-axis) and teacher disappointment (on the y-axis). The different lines represent changes in cardiac output, with the stacked line with green triangles representing teachers with a relative challenge motivational state, while the filled line with blue dots represents teachers with relative threat motivational states. Panel C shows that for teachers with the lowest baseline agency levels (i.e., -1SD), further decreases in agency during the demanding situations were associated with more disappointment only for teachers who showed a stronger tendency toward relative challenge (vs. threat) during the peak moments of motivated performance.

No significant relations were found between teacher communion and the overall positive versus negative emotion factors. It should be noted that teachers in the current sample differed less in their communion than in their agency levels and changes (i.e., less variance), which possibly explains the non-significant (interaction) effects for communion. The analyses with the discrete emotional outcomes revealed two significant effects. There was a negative association between overall communion levels during the lesson and self-reported anger ($b = -.29$, $p = .03$). Moreover, for relief, a significant three-way interaction was found. Here, we found again the most pronounced differences for the group of teachers with overall lower communion levels. For these teachers, lowering their communion during motivated performance situations, combined with threat physiological responses, was associated with the highest relief, as self-reported after the lesson.

Robustness checks

We performed two robustness checks for the main findings, considering alternative explanations and analysis strategies (see Supporting file B). First, as cardiac output is the product of heart rate and stroke volume (the mean amount of blood pumped-out at a single heartbeat), we examined the extent to which increases in cardiac output were driven by heart rate (vs. stroke volume) to examine a potential confound between engagement (increased heart rate) and challenge (increased cardiac output). Analyses showed that the reported results were similar when using stroke volume instead of cardiac output in the analyses, thereby eliminating a potential cofound between engagement (heart rate) and challenge–threat (cardiac output). Second, we checked the robustness of our findings by entering teachers' physical activity as a covariate in the regression analyses. Results were similar to the original analyses.

Discussion

The present study investigated how teachers handle demanding situations during teaching, and how their behavioral and physiological reactions in these moments shape their self-reported emotions after the lesson. By selecting situations based on peaks in teachers' heart rate, we focused on the most demanding moments for teachers with potentially most impact on their post-lesson emotions (De Ruiter et al., 2019; Hase et al., 2020).

Overall, we found that teachers differed substantially in how they responded to motivated performance situations in terms of interpersonal behavior and physiological responses. Although teachers with high average agency levels during their lessons reported more positive and less negative emotions, their specific behavioral responses during peak moments of motivated performance were not associated with their emotions after the lesson. Physiological challenge–threat responses moderated only a few of the associations between teachers' interpersonal behavior during the demanding situations and emotions.

Research question one concerned the frequency and characteristics of demanding situations. Teachers varied largely in the frequency of these moments. Relatively many of these demanding situations involved pre-lesson activities and plenary classroom teaching. It could thus be concluded that especially these activities are demanding for teachers. Interestingly, more experienced teachers had more motivated performance situations, which suggests that these teachers might be better in identifying situations that are relevant and incongruent with their teaching goals (Wolff et al., 2015). Further research could investigate whether these teachers also felt better equipped to deal with the situation.

Three teachers in our sample had no peak motivated performance situations at all, at least according to our operationalization in terms of a heart rate above two standard deviations of their lesson mean (i.e., baseline). These teachers might not have engaged in strong motivated performance situations due to their high teaching efficacy, which corresponds to their relatively low scores on burnout scales, although there were no other particular features of these teachers in terms of their gender, age, and experience. It could also be that their cardiovascular response was 'blunted' due to general disengagement or parasympathetic and sympathetic co-activation (Hase et al., 2020).

Although there were large differences *between* teachers, an individual teacher tended to handle demanding situations in a rather similar way (i.e., high ICC), supporting our choice to do the analyses at the teacher level. Overall, teachers predominantly reacted to demanding situations with an increase in agency and a decrease in communion, and thus more strict or imposing interpersonal behavior, which can be seen as a less-preferred classroom management strategy (Pennings et al., 2018). Moreover, while overall teachers showed increased cardiac output during the motivated performance situations (i.e., indicative or relative challenge; Blascovich, 2008;

Seery, 2011a), there were also teachers who showed a *decrease* in cardiac output, which indicates a tendency away from challenge (and toward more threat), compared to their overall motivational tendency during the lesson. This variety within our sample underscores the importance of intra-individual measures of motivation, behavior, and emotion, to get a grip on idiosyncratic processes in the classroom.

There was no main effect of changes in agency or communion during the motivated performance situation on teachers' emotions (RQ2; Path A). However, in line with previous studies using self- or student-reported teacher behavior (Malmberg & Hagger, 2009; Wubbels et al., 2006), a higher mean level of agency during the lesson was directly associated with more positive emotions (enjoyment and pride) and fewer negative emotions (anxiety, disappointment, and shame) after the lesson. Showing high agency levels might thus function as a *mastery experience* that generally provides teachers with confidence (Seery, 2011b).

Physiological challenge–threat responses moderated only the association between teachers' change in agency during the motivated performance situations and positive emotions (pride in particular). That is, even though some teachers' physiology pointed toward positive challenge, when they simultaneously decreased their agency during such situations, this resulted in less self-reported positive emotions after the lesson. These teachers might have been initially positively challenged by the situation, but because they felt they did not manage the situation well (i.e., they lowered their agency level), they still reported less pride after the lesson. In line with this, the post-hoc analyses with discrete emotions showed that this moderating effect was significant also for disappointment, but only for teachers with low dispositional agency levels. Thus, it were especially teachers with already low baseline levels of agency, who were initially relatively challenged by the situation, but then further decreased in agency during the peak moments of motivated performance, who were most disappointed after the lesson. Failing to take agency during demanding moments might thus lead to feelings of less pride and disappointment.

Regarding communion, we only found an association between higher mean levels during the lesson and less self-reported anger, which replicates previous findings (Donker et al., 2020). Furthermore, in teachers with low levels of communion during their lesson, a further decrease in communion combined with physiological signs of relative threat (lower cardiac output despite increased heart rate), resulted in feelings of relief after the lesson. Together, these results suggest that supporting teachers in showing high levels of agency and communion in the classroom might be beneficial not only for their students (Wubbels et al., 2006), but also for their own emotions and well-being.

Limitations and future directions

The innovative nature of our measures and their application in a real-life context have given us extra insight in what is demanding for teachers, but also comes with some limitations and ideas for future research. First, because of the naturalistic school context, there was a potential confound between teachers' physical activity and physiological reactions. We did not want to restrict our analyses to moments without physical activity, because this would misrepresent the nature of teaching. For example, whole group lecturing in front of the classroom has been found to be stressful (Junker et al., 2021) and thus particularly relevant for the current aims, even though it also encompasses physical activity. The non-significant correlations between changes in cardiac output and physical activity suggest that not all changes in cardiac output during the lesson can be explained by physical activity only.

Related to this, we were not able to supplement cardiac output with teachers' ventricular contractility (VC) or total peripheral resistance (TPR), because this requires blood pressure assessments, which are heavily susceptible to motion artifacts (Vrijkotte et al., 2004) and therefore hard to measure reliably in ambulatory settings (Friedman et al., 2004). Moreover, although the VU-

AMS system also measures Pre Ejection Period (PEP, i.e., a measure of VC), the relatively short epochs we focused on (i.e., 25 s) made it impossible to score PEP in a reliable and valid way. Therefore, we could not triangulate changes in heart rate and cardiac output with other, more specific, physiological measures. However, because we focused on motivated performance situations with an increased heart rate, it is likely that decreased cardiac output was due to increased total peripheral resistance (Seery, 2011a; Snijdewint & Scheepers, 2023). This was also supported by sensitivity analyses using stroke volume instead of cardiac output. As stroke volume is not affected by heart rate, our replication of the results using this measure supports an interpretation of changes in cardiac output as indicators of relative challenge vs. threat responses. However, we need to be cautious to draw definitive conclusions until our findings are replicated with other, more precise physiological measures (e.g., PEP and TPR), and in a larger sample.

Second, we used a *lesson* average rather than a baseline at rest to calculate difference scores with cardiac output, agency, and communion during the motivated performance situations. We were not able to measure baseline cardiac output at rest due to the short breaks between teachers' lessons. Also, although baseline measures at rest might be more controlled in terms of teachers' physical activity, it can be imagined that psychological stress or feelings of threat are even more present just before the lesson than during the lesson. Given that almost all teachers had a relatively high mean cardiac output during the lesson compared to baselines at rest reported elsewhere, using the lesson-baseline as criterion for relative change within a lesson, has possibly resulted in an underestimation rather than overestimation of the effects. For interpersonal behavior, we could not use a resting period, because agency and communion cannot be scored when there is no interpersonal interaction. Moreover, we know from previous research that overall agency and communion mean scores are relatively stable (Mainhard et al., 2011; Praetorius et al., 2014). Therefore, the lesson-baseline can be expected to give a good indication of teachers' behavioral dispositions in class.

Third, future studies could include more elaborate descriptions of teacher behavior in addition to the mean (e.g., trend, variability, and stability; Donker et al., 2020) to get more specific insight into how teachers handle demanding situations. Furthermore, it would be interesting to use experience sampling methods or video-stimulated interviews (e.g., Becker et al., 2015; Schepens et al., 2007) to triangulate teacher's observed behaviors and implicit physiological responses with their self-reported lesson goals and explicit appraisal of motivated performance situations. This would give us a more complete picture of how behavior, physiology, and emotions are interrelated and affect teachers' well-being. Moreover, results should be replicated in different samples, for example teachers in elementary grades and higher education, and in different countries.

Conclusion

Notwithstanding these limitations, the current study showed that teachers differ largely in what they perceive as demanding during teaching, as well as in how they typically change their interpersonal behavior and physiological responses during demanding situations. Our study provided first evidence that the intra-individual nature of our observational and physiological measures are well-suited to get better insight in what is demanding for specific teachers. Such information on personal difficulties can be the starting point of personalized interventions to help teachers deal with their individual difficulties in teaching.

Although teachers' behavioral and physiological changes were not a straightforward predictor of their emotional outcomes, some patterns emerged. Overall, especially teachers with dispositional low agency or communion appeared to be at risk of less positive and more negative emotions; not only directly, but also *via* differential effects of challenge-threat responses when these teachers decreased their agency or communion during motivated performance situations. Further research is needed to elucidate how we can help especially this group of teachers in profiting

more from their challenge motivational state. Teachers' actual behaviors could for example be trained by providing classroom management training (Emmer & Evertson, 2016), but also training arousal reappraisal (Hangen et al., 2019; Jamieson et al., 2010) or motivational self-talk (e.g., Hase et al., 2019) to counteract the negative effects of threat.

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