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Teachers' ambulatory heart rate variability as an outcome and moderating variable in the job demands-resources model

Background and Objectives: According to the job demands-resources (JD-R) model, strain reactions are based on the level of job demands and moderating resources. The present study aims to contribute to psychophysiological research by integrating vagally mediated heart rate variability (HRV) into the JD-R framework. **Design and Methods:** Using a sample of school teachers, we conducted an ambulatory assessment study to investigate HRV as (1) a state outcome measure of job demands and resources and (2) a trait moderator in the relationship between job demands and emotional exhaustion. In total, 101 participants wore an electrocardiogram device on two school days and rated their level of job demands (emotional demands and time pressure), job resources (control and support), and exhaustion six times a day. Based on 669 measurements, multilevel models of the 5-minute state HRV measure and emotional exhaustion were built. **Results:** The results supported the health-impairing effects of job demands on emotional exhaustion but not state HRV. There was no evidence of the moderating effects of job resources. Notably, the 48-hour trait HRV measure significantly buffered the effect of emotional demands on exhaustion. **Conclusions:** These findings highlight the stress-buffering potential of trait HRV as theoretical research extension and practical intervention goal.

Keywords: job demands-resources model; heart rate variability; emotional exhaustion; school teacher; ambulatory assessment

Introduction

Frequently encountering emotionally demanding student misbehaviors and classroom disturbances, teachers are continuously under time pressure due to tight curricula (Dicke, Stebner, Linninger, Kunter, & Leutner, 2018; Keller, Chang, Becker, Goetz, & Frenzel, 2014). It is well known that teachers are subjected to a substantial amount of job strain and that teaching demands are associated with adverse affective adjustments (Dicke et al., 2018) and changes in cardiac measures (Pieper, Brosschot, van der Leeden, & Thayer, 2010).

One of the most influential theories of job-related stress is the job demands-resources (JD-R) model (Bakker & Demerouti, 2017; Demerouti, Bakker, Nachreiner, & Schaufeli,

2001). The JD-R model distinguishes between two types of work characteristics. Job demands represent toxic psychosocial or organizational conditions that may produce job strain, whereas job resources refer to the positive aspects of the job that may help people cope with demands. Consistent with the conservation of resources (COR) theory (Hobfoll, 1989), people strive to deploy their resources, but when resources are lost due to exceeding demands, strain reactions are likely. Accordingly, high demands seem to deplete resources and have detrimental effects on mental and physical health, which is known as the *health-impairment process* (Bakker & Demerouti, 2017). A well-studied outcome measure in the JD-R model is the level of emotional exhaustion, which is defined as a central component of burnout and an indicator of psychological strain, poor well-being, and low energy (e.g., Demerouti et al., 2001; Maslach & Jackson, 1981). Many studies demonstrate that the model is also applicable to within-person studies of situational fluctuations in emotional exhaustion (e.g., Riedl & Thomas, 2019). Directly related to the teaching context, numerous studies have examined the JD-R model at both the between-subject (e.g., Dicke et al., 2018; Guglielmi, Panari, & Simbula, 2012) and within-subject (Garrick et al., 2014; Simbula, 2010; Tadić, Bakker, & Oerlemans, 2015) levels. Given the great variety of job demands, emotional demands and time pressure seem to be particularly hazardous with respect to teachers' health (Dicke et al., 2018; Guglielmi et al., 2012; Sonnentag, 2001). According to the authors, emotional demands may specifically occur in terms of disruptive students and interpersonal conflicts in the classroom, while temporal constraints may be provoked mainly by means of timetables and curricula. An additional assumption of the JD-R theory states that resources can buffer the detrimental effects of job demands on health-related outcomes (Bakker & Demerouti, 2017). According to this so-called *stress-buffering hypothesis*, resources render employees more resilient and less vulnerable to stress, which may help them cope with stressors (Hobfoll, 1989). Reflecting influence by Karasek (1979) and Johnson and Hall (1988), job control and social support are

among the most prominent resources in the JD-R framework (Demerouti et al., 2001). The buffering potentials of control and support have also been confirmed empirically in studies related to teachers' fatigue (Garrick et al., 2014) and positive affect (Tadić et al., 2015).

However, while flourishing research has investigated daily psychological strain reactions (e.g., Keller et al., 2014; Simbula, 2010), fewer studies address daily physiological pathways (Bakker & Demerouti, 2017). To date, the psychophysiological processes involved in coping with job demands at the within-person level are not sufficiently understood. Of the wide range of sympatho-adrenal and hypothalamic-pituitary-adrenal (HPA) biomarkers, Chandola, Heraclides, and Kumari (2010) suggest that heart rate variability (HRV), which is an indicator of the autonomic nervous system, is a particularly valid biological correlate of workplace stressors. Consistently, reviews have provided evidence suggesting that heightened job demands are closely related to decreased levels of HRV (Jarczok et al., 2013; Togo & Takahashi, 2009). Specifically, HRV represents a measure of the irregularity of time between consecutive heartbeats and is sensitive to both sympathetic and parasympathetic (vagal) efferences (Jarczok et al., 2013; Malik, 1996). For example, HRV indexes the “contribution of the parasympathetic nervous system to cardiac regulation” (Laborde, Mosley, & Thayer, 2017, p. 1) and has been associated with both physiological and psychological flexibility and adaptability in response to different situations (Grossman & Taylor, 2007; Thayer & Lane, 2009; Togo & Takahashi, 2009). Notably, HRV can be investigated at the short-term phasic level (state HRV) and long-term tonic level (trait HRV).

State HRV is thought to reflect mainly cardiac vagal activity and to be sensitive to immediate changes in environmental requirements (Laborde et al., 2017; Thayer & Lane, 2009). For instance, studies have linked short-term vagal tone to state positive affect (Schwerdtfeger & Gerteis, 2014), momentary resilience (Schwerdtfeger & Dick, 2019), acute stressful events (Pieper, Brosschot, van der Leeden, & Thayer, 2007), and situational worry

episodes (Pieper et al., 2010). It is important to note that some of the results remain equivocal, e.g., the association between state HRV and positive affect apparently depended on the arousal level (i.e., only deactivated, but not activated, positive affect was related to higher HRV), and the negative relationship between state HRV and resilience somewhat contradicted the hypotheses. However, empirical support for a demand-induced reduction in HRV was found in ambulatory studies investigating the job demand-control model (e.g., Borchini et al., 2015; Collins & Karasek, 2010), and even the deleterious combination of high demands and low control or support was found to predict a decreased HRV (Borchini et al., 2015; Chandola et al., 2010; Collins & Karasek, 2010). Nonetheless, evidence for the JD-R model is generally mixed (Chandola et al., 2010), and only a few studies have investigated the relations between acute teaching demands and HRV (Filaire, Portier, Massart, Ramat, & Teixeira, 2010).

In contrast, tonic HRV typically refers to resting or baseline measures collected over longer periods (e.g., 24 h). Certainly, trait HRV is highly correlated with state HRV (Martens, Greenberg, & Allen, 2008) but is mainly known to constitute the level at which interindividual differences concerning adaptive and maladaptive vagal response patterns are manifested (Laborde et al., 2017). For example, a higher trait HRV is positively associated with health and resilience and negatively associated with chronic stress, depression, diseases, and mortality (for an overview see Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012). Consistent with the neurovisceral integration model (Thayer & Lane, 2009) and the biological behavioral model (Grossman & Taylor, 2007), which assume that vagally mediated cardiac regulation is reflected in healthy self-regulation, tonic HRV has been previously considered “a resource that enables cognitive and emotional regulation” (Martens et al., 2008, p. 377) and “a functional energy reserve capacity from which the organism can draw during more active states” (Grossman & Taylor, 2007, p. 279). Hence, studies have shown the potential of trait HRV to moderate non-work-related stress- or threat-induced effects (Martens et al., 2008;

Murdock, LeRoy, & Fagundes, 2017; Utsey & Hook, 2007). Given the flexibility of the JD-R model in incorporating almost all types of resources (Bakker & Demerouti, 2017), we shed further light on personal physical health resources. An elevated trait vagal tone may function similarly to favorable aspects of the job or personality because of its similar relationships with the above-mentioned constructs related to regulatory strength, coping, well-being, and health.

In the present study, we aimed to elucidate the psychophysiological role of HRV in the JD-R theory and studied HRV, as recommended by Laborde et al. (2017), not only as a sensitive dependent variable at the within-subject level but also as a stable moderating variable at the between-subject level. Different types of demands and resources and their relationship with fluctuations in subjective exhaustion and objective cardiac vagal outcome measures were analyzed applying the ambulatory assessment or so-called experience sampling methodology (ESM; Ohly, Sonnentag, Niessen, & Zapf, 2010). Recently, Bakker and Demerouti (2017) and Eatough, Shockley, and Yu (2016) called for such a multimethodological approach in ambulatory occupational health research. In accordance with our health-related outcomes, we specifically focused on the health-impairment process as presented above (e.g., Demerouti et al., 2001). We hypothesized that job demands, namely, emotional demands and time pressure, will be negatively related to state HRV (H1a) and positively related to emotional exhaustion (H1b). Given the stress-buffering prediction (Bakker & Demerouti, 2017), job resources, namely, job control and social support, were expected to moderate the health-impairment process on state HRV (H2a) and emotional exhaustion (H2b) such that high job resources reduce the detrimental effects of high job demands on the outcome measures. Similarly, following relevant psychophysiological approaches (e.g., Grossman & Taylor, 2007; Martens et al., 2008), we expected long-term HRV to moderate the effect of job demands on emotional exhaustion such that high trait HRV reduces the detrimental effects of high job demands on emotional exhaustion (H3).

Methods

Participants

Initially, 121 German school teachers volunteered to participate in this study. In total, 20 subjects could not be included in the analysis due to sick leave and dropout ($N = 7$), insufficient data recordings ($N = 5$), technical failure ($N = 3$), excessive artifacts ($N = 3$), and missing nocturnal HRV data ($N = 2$). The final sample consisted of $N = 101$ participants (70 females) from different school types with a mean age of 42.87 years ($SD = 11.46$) and a mean body mass index (BMI) of 23.92 ($SD = 3.35$). The teachers were employed at 22 different schools, including elementary (48%), secondary (31%), vocational (16%), and mixed (6%) schools. On average, the subjects taught 22.53 lessons a week ($SD = 4.91$) and spent an additional 18.39 ($SD = 8.42$) working hours at school or home. The following inclusion criteria had to be met: at least 50% employment, no heavy smoking or alcohol consumption, no excessive physical activity, and no cardiovascular, mental, or metabolic diseases or related medication. All teachers gave their written informed consent and did not receive monetary compensation for their participation. The study was approved by the ethics committee of the Catholic University of Eichstätt-Ingolstadt and the Bavarian State Ministry for Education, Culture, Science, and Arts.

Design and procedures

We conducted an ambulatory assessment study by continuously collecting physiological data for 48 h and repeatedly assessing subjective state measures over the same 48-hour period. To recruit the teacher sample, we contacted 40 German principals in diverse schools to introduce our research aims. Prior to participation, all teachers received verbal or written information concerning the study, its procedure and the use of the technical equipment. To maximize compliance, we offered individual feedback regarding the HRV parameters. The participating

teachers chose two typical school days as measurement days from Tuesday to Thursday and were subsequently equipped with study materials on the Monday before the measurement started. These materials included an information sheet, an electrocardiogram (ECG) device, a smartphone, and a demographic questionnaire. At the beginning of the first study day, the teachers were asked to attach the ECG and carry both the physiological (ECG) and subjective (smartphone) monitoring device during the following two study days. After participation, all materials were returned to the school to be collected by the study personnel.

Measures

Subjective state questionnaire

The smartphones were programmed with the movisensXS application (movisens GmbH, Karlsruhe, Germany) to implement the ESM items. Signal-contingently, the subjective ratings were assessed six times per day. The teachers were presented with beeps by their smartphones randomly between 7:30 AM and 9:00 PM outside the official lessons. The minimum time between two prompts was set at approximately 1–2 h according to the schools' timetables. Each questionnaire had a maximum delay time of 15 min. All variables were answered on a seven-point Likert scale ranging from “strongly disagree” to “strongly agree,” such that higher scores indicated more demands, resources, and exhaustion. Because ESM items must be answered at a very high frequency, we applied single-item scales to maintain compliance as recommended by Ohly et al. (2010). To capture short-term changes, we used the wordings “In the last two hours...” and “At the moment...” when referring to the predictor and outcome variables, respectively.

Job demands. We focused on emotional and temporal demands by adapting two questions from the German Copenhagen Psychosocial Questionnaire (Nübling, Stöbel, Hasselhorn, Michaelis, & Hofmann, 2006). The items were “...my work puts me in emotionally

disturbing situations” (emotional demands) and “...I had to work very fast” (time pressure).

Job resources. To assess momentary job resources, we administered two adapted items from the same questionnaire (Nübling et al., 2006) to measure job control (“...I had a large degree of influence concerning my work”) and social support (“...I felt supported”).

Emotional exhaustion. Emotional exhaustion was assessed with the item “...I feel emotionally exhausted” adapted from the German Maslach Burnout Inventory (Büssing & Perrar, 1992).

Physiological recordings

The data were recorded over 48 h, usually starting at 7:00 AM, using the EcgMove3 and EcgMove4 devices (movisens GmbH, Karlsruhe, Germany). The sensor capturing the single-channel ECG recordings and physical activity was connected to a chest belt with two dry electrodes. The sensor was worn at the sternum base and scanned cardiovascular signals at 1024 Hz and bodily movement through a three-dimensional acceleration sensor sampling at 64 Hz.

Data analysis

Prior to the statistical analysis, we visually inspected the 48-hour ECG signals of each individual to exclude subjects with massive artifacts. A final total of 80% of the included participants had a proportion greater than 90% of valid HRV data. Then, the HRV and bodily movements were analyzed using the movisens DataAnalyzer (movisens GmbH, Karlsruhe, Germany). The algorithms produce outputs on a minute-by-minute basis derived from 2-minute segments, which were averaged every 30 s. Concerning bodily movement, the mean value of acceleration across the three axes attributable to bodily movements was calculated. The software used a bandpass filter for each axis (0.25–11 Hz). Concerning HRV, the procedure used to detect the R-peaks was adapted from Hamilton (2002); the filter used to exclude artifacts was based on the recommendations by Clifford, McSharry, and Tarassenko

(2002). Specifically, interbeat intervals above or below 250–2000 ms and R-peak amplitudes above or below 0.1–5 mV were removed. The maximum variation in the RR intervals was set at 20%, and that for the R amplitudes was set at 30%. Overall, the software eliminated 6% of the segments due to artifacts. To match the state subjective and physiological data, we extracted the 5-minute means of the 48-hour ECG and activity data prior to each ESM questionnaire. This duration is recommended for analyzing short-term HRV (Malik, 1996). To examine long-term HRV, we calculated the mean 48-hour HRV. Thus, we used physiological state measures as outcome (5-minute HRV) and covarying (5-minute bodily movement) variables and a physiological trait measure as a moderating variable (48-hour HRV). To quantify the HRV, a time-domain parameter, i.e., the root mean square of successive differences (RMSSD), was selected. According to Malik (1996), the RMSSD is recommended for detecting variations in parasympathetic activity and has good statistical properties. Moreover, the ambulatory RMSSD has been proven to reliably index the short-term vagal tone (Goedhart, van der Sluis, Houtveen, Willemsen, & de Geus, 2007). To correct for skewness, we performed a natural logarithmic transformation (lnRMSSD). To search for relevant covariates, we further performed separate tests assessing bodily movement, age, BMI, and gender as predictors of the dependent variables. As a result, bodily movement, age, and BMI were significantly associated with lnRMSSD and, therefore, considered covariates in the analyses predicting HRV. Other covariates were excluded to avoid model overspecification.

Due to the hierarchical data structure in which the within-person variables (level 1) are nested in persons (level 2), multilevel models were separately estimated for each outcome (state lnRMSSD and emotional exhaustion). We used the R statistic software (version 3.6.1; R Core Team, 2019) with the package “nlme” (version 3.1–140; Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2019). First, to estimate the variance partitioning of the dependent

variables, we calculated the intraclass correlations (*ICC*) based on null models. For the hypothesis testing, the independent variables were entered step-by-step. Concerning the prediction of lnRMSSD, we initially added the covariates bodily movement, age, and BMI (covariates model). Then, for both outcomes, we included the main effects of emotional demands, time pressure, control, and support (main effects model). Subsequently, the interaction effects emotional demands \times control, emotional demands \times support, time pressure \times control, and time pressure \times support were modeled (interaction model). Finally, for emotional exhaustion, we introduced the main and demand-moderating effects of trait lnRMSSD (cross-level interaction model). The models included a random intercept. In the exhaustion model, we also included random slopes for emotional demands and time pressure since these variables served as the random effects of interests due to the cross-level interactions (Snijders & Bosker, 2012). No other random slopes were specified to avoid overparameterized or non-converging models (Bates, Kliegl, Vasishth, & Baayen, 2015; Fox & Weisberg, 2015). As recommended by Ohly et al. (2010), all situation-related predictors were person-mean centered, and all person-related predictors were centered on the grand mean. To quantify the model improvement, we additionally calculated the differences between the log likelihood ratios and degrees of freedom and determined the *p*-value by chi-square tests. Finally, we specified a continuous first-order autoregressive error structure because of our unequally distributed random time prompts over the two study days (Schwartz & Stone, 1998). This approach was used to account for the declining correlation between the residuals of two time points by a function of the trigger time and led to a better model fit for both outcomes (state lnRMSSD: $\phi = 0.17$; emotional exhaustion: $\phi = 0.28$). The significant two-way interaction was tested online (<http://www.quantpsy.org>) with simple slope analyses and conditional values 1 *SD* below and above the mean (Preacher, Curran, &

Bauer, 2006) and was plotted graphically. For all tests, the level of significance was set at 5% (two-tailed).

Results

Compliance rate and database

The teachers were presented with beeps 1193 times. A total of 1030 questionnaires were completed, 147 beeps were ignored, and 16 beeps were dismissed. These numbers correspond to a compliance rate of 86% and an average of 10.20 ($SD = 1.83$, range: 3–12) completed questionnaires per person. Similarly, 14% of the prompts were skipped, which is discussed later. However, notably, the questionnaires cover both work and leisure time because of the teachers' flexible working schedules in the afternoon and evening hours. Therefore, in the present JD-R study, we needed to exclude situations that were not related to job activities. To identify such situations in the ESM data, the subjects initially responded to a multiple-choice question regarding their activities during the last two hours. When “teaching,” “class preparation,” “student evaluation” or “administrative tasks” were selected instead of only “leisure time” or “private commitments,” the events were included in the analyses. Overall, 669 of the completed questionnaires were relevant to the teachers' jobs. Most work-related activities addressed teaching (56%), followed by administrative tasks (29%), class preparation (25%), and student evaluation (14%). Because the subjects could select several options in the multiple-choice question, the total number exceeds 100%.

Descriptive analyses

The descriptive statistics are presented in Table 1. All significant correlations were consistent with our expectations. Most of the variance in the ESM variables was located at the within-person level ($ICC = 0.13$ – 0.31), suggesting that the variables substantially varied within the

teachers across situations. Only the state HRV measure ($ICC = 0.57$) suggested higher between-subject than within-subject differences. [Table 1 near here]

Tests of hypotheses

Prediction of state heart rate variability

Table 2 presents the final model results of both outcomes. Concerning state HRV, the covariates bodily movement ($\gamma = -2.58$, $t(524) = -10.62$, $p < .01$), age ($\gamma = -0.01$, $t(97) = -3.36$, $p < .01$), and BMI ($\gamma = -0.02$, $t(97) = -2.01$, $p < .05$) were negatively associated with state HRV. However, the health-impairment process (H1a) could neither be supported for state emotional demands ($\gamma = 0.00$, $t(524) = 0.34$, $p = .736$) nor time pressure ($\gamma = -0.02$, $t(524) = -1.89$, $p = .060$). Similarly, no effects of job control ($\gamma = 0.01$, $t(524) = 1.39$, $p = .166$) or social support ($\gamma = -0.01$, $t(524) = -1.47$, $p = .143$) on state HRV could be detected. Regarding the interaction effects between job demands and resources (H2a), none of the four interaction terms were significant (emotional demands \times control: $\gamma = 0.00$, $t(524) = 0.45$, $p = .654$; emotional demands \times support: $\gamma = 0.01$, $t(524) = 1.08$, $p = .280$; time pressure \times control: $\gamma = -0.00$, $t(524) = -0.21$, $p = .831$; time pressure \times support: $\gamma = -0.01$, $t(524) = -1.32$, $p = .187$). In summary, both the health-impairment hypothesis and stress-buffering hypothesis regarding state HRV must be rejected. [Table 2 near here]

Prediction of state emotional exhaustion

Concerning emotional exhaustion, both momentary emotional demands ($\gamma = 0.21$, $t(556) = 6.09$, $p < .01$) and time pressure ($\gamma = 0.17$, $t(556) = 4.00$, $p < .01$) were positively associated with the outcome measure. Consistent with the health-impairment hypothesis (H1b), the teachers reported higher levels of exhaustion under the conditions of high emotional demands and time pressure. Regarding resources, situational social support ($\gamma = -$

0.11, $t(556) = -3.14, p < .01$) and trait HRV ($\gamma = -0.45, t(99) = -2.00, p < .05$) had negative effects on emotional exhaustion, while momentary control was unrelated to emotional exhaustion ($\gamma = -0.03, t(556) = -0.92, p = .358$). Regarding the buffering hypothesis (H2b), the analyses again revealed no moderating effects of job resources in the stressor-strain process predicting emotional exhaustion (emotional demands \times control: $\gamma = 0.00, t(556) = 0.04, p = .967$; emotional demands \times support: $\gamma = -0.04, t(556) = -1.90, p = .058$; time pressure \times control: $\gamma = 0.02, t(556) = 0.95, p = .342$; time pressure \times support: $\gamma = -0.05, t(556) = -1.84, p = .066$).

Concerning the moderating role of the 48-hour HRV measure (H3), evidence of an interaction effect with emotional demands ($\gamma = -0.18, t(556) = -2.35, p < .05$), but not time pressure ($\gamma = 0.19, t(556) = 1.94, p = .053$), on emotional exhaustion was found (see Table 2). As shown in Figure 1, the significant interaction effect between emotional demands and trait HRV on emotional exhaustion represents the expected stress-buffering effect. The simple slope analyses showed that the problematic effect of high emotional demands on exhaustion when trait HRV was high ($\omega = 0.13, z = 2.64, p < .01$) was less pronounced than that when it was low ($\omega = 0.28, z = 6.27, p < .01$). High levels of HRV were particularly beneficial in cases of high ($\omega = -0.33, z = -3.11, p < .01$) as opposed to low ($\omega = -0.06, z = -0.49, p = .623$) emotional demands. Further analysis additionally considering the trait covariates of HRV (mean 48-hour bodily movement, age, and BMI) resulted in essentially the same findings in terms of the interaction term; thus, we reported the more parsimonious model here. Overall, H3 could be partially supported as trait HRV proved to be a relevant stress-buffering moderator of high emotional demands but not high time pressure. [Figure 1 near here]

Discussion

The aim of the present ambulatory field study was to investigate teachers' momentary cardiac vagal tone and emotional exhaustion in relation to changing job demands. Therefore, a real-life real-time approach combining smartphone questionnaires and 48-hour ECG recordings over two days was carried out. Embedded in the JD-R framework (Demerouti et al., 2001), we analyzed different demand and resource types and their associations with fluctuations in subjective (emotional exhaustion) and physiological (HRV) state measures. We also shed light on trait HRV as a moderator that potentially buffers the detrimental effects of job demands on emotional exhaustion. Therefore, this study provides insights into the health-impairment process (H1) and stress-buffering effects of both state job resources (H2) and trait HRV (H3). While good support was found for H1 with regard to emotional exhaustion, no evidence was found with regard to state HRV. H2 must be rejected for both outcomes. Notably, long-term HRV significantly moderated the effect of emotional demands, but not time pressure, on emotional exhaustion (H3). Considering the predominantly psychological research focus, these psychophysiological results contribute to the literature by integrating HRV into the JD-R theory as both an outcome and a moderator, which might be important not only for theoretical model extensions but also for practical interventions.

Explanations and interpretations

Role of job demands

Considering the direct effects of job demands, we hypothesized that there would be health-impairing effects of emotional demands and time pressure on state HRV (H1a) and emotional exhaustion (H1b). Therefore, situations with high emotional or temporal demands were expected to be accompanied by diminished values of HRV and higher levels of exhaustion.

Concerning the effect of job demands on state HRV, we found no cardiovascular changes in fluctuating emotional or temporal demands after adjusting for the covariates. This result indicates that there were no acute biological adjustments in terms of an increased sympathetic and decreased vagal control of the heart when teachers were emotionally charged or pressed for time, which contradicts our hypothesis. Similarly, Pieper et al. (2010) and Vahle-Hinz, Bamberg, Dettmers, Friedrich, and Keller (2014) also failed to confirm comparable effects. The lack of support may be due to the characteristics of the state HRV measure, which generally shows a greater amount of between-subject variance ($ICC = 0.57$) and a strong positive correlation with the trait measure ($r = .88$). This finding is meaningful because it implies that there may have been insufficient statistical power to detect demand-induced fluctuations in HRV. Another explanation may be that the 5-minute time spans may have been too short for the demands to elicit physiological reactivity. However, Malik (1996) introduced the 5-minute period as the recommended duration for short-term analyses to facilitate comparability between research findings, and we aimed to achieve such comparability. Importantly, however, various previous studies have revealed opposite results that show associations between demanding job conditions and a low variability in the heart rhythm (e.g., Borchini et al., 2015; Chandola et al., 2008; Filaire et al., 2010). To address the mixed evidence regarding the prediction of HRV, additional research is needed.

Concerning the effect of job demands on emotional exhaustion, our results fully confirm the health-impairment process. In situations with emotional hindrances or temporal constraints, teachers were more likely to be exhausted. These results are consistent with the predictions of the JD-R model (e.g., Demerouti et al., 2001) and the COR theory (Hobfoll, 1989), which state that high levels of job demands deplete individuals' resources and impair health. Similarly, this finding replicates numerous previous findings showing the potentially damaging concomitants of emotional and temporal demands between teachers (Dicke et al.,

2018; Guglielmi et al., 2012; Pomaki & Anagnostopoulou, 2003) and within teachers (Keller et al., 2014; Sonnentag, 2001). Overall, H1a (decreased HRV) must be rejected for both emotional and temporal demands, while H1b (increased emotional exhaustion) is supported for both demand types.

Notably, although we investigated state HRV and exhaustion by means of a job-related theory of stress (Bakker & Demerouti, 2017), we cannot equate the outcome measures with physiological or psychological stress responses. It is debatable whether daily life events as assessed in the present study justify the use of the term “stress” (Kagan, 2016; Slavich, 2019). According to the authors, not all unpleasant situations accompanied by momentary changes in affective or biological systems can be considered stressful events as such labeling would only be appropriate for long-lasting and serious health-endangering events. Since our outcomes might also have been affected by other environmental, motivational or affective circumstances or even long-term chronic difficulties and since we only captured two sorts of job demands appearing during only two days, our study does not allow conclusions regarding stress reactions (Slavich, 2019). Moreover, temporary changes in HRV or exhaustion do not necessarily indicate a clinically relevant “health impairment.” Instead, such changes may also be considered an organism’s ability to situationally activate resources and supply energy for “an adaptive, flexible responding to challenging environmental demands” (Schwerdtfeger & Dick, 2019, p. 599). Hence, researchers should pay attention to avoid the overly permissive use of the term “stress.”

Role of job resources

Although beyond the scope of our research question, the modest main effects of job control and social support on short-term HRV and emotional exhaustion require further attention. The reason explaining why none of the resources were related to the state vagal tone might again be found in the above-mentioned limitations of the phasic HRV measure. However, only

social support, but not job control, was negatively associated with emotional exhaustion.

While the beneficial effect of support in terms of lower feelings of emotional exhaustion is in accordance with other studies involving teacher samples (e.g., Näring, Briët, & Brouwers, 2006), the missing control effect contradicts existing results (e.g., Näring et al., 2006).

However, the failure of control to predict teachers' emotional exhaustion is not unknown (Kittel & Leynen, 2003; Pomaki & Anagnostopoulou, 2003) and may arise from the potential non-linearity of this relationship (Warr, 1990) or a dependency on third variables, such as desire of control (e.g., Parker, Jimmieson, & Amiot, 2009). Another explanation may be that job control in general is more strongly associated with motivational rather than health-related outcomes (Bakker & Demerouti, 2017; Demerouti et al., 2001), but additional studies are certainly desirable.

Considering the interaction effects between job demands and resources, we expected a stress-buffering potential of momentary job control and social support on state HRV (H2a) and emotional exhaustion (H2b). Therefore, situations with high demands were expected to be less threatening when job resources were present. However, in contrast to our expectations, control and support did not mitigate the effects of emotionally or temporally demanding situations on either HRV or exhaustion. Although the buffering hypothesis has attracted much theoretical attention, the empirical evidence appears to be sparse. Many studies have paralleled our nonsignificant results on both cardiac and exhaustion outcomes (e.g., Cendales-Ayala, Useche, Gómez-Ortiz, & Bocarejo, 2017; Pomaki & Anagnostopoulou, 2003). Thus, support for the buffering effect of job resources seems to be weak not only in our study but also in occupational health research in general. One of the most prominent explanations for the missing evidence is the lack of consideration given to the so-called *matching principle*, which is discussed elsewhere (van der Doef & Maes, 1999). It might also have been the case that the nonsignificant findings arise from methodological restrictions. As mentioned above,

the school questionnaires were only completed during breaks and not during lessons. In addition, several prompts were skipped, implying that some situations may have been too demanding to allow a timely response. Altogether, these issues may have contributed to a bias in the answered alarms such that the questionnaires were completed under low-strain rather than high-strain conditions, which, in turn, could have artificially reduced the variance in the measures of demands and resources (see also the means and standard deviations in Table 1).

Role of trait heart rate variability

The results indicate that basal HRV is negatively associated with emotional exhaustion. Thus, the teachers with high tonic HRV were on average less exhausted throughout the work activities than the teachers with low tonic HRV. One interpretation might be that stable between-subject differences in HRV along with the interrelated capacity to use appropriate self- and emotion-regulation strategies (Thayer & Lane, 2009) may determine the mean extent to which a person experiences exhaustion during the day. Importantly, chronically poor levels of HRV may have a threatening effect in the long term as they have been related to serious health risks and mortality (for an overview see Malik, 1996).

Concerning the interactive effects, the present study analyzed whether the buffering hypothesis is applicable to elevated long-term HRV. We expected that a high person-mean HRV would act as a moderator in the relationship between job demands and exhaustion (H3). Indeed, trait HRV significantly buffered the effect of emotional demands on exhaustion, which is consistent with the JD-R framework (Demerouti et al., 2001). The teachers with an elevated tonic HRV were less exhausted in the case of high emotional demands than the teachers whose cardiac vagal tone was chronically restricted. This result also parallels the predictions of psychobiological models (e.g., Thayer & Lane, 2009) in which a stable high vagal control of the heart is discussed as a correlate of psychobiological self- and emotion-regulation skills, which have health-protective roles and facilitate coping with job demands

(Eatough et al., 2016; Grossman & Taylor, 2007; Thayer & Lane, 2009). Similarly, Utsey and Hook (2007) demonstrated that HRV weakened the association between social race-related stress and psychological distress. Moreover, Murdock et al. (2017) found a reduced effect of hostility on cortisol secretion in individuals with high HRV.

However, the relationship between time urgency and emotional exhaustion remained unaffected by trait HRV. The inability of the basal vagal tone to moderate the pressure effect is contradictory to our expectations based on psychophysiological and occupational health models (e.g., Demerouti et al., 2001; Grossman & Taylor, 2007). An explanation for why the buffering effect applies to emotional, but not temporal demands may stem from the matching principle (van der Doef & Maes, 1999) and the fact that emotional demands are more strongly connected to the requirement of emotion-regulation capacities, which, in turn, are interrelated with trait HRV (Thayer & Lane, 2009). Notably, previous studies also failed to confirm moderating effects of resources in the relationship between quantitative demands and teachers' exhaustion (e.g., Näring et al., 2006). According to the authors, being pressed for time may always be exhausting regardless of whether individuals are resourceful because a high workload may interfere with mobilizing coping resources and may cancel any buffering effect (e.g., Pomaki & Anagnostopoulou, 2003; Searle, Bright, & Bochner, 1999). Importantly, the latter explanation was formulated for resources other than HRV; hence, the transferability to the current finding might be limited.

Overall, the present results suggest that subjects with high tonic HRV, which is characterized as a correlate of good health and psychophysiological adaptivity to changing situations (Grossman & Taylor, 2007; Thayer & Lane, 2009; Togo & Takahashi, 2009), cope with emotionally, but not temporally, demanding periods more easily than individuals with low tonic HRV. Given this finding and previous evidence, one could interpret that high HRV may allow full power and concentration to be targeted to the emotional demand and coping

process and may help efficiently detach from such demand. However, this interpretation is speculative, and certainly, given the mixed results, more research is needed before conclusions can be drawn regarding the stress-buffering and health-protective potential of trait HRV.

Practical implications

Our major results suggest that situationally increased levels of demands seem to be accompanied by momentary feelings of exhaustion and that a flexible cardiac vagal response may be a moderator of this relationship. Although it is tempting to draw the conclusion that, for example, emotional demands have pathological consequences on exhaustion and that high trait HRV dampens this effect, the present cross-sectional study design precludes any causal assumptions. Hence, it could also have been possible that being emotionally exhausted (combined with having low or high trait HRV) resulted in perceiving more (or less) emotional demands. Therefore, future research should aim to clarify the directionality of these relationships. Nevertheless, if the demand effects on exhaustion outweigh the exhaustion effects on perceived demands, it could be suggested to reduce job demands and provide resources. However, directly reducing job demands does not appear to be a viable solution because engaging in the emotionally demanding classroom management and completing teaching tasks on time are as important in the teaching profession as the act of teaching itself. Earlier recommendations with regard to strengthening job resources (e.g., Demerouti et al., 2001) are also inconsistent with our findings because the present resources did not buffer the negative concomitants of teaching hazards. We suggest focusing on interventions that increase trait HRV to support adaptive coping with emotionally charged situations with regard to psychophysiological self-regulation capacities (Thayer & Lane, 2009). People could positively influence their vagal tone in various ways, e.g., exercise training (Malik, 1996). Again, proof of causality must have priority and should be achieved by future studies.

Limitations and directions for future research

Our study is not free from limitations. First, a bias may exist in the recruited sample because only healthy teachers, mostly females, participated in the study. Although exclusion criteria are commonly used in physiological studies (e.g., Vahle-Hinz et al., 2014), such criteria may lead to an unrepresentative sample because subjects suffering from chronic diseases, which often exist only due to prolonged strain, do not participate. Therefore, future studies should extend the current results by analyzing different samples. The second limitation concerns our measures. Although single-item scales are recommended for ESM studies (Ohly et al., 2010), one might argue that these scales are more prone to errors and only assess a broad, less differentiated picture of the demand setting. However, it was necessary to keep the instrument as brief as possible to enable the teachers to complete the assessments even during short school breaks and compensate for the rather high participant load produced by wearing sensors. Another critical aspect is that we only investigated a limited set of demands, resources, and outcomes. There may have been other aspects of the teachers' working environment, personality or physical health that play similar roles in the health-impairment process. To gain a complete picture of the HRV correlates in the JD-R model, the relationships with other demands, resources, and outcomes in addition to the motivational process (Bakker & Demerouti, 2017) must be explored.

Conclusion

In summary, the present study applied a multimethodological ambulatory assessment approach to study state HRV and exhaustion in a large teacher sample. This study aimed to contribute to the JD-R theory (Bakker & Demerouti, 2017) by analyzing psychophysiological approaches to coping with job demands and introducing a relatively new moderator to the stressor-strain relationship, namely, trait HRV. By examining ecologically valid objective and

subjective outcome measures in light of different demand and resource types, we offer a holistic picture of the health-impairment and stress-buffering processes that disclose possible roles of HRV in the JD-R model as both a (state) outcome and a (trait) moderating variable. Our results seem to corroborate earlier findings suggesting that unfavorable teaching conditions are associated with situationally increased exhaustion, but not HRV, and that job resources did not buffer these relationships. The question of why none of the JD-R effects on state HRV could be confirmed needs more attention. Although several authors have proven the sensitivity of ambulatory short-term cardiac responses (e.g., Schwerdtfeger & Dick, 2019; Schwerdtfeger & Gerteis, 2014), the present results suggest that such responses represent a rather insensitive within-subject measure. The fact that there are more findings similar to ours (e.g., Pieper et al., 2010) depicts a mixed picture of support for the variability of ambulatory state HRV, underlining the importance of future studies. However, concerning trait HRV, we found a moderating effect in the relationship between emotional demands and exhaustion, suggesting that high tonic HRV may be beneficial as a stress-buffering variable when facing high emotional demands. Before the tentative conclusion that high trait HRV might index a new category of personal physical health resources can be drawn, further research is needed.

Disclosure of interest

The authors report no conflicts of interest.

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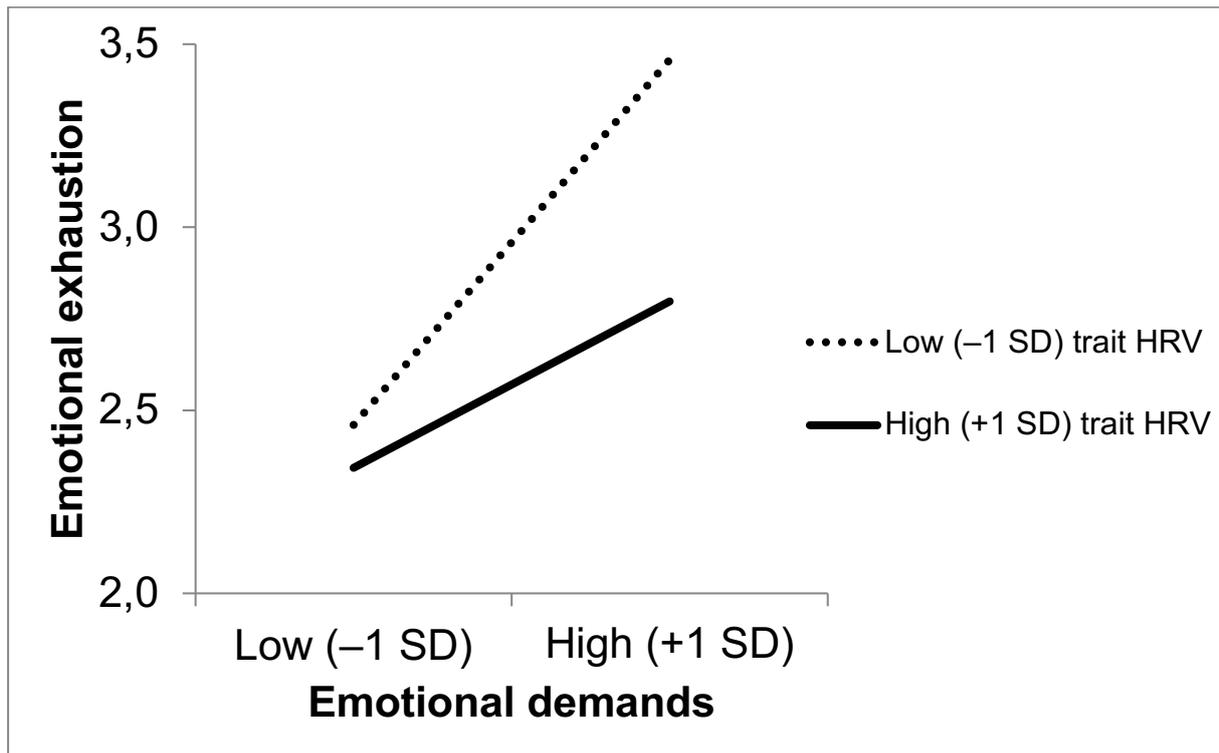


Figure 1. Interaction effect of emotional demands and trait heart rate variability (HRV) on emotional exhaustion.

Table 1. Means (*M*), standard deviations (*SD*), intraclass correlations (*ICC*), and intercorrelations of the measured variables.

| Variable | <i>M</i> | <i>SD</i> | <i>ICC</i> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------------------|----------|-----------|------------|--------|--------|---------|--------|---------|--------|---------|--------|
| 1 5-minute HRV (RMSSD) | 27.67 | 11.64 | 0.51 | | 0.89** | -0.06 | -0.05 | -0.11** | 0.04 | -0.07 | |
| 2 5-minute HRV (lnRMSSD) | 3.19 | 0.43 | 0.57 | 0.96** | | -0.12** | -0.02 | -0.11** | 0.03 | -0.03 | |
| 3 Emotional exhaustion | 2.79 | 0.99 | 0.25 | -0.14 | -0.15 | | 0.30** | 0.29** | -0.09* | -0.15** | |
| 4 Emotional demands | 2.74 | 0.99 | 0.13 | -0.12 | -0.14 | 0.36** | | 0.28** | -0.00 | -0.00 | |
| 5 Time pressure | 3.34 | 1.08 | 0.23 | 0.02 | -0.02 | 0.34** | 0.39** | | -0.03 | -0.08* | |
| 6 Job control | 4.32 | 1.12 | 0.28 | -0.02 | 0.00 | -0.12 | -0.06 | -0.01 | | 0.19** | |
| 7 Social support | 4.00 | 1.20 | 0.31 | -0.14 | -0.10 | -0.08 | 0.12 | 0.13 | 0.10 | | |
| 8 48-hour HRV (RMSSD) | 31.48 | 14.37 | | 0.88** | 0.82** | -0.20* | -0.07 | -0.03 | 0.01 | -0.12 | |
| 9 48-hour HRV (lnRMSSD) | 3.36 | 0.43 | | 0.87** | 0.88** | -0.25* | -0.10 | -0.04 | 0.06 | -0.07 | 0.95** |

Note. Correlations below the diagonal are between-person correlations with level 1 variables aggregated to level 2 ($N_2 = 101$). Correlations above the diagonal are within-person correlations ($N_1 = 669$). HRV = heart rate variability. RMSSD = root mean square of successive differences. lnRMSSD = natural logarithmic transformation of root mean square of successive differences. ** $p < .01$, * $p < .05$.

Table 2. Multilevel model estimates of state 5-minute heart rate variability (HRV) and emotional exhaustion.

| Fixed effects | State 5-minute HRV (lnRMSSD) | | | | State emotional exhaustion | | | | | |
|--------------------------|------------------------------|------------|--------------|-------------|----------------------------|------------|--------------|-------------|-------------------------|---------|
| | Estimate (<i>SE</i>) | <i>df</i> | <i>t</i> | <i>p</i> | Estimate (<i>SE</i>) | <i>df</i> | <i>t</i> | <i>p</i> | | |
| Intercept | 3.19 (0.04) | 524 | 83.15 | < .001** | 2.76 (0.10) | 556 | 28.49 | < .001** | | |
| 5-minute bodily movement | -2.58 (0.24) | 524 | -10.62 | < .001** | | | | | | |
| Age | -0.01 (0.00) | 97 | -3.36 | .001** | | | | | | |
| BMI | -0.02 (0.01) | 97 | -2.01 | .048* | | | | | | |
| ED | 0.00 (0.01) | 524 | 0.34 | .736 | 0.21 (0.03) | 556 | 6.09 | < .001** | | |
| TP | -0.02 (0.01) | 524 | -1.89 | .060 | 0.17 (0.04) | 556 | 4.00 | < .001** | | |
| Job control | 0.01 (0.01) | 524 | 1.39 | .166 | -0.03 (0.04) | 556 | -0.92 | .358 | | |
| Social support | -0.01 (0.01) | 524 | -1.47 | .143 | -0.11 (0.04) | 556 | -3.14 | .002** | | |
| 48-hour HRV (lnRMSSD) | | | | | -0.45 (0.23) | 99 | -2.00 | .048* | | |
| ED × job control | 0.00 (0.01) | 524 | 0.45 | .653 | 0.01 (0.02) | 556 | 0.04 | .967 | | |
| ED × social support | 0.01 (0.01) | 524 | 1.08 | .280 | -0.04 (0.02) | 556 | -1.90 | .058 | | |
| ED × 48-hour HRV | | | | | -0.18 (0.08) | 556 | -2.35 | .019* | | |
| TP × job control | -0.00 (0.01) | 524 | -0.21 | .831 | 0.02 (0.03) | 556 | 0.95 | .342 | | |
| TP × social support | -0.01 (0.01) | 524 | -1.32 | .187 | -0.05 (0.03) | 556 | -1.84 | .066 | | |
| TP × 48-hour HRV | | | | | 0.19 (0.10) | 556 | 1.94 | .053 | | |
| Random effects variances | Estimate (<i>SD</i>) | | | | Estimate (<i>SD</i>) | | | | | |
| Var (intercept) | 0.12 (0.35) | | | | 0.56 (0.75) | | | | | |
| Var (ED) | | | | | 0.01 (0.10) | | | | | |
| Var (TP) | | | | | 0.03 (0.18) | | | | | |
| Model comparison | Null model | Covariates | Main effects | Interaction | CAR(1) | Null model | Main effects | Interaction | Cross-level interaction | CAR(1) |
| -2* Log likelihood | 679.06 | 568.76 | 592.30 | 623.07 | 615.02 | 2489.77 | 2396.37 | 2413.62 | 2410.42 | 2389.92 |
| Δ-2*Log likelihood | | 110.30** | 23.54** | 30.77** | 8.04** | | 93.41** | 17.25** | 3.20 | 20.50** |
| <i>df</i> | | 3 | 4 | 4 | 1 | | 9 | 4 | 3 | 1 |

Note. N_2 (persons) = 101, N_1 (situations) = 669. lnRMSSD = natural logarithmic transformation of root mean square of successive differences. BMI = body mass index. ED = emotional demands. TP = time pressure. CAR(1) = continuous first-order autoregressive correlation structure. ** $p < .01$, * $p < .05$.