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Under Pressure: Heart Rate Variability in Academic Examination

Exposé of Indra Thiemann's master's thesis

1. Objective:

The aim of this study is to examine students' exam performance in relation to their heart rate variability (HRV). It is to be determined whether a higher HRV in exam situations can provide better cognitive performance. If this correlation is confirmed, targeted HRV training could provide a tool for preparing for the stress of exam situations and delivering the best possible cognitive performance.

2. Current state of research:

Stress is an integral part of academic life and academic performance (Vogel & Schwabe, 2016). In the 13th survey on the study situation and student orientations conducted by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Förderung, BMBF), around 50% of students reported test anxiety and over 40% reported experiencing at least one blackout during an exam, i.e. forgetting what they had learned during the exam (Multrus et al., 2017). Test anxiety refers to a cognitive, affective and physiological reaction in the assessment context (Grabo et al., 2025), characterised, for example, by fear of failure, palpitations or sweating (Klier & Buratto, 2020). The experience of stress depends on personal and subjective appraisal. The same stressor can be perceived very differently by different individuals (Vogel & Schwabe, 2016). At the

physiological level, stress is highly complex, but there are two systems that are particularly important: the faster autonomic nervous system (ANS) and the slower hypothalamic-pituitary-adrenal-axis (HPA-axis; Klier & Burrato, 2020; Vogel & Schwabe, 2016). The ANS reacts within seconds and releases catecholamines such as noradrenaline (NA; Vogel & Schwabe, 2016), which put the body into the so-called fight-or-flight mode (Vogel & Schwabe, 2016). Among other things, this mode influences the processes in the hippocampus, amygdala and prefrontal cortex, which play a crucial role in learning and memory (Vogel & Schwabe, 2016). Via the HPA-axis, corticosteroids such as cortisol are released reaching a peak 20-30 minutes after the stressor occurs (Vogel & Schwabe, 2016). The corticosteroids bind to two different receptors, again with both a faster and a slower process taking place. The faster reaction, primarily involving the mineralocorticoid receptor (MR), increases neural excitability in the hippocampus and amygdala, among other areas, similarly as the ANS. The second, somewhat slower process takes place approximately 60-90 minutes after the onset of the stressor, primarily via the glucocorticoid receptor (GR), which is widely represented throughout the brain (Vogel & Schwabe, 2016). This process causes longer-lasting changes to DNA translation and transcription and neural excitability in the amygdala and hippocampus decreases.

It is still not entirely clear whether stress and test anxiety impair or enhance cognitive performance (Vogel & Schwabe, 2016). While there is often evidence of impairments in cognitive performance such as memory retrieval or a decline in grades in stressful situations or in relation to test anxiety (Klier & Buratto, 2020; Multrus et al., 2017; Vogel & Schwabe, 2016; Von der Embse et al., 2018), there are also findings that cognitive performance remains unchanged or is enhanced by stress (Klier & Buratto, 2020). Various explanations are being considered in this regard. On the one

hand, the difference in findings could depend on the timing of the measurement. While measurements taken at the moment the stressor occurs and thus influenced by the faster part of the stress process tend to indicate cognitive enhancement (Vogel and Schwabe, 2016), measurements taken with a certain delay tend to indicate cognitive impairment, which could correspond to the slower stress response (Klier & Buratto, 2020). The latter is particularly relevant when considering stress in exam situations, as these temporal patterns tend to correspond. Furthermore, the content of cognitive tasks especially concerning memory tasks can be considered (Vogel & Schwabe, 2016). While the recall of content that is emotionally charged or related to the stressor seems to be improved, the retrieval of neutral or thematically unrelated content is found to be impaired. However, there is also evidence to the contrary (Vogel & Schwabe, 2016). Another possible explanation may be that cognitive abilities follow an inverted U-shape depending on stress. While mild stress can have an enhancing effect, severe stress can impair abilities. Finally, Yoo et al. (2021) suggest that there are several interindividual differences that influence the relationship between stress, test anxiety and cognitive performance.

One potential approach to examining the response to a stressor at the individual level is to consider the cardiac response. The heart possesses intrinsic pacemakers for adapting to environmental demands, which are influenced by the ANS (Peabody et al., 2023). The balance between the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS) is crucial in this regard (Peabody et al., 2023). At rest, the influence of the vagus-modulated PNS and its release of acetylcholine predominates, while during stress the relative influence of the SNS increases. After the stressor ceases, the release of acetylcholine by the vagus nerve increases again

and the influence of the PNS prevails to re-regulate the heart (Grabo et al., 2025, Peabody et al., 2023). The heart's ability to adapt to its environment therefore depends on how flexibly and quickly the vagus nerve can regulate this balance (Grabo et al., 2025, Peabody et al., 2023). The interaction between the PNS and SNS is reflected measurably in the variance of the heartbeat, known as heart rate variability (HRV). HRV describes the varying temporal distances between two heartbeats, which constantly change in length as the heart adapts to the environment (Grabo et al., 2025). Different components of HRV can be analysed, but most commonly the time domain and/or frequency domain are considered (Nicolini et al., 2024). In the time domain, the time between successive Q-waves on an electrocardiogram in normal cardiac cycles is assessed. These time intervals can be used to calculate the mean normal-to-normal (N-N) interval and the standard deviation from the mean value of N-N intervals (SDNN; Peabody et al., 2023; Nicolini et al., 2024). In addition, the proportion of successive N-N intervals that exceed a difference of at least 50 ms can also be considered in comparison to the total number of N-N intervals (pNN50). From the root mean square of this described proportion, the root mean square of the successive differences (RMSSD) can be calculated. A high RMSSD indicates a greater HRV (Peabody et al., 2023). In the frequency domain, the power spectral density (PSD) is usually considered. A phenomenon that can be observed examining the frequency is the so-called respiratory sinus arrhythmia (RSA) which describes the heart adapting to respiration. During exhalation, the influence of the vagus nerve increases, the heartbeat slows down and the interval between heartbeats becomes longer. During inhalation, the vagus nerve is inhibited and the relative influence of the SNS increases, causing the heartbeat to increase and the interval to become shorter. In frequency analysis, RSA is found in the high

frequency (HF) band (0.15-0.40 Hz), while the low-frequency (LF) band (0.04-0.15 Hz) reflects information during inhalation, i.e. during PNS inhibition. The ratio of the two frequency bands, the low-frequency-to-high-frequency ratio (LF/HF), represents the proportion of SNS/vagal inhibition relative to PNS/vagal stimulation (Peabody et al., 2023; Nicolini et al., 2024).

HRV has been found to be a reliable stress marker and an objective measurement tool (Yoo et al., 2021). There is a consistent, albeit not always significant, pattern of change in HRV under stress (Peabody et al., 2023). In the time domain, a reduction in SDNN and RMSSD can be observed during stress (Peabody et al., 2023). In the frequency domain, an increase in the LF/HF ratio becomes evident (Peabody et al., 2023). Even when the time and frequency domains are considered simultaneously, consistent patterns emerge (Peabody et al., 2023). In the academic field, HRV has been used to predict test anxiety, revealing a negative correlation (Grabo et al., 2025). In addition, a correlation between HRV and the mental and emotional state of students after academic examinations has been found (Yoo et al., 2021).

A general correlation between HRV and cognition reveals in both healthy and clinical populations (Nicolini et al., 2024). The majority of studies to date have found that high HRV is beneficial for both global and domain-specific cognition (Nicolini et al., 2024). Higher vagally-mediated HRV has often been linked to better executive functioning (Nicolini et al., 2024) and improved emotion regulation (Appelhans & Lücken, 2006; Grabo et al., 2025). There are three possible explanations for these data patterns. First, the central autonomic network (CAN) represents a shared neural substrate (Nicolini et al., 2024), as it is a complex system that plays a crucial role in both cognitive processing and the autonomic modulation of cardiovascular function via projections

to the preganglionic neurons of the SNS and PNS (Nicolini et al., 2024). Secondly, the ANS also regulates cerebral blood flow, which in turn is the prerequisite for cognitive functioning (Nicolini et al., 2024). Thirdly, regarding rather long term effects, the acetylcholine of the vagus nerve inhibits the synthesis of pro-inflammatory cytokines (Nicolini et al., 2024). A high PNS component therefore has a protective effect on cognitive abilities, whereas a comparatively high SNS component significantly reduces this protection, which could be why HRV is also found to be a longitudinal predictor of cognition (Nicolini et al., 2024).

Another important point that highlights HRV as a decisive factor in academic contexts, among others, is its targeted trainability and improvement (Manresa-Rocamora et al. 2021). Since the individual HRV can be deliberately influenced, it is not only well suited for understanding interrelationship but also for developing interventions.

Regarding methodological aspects, HRV measurements have several advantages compared to other methods. For example, questionnaires such as the State Trait Anxiety Inventory (Grimm, 2009) are simple and frequently used tools (Peabody et al., 2023). HRV measurements correlate with the results of these questionnaires and offer an even more objective assessment. Furthermore, some studies artificially induce stress using for example the Trier Social Stress Test (Kirschbaum et al., 1993) or the Cold Pressure Test (Hines & Brown, 1936; Klier & Buratto, 2020). Although these methods reliably detect a stress response, the simultaneously investigated cognitions are not directly related to the stressor, which, as mentioned above, can have a decisive influence on the enhancement or impairment of cognitive abilities under stress (Vogel & Schwabe, 2016). Cortisol tests are also used to investigate issues related to stress, but these tests are more expensive than

HRV measurements and sensitive to daily fluctuations (Peabody et al., 2023). In addition, the results of cortisol tests correlate with HRV measurements as well. Another possible method is the use of urine catecholamines, however, this method is not time-specific, as the measurement is limited to the time of collection. Finally, heart rate elevation alone has also been considered in some studies, but a strong influence by confounding factors cannot be excluded using this method. In summary, HRV is a reliable, simple and non-invasive method of investigating stress and quantitatively evaluating the balance between the PNS and SNS (Nicolini et al., 2024; Yoo et al., 2021) especially when compared to possible alternatives.

In summary, previous research suggests that high HRV tends to have beneficial effects on cognitive abilities and stress management. As described above, both stress management and cognitive abilities play a fundamental role in academic success, although the evidence is less clear. Nevertheless, despite the known connection between HRV and academically relevant constructs as well as the potential of HRV measurements, to the best of knowledge, there is only one other study to date that has used HRV in an exam context and examined its connections to performance (Yoo et al., 2021). Surprisingly, this study found that performance in written exams was better with unhealthy SDNN, a comparatively higher SNS component and a high stress index, rather contradicting the current state of research.

3. Hypotheses, study design and sample:

Due to the presumed relevance of HRV in the examination context and the rather contradictory findings, HRV measurement is to be used once again in the examination context,

investigating the influence of HRV on exam performance. Analysing students taking an exam, a baseline measurement is to be carried out some time before said examination, followed by a second measurement during the examination itself. Based on the current state of research, it is hypothesised that higher baseline-HRV and during the examination will result in better performance. For additional validation, the State Trait Anxiety Inventory (STAI, Grimm, 2009) will be used at baseline to control for subjective stress levels outside of the examination. Since influences of gender (Klier & Buratto, 2020; Yoo et al., 2021) and age (Klier & Buratto, 2020) have been found, these variables will also be collected and controlled. In addition, correlations with caffeine consumption, preparation time and total number of semesters are suspected, which is why these variables will also be collected and controlled.

The following variables are therefore collected:

- Different HRV-parameters, measured with Polar H10 HR sensors and analysed with KUBIOS
- Examination performance, measured by the grade achieved, classified according to percentile rank and additionally using a subjective questionnaire
- Subjective anxiety, measured using the STAI
- Caffeine consumption, measured by subjective reporting
- Preparation time, measured by subjective reporting
- Demographic variables: age, gender and total number of semesters completed, measured by self-reporting

Investigations will be conducted on students at the Institute of Psychology at Chemnitz University of Technology in the winter semester of 2025/26. Recruitment will take place via mailing

lists, social media and personal contact. Compensation may be provided in the form of VP hours, psychoeducation or, if desired, feedback on the results. To protect data security, all results will be pseudonymised. The voluntary nature of participation and the possibility of withdrawal without consequences will be emphasised at all times. There is no evidence of any potential impairment to the well-being of students or their exam performance.

4. Procedure:

The baseline assessment of HRV and the collection of data on subjective anxiety, age, gender, caffeine consumption and total number of semesters is scheduled to take place in January 2026. During the examination period in February and March 2026, HRV measurements will be repeated during the students' respective examinations. After completing the exam, students will be surveyed about their caffeine consumption and subjective exam performance. The data will be collected in pseudonymised form. Possible relationships will be evaluated using a mixed-effects model.

5. Summary:

HRV could be a promising trainable factor influencing academic performance. In the winter semester of 2025/26, students at the Institute of Psychology at Chemnitz University of Technology will be examined using HRV measurements before and during an examination, as well as subjective assessments, to determine whether there is a positive effect of HRV on exam performance.

6. References

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