BMJ Open

Continuous heart rate variability monitoring—understanding patterns of stress and recovery and their relationship with self-reported burnout, resilience and well-being in doctors: a protocol for a sequential explanatory mixed-methods study

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To cite: Kane L, Ball D, Martin KR, *et al*. Continuous heart rate variability monitoring—understanding patterns of stress and recovery and their relationship with self-reported burnout, resilience and well-being in doctors: a protocol for a sequential explanatory mixed-methods study. *BMJ Open* 2025;**15**:e097849. doi:10.1136/bmjopen-2024-097849

► Prepublication history for this paper is available online. To view these files, please visit the journal online (https://doi.org/10.1136/bmjopen-2024-097849).

Received 11 December 2024
Accepted 24 April 2025

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ABSTRACT

Introduction The medical profession is facing an unprecedented crisis. Reasons for this are complex and multifactorial; however, rising rates of burnout will undoubtedly contribute to problems with recruitment and retention. Chronic workplace stress, whereby there are insufficient resources available to meet the demands doctors face, is a contributor to burnout. There are a wide variety of available self-report measures for stress, with heart rate variability (HRV) shown to be a biomarker of stress and recovery in doctors. We aim to triangulate continuous HRV measurements with validated self-report measures and qualitative data to better understand the patterns of stress and recovery.

Methods and analysis This study has a sequential explanatory mixed-methods design. Participants will be recruited from multiple sites within National Health Service (NHS) Grampian. Initially, participants will complete a suite of validated scales, including the Maslach Burnout Inventory for Medical Personnel, the Resilience Scale for Adults and the Interpersonal, Community, Occupational, Physical, Psychological (ICOPPE) well-being scale. Following this, participants will undertake seven consecutive days of ecological momentary assessment of real-time demands, resources and fatigue, alongside 7 days of continuous ambulatory assessment of HRV via Firstbeat Bodyguard 3 chest-worn monitors. Participants will be provided with a summary report following their study period. If 40 participants are recruited within the recruitment timeframe, multilevel modelling will be used to analyse data; otherwise, N-of-1 statistical techniques will be used. Following initial analysis of the quantitative data, participants of interest will be invited to take part in semistructured interviews, which will be thematically analysed and presented alongside the quantitative data.

Ethics and dissemination This study was approved by the University of Aberdeen, School of Medicine, Medical Sciences and Nutrition ethics review board (ref. 3389193) and the NHS Grampian research and development team.

Results will be disseminated in international peer-reviewed journals.

Trial registration number NCT06721312.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study addresses the growing problem with burnout in the medical profession.
⇒ This study is the first of its kind to be conducted in the UK.
⇒ Conceptualised and designed by a doctor with over a decade lived experience of working in the National Health Service in collaboration with Participant and Publinc Involvement (PPI) groups.
⇒ Conducted by an interdisciplinary research team.
⇒ Limited by single trust design and fixed delivery time periods associated with funding.

INTRODUCTION

The General Medical Council survey reported record levels of moderate-to-high burnout risk among doctors; 63% for trainee doctors and 52% for trainers (senior doctors).[1] WHO recognises burnout as an occupational syndrome arising from chronic workplace stress, which has not been adequately managed.[2] Burnout is characterised as having three dimensions: (1) feelings of energy depletion and exhaustion; (2) increased mental distance from one's job or negative or cynical feelings about one's job and (3) a sense of ineffectiveness or lack of accomplishment from one's job.

Burnout has wide-reaching consequences. At an individual level, those with burnout have reduced professional efficacy[3 4] and are more likely to suffer from conditions such as

anxiety and depression, memory loss, sleep disturbance and substance misuse.[5 6] Burnout is also associated with increased cardiovascular disease in men and musculoskeletal disease in women.[5 6] Doctors with burnout are also at increased risk of making medical errors.[3] The cascade effects of unfilled senior vacancies, high levels of absenteeism and medical errors from those who remain in work raise concerns for patient safety and are contributing to a recruitment and retention crisis within the profession.[7]

A certain degree of stress is understood to be beneficial and can promote optimal growth and performance,[8] but chronic physical and psychological harm can result if an imbalance occurs between stress and recovery.[9] It is this unchecked chronic stress that is thought to contribute to burnout.[10]

Many of the available measures of stress focus on mental or psychological stress. However, it is known that both physical and mental demands contribute to the overall physiological burden of stress.[10] Self-reported measures are also not without limitations: the use of varying tools and poorly used and described use of cut-off values, as well as factors such as survey length, time to complete and survey fatigue, are all recognised issues.[3] Furthermore, it is understood that individuals, in particular males, often under-report stress and that there is also often a disparity between subjective and more objective measures of well-being.[3]

One way to more objectively measure stress is through heart rate variability (HRV), a calculation of the beat-to-beat variation of the R-R interval on a normal ECG. HRV is a function of the autonomic nervous system (ANS) and reflects the combined sympathetic and parasympathetic activity of the ANS. The ECG data can be translated into episodes of sympathetically driven stress (low HRV) and episodes of parasympathetically driven recovery (high HRV).[11 12] The use of HRV as a biomarker of stress is well established and is widely used in performance sports[12] and is an increasingly available metric in wearable devices.[13] In a meta-analysis of HRV across a range of psychological stressors, the analytical tool demonstrates its value as a measure of psychological stress, as well as the physical stress commonly assessed in performance sports.[9] Furthermore, a systematic review of HRV assessment in emergency department doctors confirmed the acceptability of using HRV measurements as a marker of occupational stress but acknowledged that the studies conducted so far have been limited to small numbers of participants, over short time periods and contain a number of methodological flaws: such as a failure to recognise and establish a baseline HRV for participants, issues in contextualising HRV measurements and substandard reporting of HRV measurements standards are areas to be addressed.[14]

Resilience is often considered an ability to bounce back from adversity; however, a 2015 review[15] found that there was no universal definition of resilience, but the literature has identified five key themes: rising above adversity, adapting and adjusting, resilience as a dynamic process and mental health as a marker of resilience.

When considering resilience as a dynamic trait,[16] it is often promoted within healthcare organisations as a way of combating occupational stress and burnout. There is conflicting literature on the relationship between resilience and burnout. Traditionally, it was believed that low levels of resilience in doctors may contribute to burnout[17] and that building resilience may be a helpful skill.[18] However, the conflict within this area continues, with more recent work conducted in Ireland demonstrating that within their study cohort of doctors, participants were both highly resilient but also suffering high levels of burnout.[19] In contrast, a study in Australia found a cohort of general practice trainees to have low levels of resilience and low levels of burnout.[20]

Well-being, much like resilience, is also now promoted across healthcare organisations. While well intentioned, both measuring well-being and developing interventions remain problematic. There is a lack of consensus across the academic literature as to the definition of well-being; however, there is agreement that any subjective measures of well-being should be multifaceted.[21]

The Job Demands-Resources model[22] developed in 2001 provided a theoretical model to better understand the occupational demands and resources that contribute to job strain and motivation, and any imbalance in these which may cause burnout. Figure 1 outlines an adaptation of a more recent iteration of the model which incorporates the state of 'flow'.[23] Flow is described as a time of optimal experience "when a person's body or mind is stretched to its limits in a voluntary effort to accomplish something

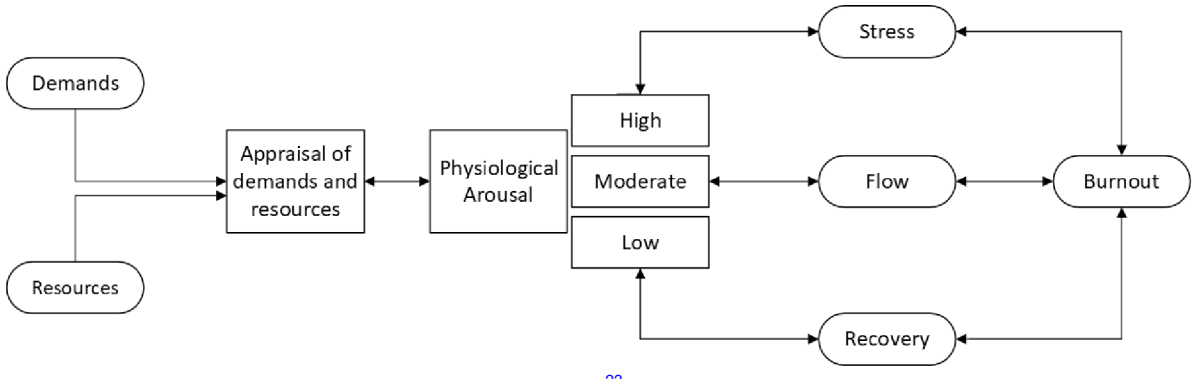

Figure 1 Adapted demands, resource and flow-burnout model.[23]

that is difficult or worthwhile".[24] In the context of doctors, we expect them to have several competing demands such as clinical workload and time pressure as well as various resources available to them such as supervisor support, job control and feedback. The addition of flow to the model also uniquely addresses that there is the opportunity for high-fidelity medical work to both contribute to burnout in that it will likely be very demanding, but also that being in the state of flow is highly rewarding and may also be protective against burnout.

There are several benefits to ecological momentary assessment (EMA) research methods.[25] First, they allow real-time data collection from participants that not only allows the capture of fluctuations but also reduces recall bias. Second, EMA methods support long-term tracking of longitudinal and intensive longitudinal data collection, which is invaluable for detecting changes over time. Third, EMAs provide insight into how different individuals may respond differently to similar situations, increasing our understanding of within-subject variability.

HRV is a proven non-invasive objective measure of stress in doctors.[14] A review is currently underway of HRV monitoring in doctors (PROSPERO: CRD42023413282). This review shows that the HRV metrics RMSSD (root mean square of the successive differences) SDNN (standard deviation from the mean value of normal-to-normal intervals), low-frequency and high-frequency/low-frequency ratio were all able to detect statistically significant changes between stress and recovery in doctors.

This study aims to triangulate HRV as an objective biomarker of stress, with self-reported job demands, resources and flow experience and qualitative data to develop a deeper understanding of the patterns of stress and recovery experienced by doctors that may contribute to burnout. We predict that as self-reported demands increase, HRV will decrease, as self-reported resources increase HRV will also increase, and where demands are high and resources are low, HRV will be low and will be associated with burnout.

Study objectives

Primary objective

To understand patterns of stress and recovery in medical doctors under ordinary working conditions using subjective and objective measures of stress.

Secondary objectives

- To examine medical doctors' whole experience of stress and recovery using subjective and objective measures of stress and qualitative semistructured interviews.
- To test the within-person effects of job demands (stress) and job resources (recovery) on self-reported stress and HRV.
- To explore the individual differences in mechanisms used to cope with stress by triangulating subjective and objective stress measures with qualitative outcomes.

METHODS AND ANALYSIS

Study design and setting

The proposed study has a mixed-methods n-of-1 design with 7 days of EMA followed by qualitative interviews. Full details are outlined in later sections and depicted in figure 2.

Participants and recruitment

Doctors of all grades and all specialties will be recruited from both primary and secondary care sites across a single National Health Service (NHS) trust.

Sample size

N of 1 analysis will be conducted. This requires 50 data points to be collected per participant. N of 1 analysis means that there is no minimum number of participants required.[26]

Should 40 participants be recruited to the study, multilevel modelling will be used to explore both within-person and between-person effects. Rolling blocks of 10 study participants will be recruited at a time. This allows us to understand data acquisition and study processes, amending them as necessary after each rolling block of 10. This will be done up until 31 October 2025 and until qualitative data saturation[27] is reached.

Eligibility criteria

Participants must have access to a smart mobile phone that has access to WhatsApp that participants are happy to use for the study, including downloading the Firstbeat Life app and consenting to Firstbeat end licence user agreement. Table 1 gives the full inclusion and exclusion criteria.

Recruitment and consent

Posters will be placed in the common spaces used by medical doctors in NHS Grampian. Further promotion will take place via social media and targeted emails to participant groups that work within NHS Grampian. Written informed consent will be sought from all participants prior to commencing the study.

Participants for the qualitative semistructured interviews will initially be invited to participate by email. If there is no response to the email within 48 hours, they will be contacted by telephone. It will be recorded should participants decline to participate at this stage.

All participants who complete the 7-day study will be entered into a prize draw for a £250 voucher.

Participant timeline and data collection methods

Procedure

Enrolled participants will be asked to commence the study immediately following 48 hours of rest by completing a suite of self-report questionnaires (figure 2) using the online survey platform, Qualtrics.[28] Participants will then be trained in how to use their HRV monitor, including the appropriate application of electrodes, how to know if the device is working and how to charge the device when required. Verbal and written instructions will be given

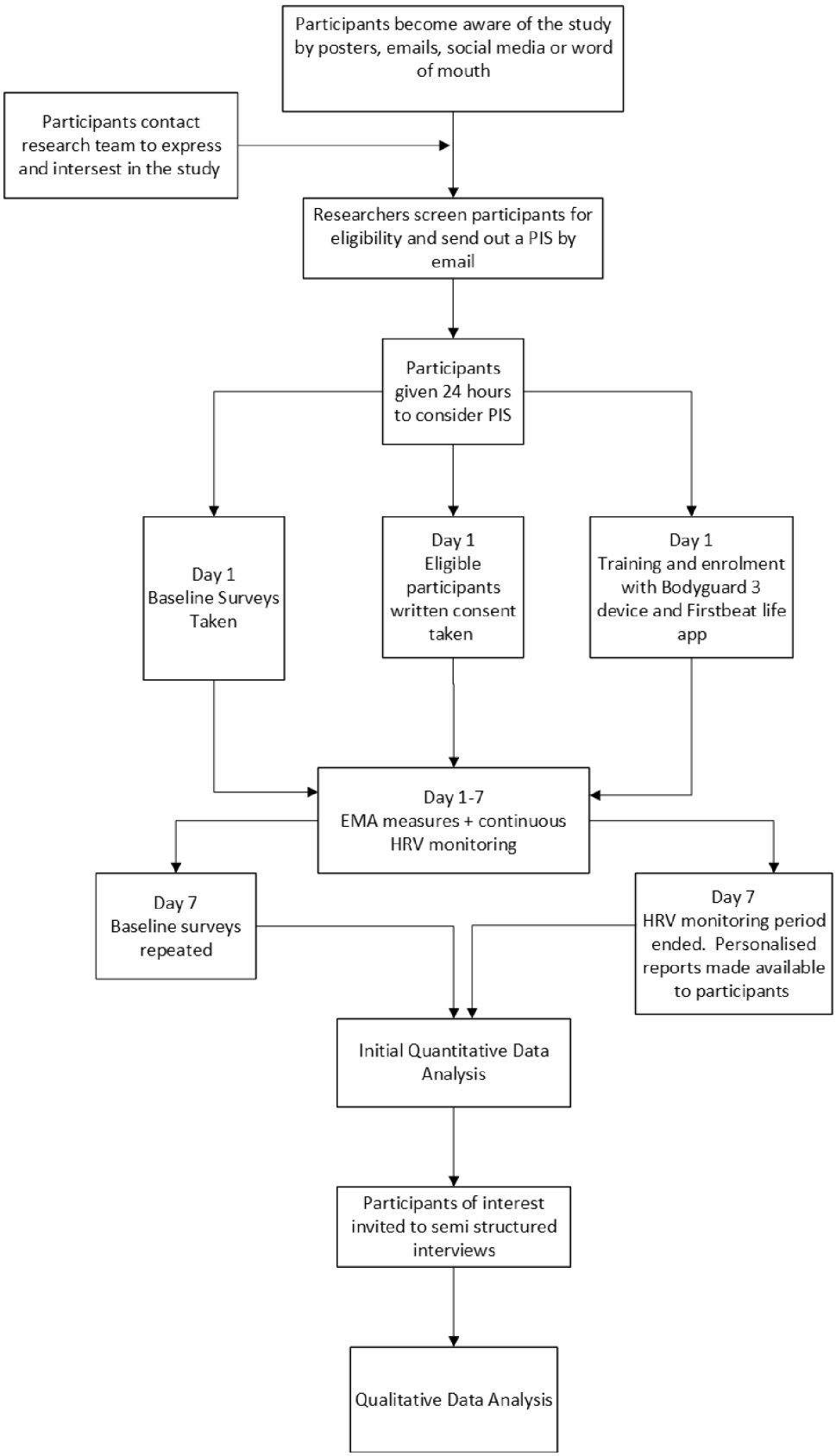

Figure 2 Participant timeline flowchart. HRV, heart rate variability; EMA, ecological momentary assessment; PIS, participant information sheet.

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Doctors working within National Health Service Grampian in either primary or secondary care	Diagnosed cardiac arrhythmias
Access to a smartphone that can be used to access WhatsApp and the Firstbeat Life app	Diagnosed endocrine disease
Consent to the Firstbeat Life end licence user agreement	Taking prescription medication known to affect heart rate variability; such as β-blockers, calcium channel blockers, ACE inhibitors, benzodiazepines, antidepressants and antianxiety medications
48 hours consecutive non-working time prior to study commencement	

for basic troubleshooting and charging instructions. A member of the study team will be contactable for further advice. Participants will apply their device and be asked to sit quietly and relax for 15 min.

Participants will wear the chest-worn Firstbeat bodyguard devices continuously for 7 days. They will be encouraged to change electrode placement regularly to decrease the chance of skin irritation. Electrode placement changes will be small and will not affect the quality of data collected.

The devices are associated with the Firstbeat Life app which will be downloaded onto the participants' own phone.[29] The app will be paired with the Firstbeat bodyguard to allow Bluetooth uploading of data. Participants will not have visual access to their data during the study period. The Firstbeat Life app also allows participants to enter relevant contextual information about their day, for example, if they were sleeping, eating, bathing, exercising or experiencing a particularly stressful event.

The 7-day EMA assessment schedule will be during waking times only with a prompt on awakening, six quasi-random prompts throughout each day, concluding with a final assessment immediately prior to going to bed (total of eight per day). Participants will be reminded by WhatsApp or email message to their personal mobile phone to complete the EMA measures. Our study population is expected to work highly variable shift patterns, including on-calls and night shifts, so bespoke assessment schedules will be generated for each day and each participant according to their own sleep–wake cycles. On completion of day 7, participants will be asked to remove their devices and complete the baseline assessments once again.

Once initial analysis of quantitative data has been completed, participants of interest, unusual cases or outliers will be invited back to take part in semistructured qualitative interviews. Participants of interest may demonstrate particularly high or low HRV measurements or answers in their baseline or EMA responses that draw interest from the study team. The semistructured interviews will be data driven using the Firstbeat stress and recovery reports produced following the quantitative monitoring period to open and guide the interviews. These interviews will be transcribed and analysed and presented in a mixed-methods explanatory format.

Measures

Primary outcome

HRV is a measure taken from the R-R interval of an ECG tracing. This will be measured using a Firstbeat Bodyguard 3, which is a 256 Hz single-channel ECG recorder worn on participants' chest and has been shown to be accurate in various conditions.[29] HRV as a biomarker has been shown to be a valid and reliable measure of both physical and psychological stress.[9 30] HRV data will be analysed using Kubios[31] HRV analysis software. HRV will be reported in accordance with the European Task Force for reporting HRV studies.[11]

Secondary outcomes

Baseline measures

Burnout

Occupational burnout will be assessed by the 22-item Maslach Burnout Inventory for Medical Personnel (MBI MP).[32] The MBI MP is a self-report questionnaire, which uses a 7-point scale for responses ('never' to 'everyday'). The survey takes approximately 10 min to complete. It has subscales focused on Emotional Exhaustion (being emotionally overextended by one's work), Depersonalisation (measures of unfeeling and impersonal responses) and Personal Accomplishment (feelings of competence and successful achievement). The MBI MP is well validated in our target population[33–35] and has been shown to be reliable.[36–38]

Resilience

Resilience will be measured with Fribord's Resilience Scale for Adults (RSA).[39] This self-report measure has been found to have high sensitivity to change.[40] The RSA is a 33-item self-report scale examining intrapersonal and interpersonal factors presumed to assist them to be able to adapt to adversities. Responses are provided via a 5-point Likert scale. It includes 33 statements with a 5-point response scale for each. Average scores are calculated from these scales. It is well validated[39–42] and shown to be reliable.[39 43 44]

Well-being

The I-COPPE scale[21] has six individual domains of interpersonal, community, occupational, physical, psychological and economic—all of which have been individually validated against overall well-being. The use of this scale will demonstrate how individuals self-report various

aspects of their life, which, alongside diarised continuous HRV measurements, should contribute to a deeper understanding regarding which domains of participants' lives are the largest contributors to stress and which domains are potentially protective or aiding recovery. The scale asks participants to rate each of the well-being domains at three different time points, now, 1 year previously and 1 year in the future, totalling 21 items. This scale has been validated in several environments[21 45–47] and has been shown to be reliable.[21 48 49]

EMA (real-time) measures

Real-time job demands

National Aeronautics and Space Administration task load index (NASA TLX)[50] is a multidimensional workload assessment tool, developed by the NASA human performance group. It has been validated for whole-day repeated measures[51] and has been shown to be reliable in healthcare workers.[52] It contains six subscales of mental demand, physical demand, temporal demand, performance, effort and frustration. The overall workload is derived from an average of the six subscales listed. This scale has been translated into 12 languages and used in a variety of settings, including healthcare and studies using within-person longitudinal designs.[53–55]

Real-time job resources

This is a six-item scale derived from the job–demands resources model of burnout.[56] The items contained within the scale are feedback, rewards, job control, participation, job security and supervisor support. The item has not previously been validated in this population but provides a useful measure of resources to further explore the demand–resources–flow model.[23]

Real-time flow

Included is a single-item question asking participants "Have you felt completely absorbed by a challenging but doable task?"[24] Given the paucity of literature understanding what 'flow' might mean within this study population and how this may relate to HRV, we have included the question "Have you felt absorbed by a challenging but doable task?" with a free text box allowing participants to expand on their experience.

Real-time fatigue

The Rating of Fatigue (ROF) scale[57] is a single-item visual analogue scale developed to track self-perceived levels of fatigue. The 10-point scale asks participants to rate their levels of fatigue from 0, not fatigued at all, to 10, total fatigue and exhaustion. This measure has been validated in sports performance environments and has not previously been used in occupational settings. However, authors do recognise that it may have utility in areas out with sports and its simple visual design is well suited to a population already assumed to be under some degree of stress while also minimising survey burden over repeated EMA measures.

Quantitative stage

Baseline surveys

Initially, participants will complete a series of questionnaires on Qualtrics via an online link sent to their mobile phone on day 1. This includes the participants' demographics, age, sex, marital status, number of dependants, care responsibilities, years of postgraduate experience, current employment and basic health information, the Maslach Burnout Inventory for Medical Professionals,[32] the RSA[39] and the ICOPPE.[21] The demographic information collected is essential in order to analyse HRV data due to individual variations associated with these parameters.[58] Although a participant characteristics questionnaire is included, answering these questions will not compromise participants' confidentiality. In total, it is expected to take 20 min to complete. Data will be collected confidentially using Qualtrics, which is a university-endorsed software that is General Data Protection Regulation compliant.

EMA surveys

Over seven consecutive days (days 1–7), participants will complete eight real-time assessments of demand (NASA TLX) and self-reported job resources. Each prompt to complete these assessments will be delivered once on wakening, six times quasi-randomly throughout the day and once shortly before bedtime. Each set of assessments will take approximately 2 min to complete.

The ROF scale will be completed by participants if they indicate that they are about to start a shift at work or if they have just completed a shift at work to understand the effects of the working day on fatigue.

Post-EMA surveys

Participants will complete the same questionnaires as they completed at baseline on day 7 using the Qualtrics survey platform.

Qualitative stage

A purposive sample of participants will be chosen after the initial quantitative analysis. These participants will be made up of outliers, extreme cases, interesting or significant results. Qualitative data will come from three streams: comments made in the diaries kept by participants during the quantitative phase, semistructured interviews and a reflective diary kept by the researcher.

Interviews will be conducted by the lead author (LK) in appropriate University of Aberdeen or NHS Grampian office spaces and recorded with a digital dictaphone. The data prompted[59] semistructured interviews will be opened by providing participants with a printed copy of their stress data reports in a format that has been trialled with key stakeholders to assess clarity and understandability. These reports are produced by the research team using the Firstbeat admin platform. The interviewer will briefly talk through the report highlighting any points of interest, which may include but not be limited to missing data, particularly high or low stress measures, or anomalous data. Interviews will then progress to following an

Box 1 Interview guide

- ⇒ What was your experience of stress and recovery during the study period?
- ⇒ How does your measured results compare to how you feel about stress and recovery in your life?
- ⇒ What do you consider the demands and resources in your life to be?
- ⇒ The state of flow can be described as a state "where people are so absorbed in their activities that nothing else seems to matter"; can you describe any times in your life and study period that this may have applied?
- ⇒ What aspects of your life and work do you find particularly stressful?
- ⇒ What do you think would be the most beneficial changes to your life to improve stress and recovery balance?

interview guide of predetermined questions (box 1) while also allowing for the exploration of any emergent themes.

It is expected that 12–20 interviews will be required to reach data saturation. If further interviews are required, then we will continue to recruit and conduct interviews should time permit until data saturation is reached.[60]

Data management and analysis

HRV data will be transferred via Bluetooth to the Firstbeat Life app on participants' mobile phones and then the Firstbeat Life Admin cloud database for researchers. Initial analysis and production of the participant reports will be produced in the Firstbeat Life Admin platform. Participant demographic, baseline survey and EMA survey information will be collected in Qualtrics and linked via a unique identifier.

Kubios software[31] will be used to analyse HRV data. Contextual and psychological information can be added to Kubios. All HRV data will undergo artefact correction prior to analysis in Kubios.

- Descriptive statistics: Participant characteristics, demographics and baseline survey results.
- Visual inspection: HRV data will be downloaded into Kubios and charted against time. EMA results will be charted alongside HRV. R-R interval data will be converted into time and frequency HRV domains using Kubios. Missing data will be explored, artefact identification and cleaning described in accordance with $STARD_{HRV}$.[61] The data charts that are produced will be visually inspected, and any trends described appropriately.
- Dynamic regression: Measured R-R interval data will be collected in accordance with the European Task Force.[11] This will be formatted in MS Excel alongside EMA outcomes, and any missing data addressed as deemed appropriate. R-R data will be converted into time and frequency HRV domains using Kubios software. Dynamic regression will be used to assess the relationship between workload reported on the NASA TLX and HRV. Dynamic correlation accounts for autocorrelation of the past on the future;[62] therefore, where appropriate, the previous EMA assessments will be taken into consideration when conducting the dynamic regressions.

Should we recruit over 40 doctors in the available timeframe, we plan to use multilevel modelling (also known as mixed-effects modelling) nesting real-time assessments within doctors to test both within-person and between-person differences.

SPSS Version 29.0.1.0 will be used for statistical analysis of quantitative data.

- Qualitative analysis: Recorded interviews will be transcribed verbatim. Transcripts will be coded by the lead researcher (LK) and double-checked by an independent researcher. An inductive approach to thematic analysis will then be followed,[63] grouping the codes into themes, which will be presented visually with a coding tree. Results from the semistructured interviews will be reported in accordance with the Consolidated Criteria for Reporting Qualitative Research checklist.[64]

The study data set will be available in the data repository PURE.

Patient and public involvement

Members of the public who are involved with the NHS Grampian PPI network contributed early during the study conceptualisation phase. Feedback from their involvement indicated the need to study the current problems with stress in doctors and that they particularly felt an objective physiological measure may be better than existing self-report measures. We therefore consulted potential participants, doctors from across NHS Grampian, via face-to-face workshops, emails and anonymised surveys on the study design, acceptability of wearing HRV monitors and for how long this could be, what they would like to be included in EMA measures and acceptable length of EMA measures. Doctors felt that although it was important to keep EMA measures brief, they were very willing to have additional items added on the grounds of academic merit (eg, resources EMA measure).

Going forward, public partners/non-study participant stakeholders from NHS Grampian will continue to be involved in further elements of the study, including interview guide design, sense-making activities of interim results from quantitative and qualitative data, as well as co-design of engagement and dissemination activities to share study findings with participants, members of the general public, as well as NHS Grampian directors and managers.

Potential implications

As an exploratory study, the results from this study may inform larger multicentre study design in this area that could better power between-person analysis. There may be areas for potential interventional studies identified as a result of this study. Although not intended as a behaviour change study, providing individualised stress and recovery reports to participants may lead to change at an individual level. These implications would all contribute to

addressing the current unprecedented recruitment and retention crisis in medicine.

ETHICS AND DISSEMINATION

This study is sponsored by the University of Aberdeen and approved by NHS Grampian Research and Development department (SERB ref.: 3389193; sponsor ref.: 2-015-24). Study results will be disseminated in peer-reviewed journals spanning these disciplines and presented at national and international conferences.

Study status

Recruitment to this study is expected to commence in December 2024 and run until October 2025. The approved protocol is V.2 23/07/24. ClinicalTrials.gov ID: NCT06721312.

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Funding This work was funded by the John and Ruth Young Clinical Academic Fellowship grant number RG16738-10. Open-access publication costs were supported by NHS Grampian funds. The funders did not contribute to study design.

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants. This study was approved by the University of Aberdeen, School of Medicine, Medical Sciences and Nutrition ethics review board (REF. 3389193) and the NHS Grampian research and development team. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

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