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INTEGRATED FIELD MONITORING OF PARAMEDIC WORKLOAD AND EXPOSURE: A MULTI-MODAL METHODOLOGICAL STUDY

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ABSTRACT

Introduction: Paramedics experience demanding physical tasks, acute stressors, and chronic under-recovery, defined as an accumulation of incomplete physiological and psychological recovery. However, occupational exposure research has primarily relied on retrospective self-report, simulation, or single-modality monitoring that poorly capture within-shift variation and operational context.

Objective: The objective of this paper was to describe, implement, and evaluate a field-embedded, multi-modal protocol for measuring paramedic occupational exposure across routine rostered shifts, cross-referenced to CAD data. Specifically, we report protocol feasibility, data completeness, artifact burden, and field validity as methodological endpoints.

Methods: We conducted a prospective methodological observational study embedded in the routine operations of a large Australian ambulance service. A work-force-aligned sample of operational paramedics completed multiple monitored shifts wearing Hexoskin smart garments for continuous heart rate, respiratory rate, and accelerometry data, with pre-/post-shift and pre/post call blood pressure measurement and Borg Rating of Perceived Exertion (RPE) where feasible. Anonymized computer-aided dispatch (CAD) records provided call type, priority, and phase timestamps (assign, en route, on scene, to hospital, at hospital), enabling minute-level linkage with biometric data. Standardized procedures were specified a priori for recruitment, device fitting, shift monitoring, logbooks, data export, cleaning, missing-data thresholds and an epoch-based hierarchical data structure (epochs within calls, calls within shifts, shifts within paramedics). Primary procedural endpoints were feasibility and adherence, data completeness and artifact profile, and field validity of Hexoskin measures.

Results: Thirty-two paramedics completed 232 monitored shifts, yielding 918 emergency calls and approximately 2,700 hours of analyzable multi modal monitoring. Protocol adherence was high, with most rostered monitoring opportunities proceeding as planned and shifts meeting the predefined 75% biometric data completeness threshold despite approximately 5% of ECG data being removed as artifact. Hexoskin heart and respiratory rate patterns demonstrated expected gradients across CAD-defined call priorities and operational phases. They were consistent with prior laboratory validation, supporting the field validity of the protocol.

Conclusions: This protocol provides a replicable, EQUATOR-aligned framework for multi-modal paramedic exposure research that could be adapted to other emergency services. By foregrounding design, measurement, data processing, and analytic structure, it provides methodological infrastructure to support future etiologic and intervention studies.

INTRODUCTION

Paramedics face substantial physical and psychological demands, with evidence of elevated cardiometabolic risk, fatigue and sleep disruption compared with the general population (Alenazi et al., 2016; Buljan et al., 2016; Kearney et al., 2021). However, existing occupational exposure studies in paramedicine have relied heavily on surveys and simulations, sometimes supplemented by monitoring, which has limited in situ ecological validity and the ability to link physiological responses to specific calls or operational phases (Janka & Duschek, 2018; Morales et al., 2016).

Despite the potential availability of computer-aided dispatch (CAD) data and wearable “smart garments,” there is no widely accepted, transparently reported methodology for integrating biometric, subjective, and operational data in paramedic field settings. Methodological studies that explicitly develop and evaluate such protocols are needed to support reproducible, scalable occupational exposure research. This paper is intended as a methodological and feasibility report rather than a definitive exposure-outcome analysis. The exemplar findings are presented to demonstrate protocol performance, data capture, and field validity; substantive occupational exposure analyses arising from this cohort will be reported separately.

OBJECTIVE

This paper presents a transparent, field tested protocol for paramedic occupational exposure research. It integrates wearable biometric monitoring, subjective exertion ratings, and CAD data. It also reports key indicators of feasibility, data quality, and field validity as exemplar outcomes of protocol performance.

To achieve this, the study pursued three specific aims:

1. To integrate wearable biometric monitoring, intermittent blood pressure measurement, perceived exertion ratings, and CAD derived operational timestamps into a single shift level monitoring protocol that can be embedded within routine ambulance operations.
2. To quantify protocol feasibility and adherence, including recruitment, monitored shifts per participant, and the proportion of rostered shifts and emergency calls successfully captured and linked across data streams.
3. To characterize data quality and field validity by describing biometric data completeness, artifact burden, and expected physiological gradients across CAD defined call priorities and operational phases as exemplar outcomes of protocol performance.

METHODS

STUDY DESIGN AND SETTING

We conducted an observational methodological study embedded in the routine operations of a large Australian state ambulance service ($n = 3,302$), in which we both developed and evaluated a multi modal field protocol. An a priori sample size calculation indicated that 27 participants would be sufficient for the planned exemplar mixed-effects analyses; accordingly, a recruitment target of 28 was set to allow for minimal attrition. Because participant interest exceeded this target and operational monitoring capacity

permitted additional enrollment, 32 paramedics were ultimately included. The power analysis should be interpreted in the context of the study's methodological rather than etiologic focus. Data was collected over 7 months of rolling recruitment, with shift monitoring conducted during routine rostered duties. The study was reported in accordance with STROBE for observational studies and emerging EQUATOR guidance for methodological research.

PARTICIPANTS AND SAMPLING

Operational paramedics rostered to front-line duties were eligible; staff in desk-based roles, recent significant musculoskeletal injury, pregnancy, and those prescribed heart-rate-limiting medications were excluded. We used workforce-aligned sampling to mirror the distribution of age, sex, clinical level, and posting (metropolitan versus regional) across the service, recruited through internal communications linked to a broader health and workload survey and local station presentations (High, 2015). Interested staff contacted the research team and provided written informed consent.

Operational context variables recorded for each monitored shift included roster characteristics and CAD-derived call information. Environmental variables such as ambient temperature and humidity were not recorded. The response platform was a two-paramedic staffed ambulance. Paramedics followed a shift rotation of four 12-hour shifts (2 days and 2 nights) followed by 5 days off.

MEASUREMENT FRAMEWORK

Primary methodological outcomes were feasibility and adherence, data completeness and artifact profile, and field validity indicators of Hexoskin measures, with operational characteristics from CAD treated as exposures.

BIOMETRIC MONITORING

Continuous biometric monitoring using Hexoskin smart garments (Carre Technologies, Montreal, Quebec), incorporating a digital ECG and dual respiratory bands to capture heart rate (HR), respiratory rate (RR), accelerometry-derived activity (G-force), and step count. Heart rate was derived from R-R intervals, and respiratory rate and volumes were measured with calibrated respiratory bands; prior validation shows minimal bias and high agreement with criterion measures across rest and exercise, supporting field use by paramedics (Cherif et al., 2018; Elliot et al., 2017; Moriarty et al., 2018; Villar et al., 2015).

BLOOD PRESSURE AND PERCEIVED EXERTION

Blood pressure (BP) was measured intermittently using the LIFEPAK 15 monitor/defibrillator (Stryker, Kalamazoo, MI, USA), which employs oscillometric measurement with a manufacturer-reported accuracy of ± 5 mmHg across the operating range for systolic, diastolic, and mean arterial pressure (Stryker, 2022). The LIFEPAK 15 monitor/defibrillator underwent routine service maintenance and pre-use operational checks in accordance with organizational practice. Measure was recorded as systolic and diastolic blood pressure taken pre- and post-shift, and, when feasible, after calls perceived as particularly demanding. Mean arterial pressure (MAP) was then calculated using a standard formula (DeMers & Wach, 2025). Perceived exertion was assessed with the previously validated Borg 0-10 Rating of Perceived Exertion (RPE) scale (Borg, 1982; Tobase

et al., 2024) immediately before and after each monitored shift and, where operationally possible, after individual calls or at mid-shift.

DEMOGRAPHIC AND OCCUPATIONAL CHARACTERISTICS

Baseline characteristics included age, sex, anthropometry, clinical level, posting (metropolitan vs regional), and years of service overall and at the current level. These measures were consistent with prior paramedic workload and health research to support interpretation and external comparability (Hunter et al., 2019).

COMPUTER-AIDED DISPATCH DATA

Emergency medical calls at this service are managed using the VisiCAD Command computer-aided dispatch system (TriTech Software Systems, FL, USA). For each monitored shift, anonymized CAD records provided a call identifier, type, priority code, and timestamps for the assign, en route, on scene, to hospital, and at hospital phases, which were used to time-anchor biometric and subjective measures and to define exposure epochs.

FIELD PROTOCOL

The protocol was designed to integrate with routine workflows and minimize disruption.

1. Orientation and familiarization: Participants attended a brief training session in person or virtually, covering garment fitting, data pack charging, syncing, BP measurement, RPE recording, and use of a simple shift log; test recordings were used to confirm signal quality and competence.
2. Pre-shift baseline: At the start of each monitored shift, participants donned the garment under their uniform, confirmed electrode contact, and sat quietly for at least five minutes to capture baseline HR, RR, and G-force, then recorded baseline BP and RPE.
3. During shift: Hexoskin recorded continuously, including breaks; BP was repeated when feasible after demanding calls and at the end of shift; RPE was recorded after each call or, where call volume was high, at least mid-shift and end-of-shift; logbooks captured device issues.
4. Post-shift: At shift end, participants repeated BP and RPE, removed the garment, and followed standard cleaning and charging procedures; data were uploaded via encrypted connections to a secure server. At the end of all shifts, the equipment was returned to the researcher in pre-paid postal packaging.

DATA MANAGEMENT, CLEANING, AND STRUCTURE

Hexoskin data were downloaded as binary data files. Time-aligned BP, RPE, and CAD timestamps were created in Excel (Microsoft, USA) and merged with the Hexoskin data file using Vivosense analytical software (Vivosense, San Diego, CA). Each shift was structured hierarchically: epochs (operational phases) nested within calls, which were nested within shifts, which were nested within paramedics. For each epoch and across the entire shift, we derived mean and peak HR and RR, G-force, most proximal BP and RPE, and CAD data, preserving temporal ordering and enabling multilevel modeling of physiological responses to operational exposures.

Physiologic time series underwent visual and algorithmic screening for artifacts, including non-physiological HR spikes or drops, implausible respiratory values, and sustained flat-lining inconsistent with reported work patterns. Artifactual segments were flagged and removed. All data were exported to an Excel spreadsheet.

Statistical analyses were conducted using IBM SPSS Statistics (IBM Corp., Armonk, NY, USA). Quantitative variables such as HR, RR, G-force, and MAP were analyzed as continuous measures; call priority and operational phase were modeled as categorical predictors, and no additional categorization of continuous variables was applied. Mixed effects models specified random intercepts for paramedics and, where applicable, for shifts nested within paramedics, with fixed effects for call priority, operational phase, and selected covariates (e.g., body mass index) and are reported elsewhere (MacQuarrie, 2019).

METHODOLOGICAL ENDPOINTS

Primary methodological endpoints were:

1. Feasibility and adherence: recruitment and retention, monitored shifts per participant, proportion of rostered shifts successfully instrumented.
2. Data quality: proportion of biometric data flagged as artifactual and proportion of shifts meeting the > 75% completeness threshold.
3. Field validity: concordance of Hexoskin heart and respiratory rate patterns with laboratory validation statistics and evidence of expected physiologic gradients across call priority and operational epochs.

Descriptive statistics summarized feasibility and data quality, and field data were interpreted against published laboratory Bland-Altman and intraclass correlation coefficients for Hexoskin. As exemplar analyses to demonstrate analytic capacity, mixed-effects models were used to illustrate within- and between-paramedic variation in HR, RR, and MAP across phases and priorities, adjusting for selected covariates; these were not treated as definitive inferential findings.

To minimize measurement bias, we applied predefined artifact-detection criteria in Vivosense and interpreted field measures in the context of laboratory validation data. Selection bias was mitigated by workforce-aligned sampling; residual selection and Hawthorne effects are considered in the Limitations section.

A completed STROBE checklist is available on request.

ETHICS

Ethical approval was granted by the university Human Research Ethics Committee and the ambulance service Human Research Ethics Committee, and all participants provided written informed consent. Data was deidentified before analysis, with linkage keys held securely by the ambulance service. External funding was not used to support this work.

RESULTS

Results are presented to demonstrate protocol feasibility and operational performance, including recruitment and adherence, shift and call capture, data completeness, artifact rates, and successful linkage of biometric and CAD-derived data streams.

Feasibility and adherence: The protocol achieved high operational feasibility. Across 32 paramedics, the protocol captured 232 monitored routine rostered shifts, comprising approximately 2,700 hours of monitoring and 918 CAD-linked (emergency/000-generated emergency) incidents

Across 232 monitored shifts, paramedics attended a mean of 4.9 ± 1.9 emergency calls and 3.3 ± 1.8 patient transports per shift, with only 4 shifts (2%) recording no emergency calls. Mean time on calls was 4.4 ± 2.4 hours per 12-hour shift, higher in metropolitan paramedics (5.0 ± 2.6 hours) than regional paramedics (3.9 ± 2.0 hours), while the number of transports per shift was similar by posting. There was no loss to follow-up among participants (Table 1). Most rostered monitoring opportunities proceeded as planned, and reasons for non-monitoring (e.g., unplanned leave, equipment logistics) were documented in shift logs.

Measure	Metropolitan (n = 16)	Regional (n = 16)	All Paramedics (n = 32)
Age (years)	35.6 (10.1)	41.0 (6.7)	38.3 (8.8)
Sex (male/female)	10/6	11/5	21/11
Years of service	11.1 (7.4)	11.6 (6.7)	11.3 (6.9)
Years at current level	4.5 (4.0)	7.8 (6.6)	6.2 (5.6)

Table 1. Demographic and occupational characteristics of paramedics.

Note: Values are mean (SD) except sex, where numbers reported are male/female.

Data quality: Physiologic data quality was acceptable within routine operations. Across shifts, approximately 5% of biometric data were flagged as artifactual and removed, with the most significant artifact burden during high-movement epochs, such as en route and on scene. Applying a prespecified 75% completeness threshold at the shift level, most monitored shifts were retained for primary analyses. CAD timestamps and Hexoskin data were successfully merged for all shifts with valid device files, yielding 918 calls with complete epoch-level biometric and operational data (Table 2).

Field validity: Field biometric profiles were consistent with prior laboratory validation and demonstrated the protocol's sensitivity to operational context (Table 3).

Aspect	Indicator	Value (n, % or description)
Shift-level inclusion	Monitored shifts	232 shifts from 32 paramedics
	Shifts with no emergency calls	4/232 (2%)
	Shifts meeting $\geq 75\%$ usable-data threshold	228
Call-level inclusion	Emergency calls with linked biometrics and CAD	918 calls with successfully merged records
Artifact proportion	Overall biometric artifact	Approximately 5% of the physiological data was flagged and removed
	Artifact pattern by phase	Highest during high-movement epochs (en route, on scene) due to torso movement and electrode displacement
Completeness of specific measures	Hexoskin HR, RR and G-force	Available for all shifts meeting the completeness threshold
	BP recordings	Pre- and post-shift BP is highly complete; within-shift post-call BP is more frequently missing during high call volume.
	RPE recordings	Shift-start and end RPE are highly complete; within-call RPE is occasionally missing when operational tempo precluded recording.
Data linkage	Success of Hexoskin–CAD linkage	CAD timestamps successfully merged with Hexoskin for all shifts with valid device files
	Exclusions for device failure	One instance of a participant who was unable to upload shift data but later succeeded.

Table 2. Data completeness, artifact profile and linkage performance.

Domain	Indicator	Value (mean $\pm$ SD or n, %)
Shift-level feasibility	Shifts with > 0 emergency calls	228/232 (98%)
	Time on calls per shift (hours)	4.4 $\pm$ 2.4 (metro 5.0 $\pm$ 2.6; regional 3.9 $\pm$ 2.0)
	Proportion of shift time on calls	~37% (higher in metropolitan)
Call-level context	Total emergency calls recorded	918 calls across monitored shifts
	Calls per shift	4.9 $\pm$ 1.9 (metro 5.3 $\pm$ 1.6; regional 4.5 $\pm$ 2.1)
	Transport per shift	3.3 $\pm$ 1.8 (metro 3.2 $\pm$ 1.7; regional 3.3 $\pm$ 1.7)
	Priority-1 calls	20/918 (2%); 17 confirmed cardiac arrests
Biometric field performance	Shift-average heart rate (bpm)	80.6 $\pm$ 10.3 (metro 80.8 $\pm$ 10.7; regional 80.4 $\pm$ 10.1)
	Call-average heart rate (bpm)	76.1 $\pm$ 16.3
	Call-maximum heart rate (bpm)	87.3 $\pm$ 15.2
	Shift-average respiratory rate (breaths min ⁻¹)	14.6 $\pm$ 3.3
	Call-average respiratory rate (breaths min ⁻¹)	21.2 $\pm$ 5.9
Occupational physical activity	Mean shift G-force (g)	0.09 $\pm$ 0.15 (Very Low–Low range)
	Mean call G-force (g)	0.11 $\pm$ 0.07
	Mean call-maximum G-force (g)	0.36 $\pm$ 0.12
	Steps per 12-hour shift	4,368 $\pm$ 1,555 (metro 4,230 $\pm$ 1,560; regional 4,469 $\pm$ 1,549)

Table 3. Protocol feasibility, call characteristics and biometric performance.

Note: Metro = metropolitan posting; regional = regional posting.

This methodological observational study was reported in accordance with the STROBE guideline for observational studies and with emerging EQUATOR guidance for methodological research.

DISCUSSION

This methodological study demonstrates that a multi-modal protocol integrating wearable biometrics, self-reported workload, and CAD data can be implemented within routine paramedic operations with high adherence and acceptable data quality. By specifying recruitment, device workflows, data processing rules, and hierarchical data structures, the protocol addresses a call for more transparent reporting of complex exposure measurement designs in paramedicine.

Key strengths include workforce-aligned sampling, the integration of validated biometric, BP, and RPE measures with CAD-derived operational epochs, and an explicit framework for artifact handling and completeness. The resulting hierarchical, epoch-based structure preserves operational context and supports multilevel modeling of physiologic responses to paramedic work.

Our finding that multi-modal monitoring was feasible within routine operations, but required close collaboration with clinical and technical stakeholders, mirrors experience in emergency department and first responder settings, where deployment of wireless biosensor systems has depended on careful integration with workflows and infrastructure (Miller et al., 2021).

Limitations include implementation within a single jurisdiction, reliance on a specific wearable platform and analytical software, and the expertise required to manage multi-modal time-series data, which may constrain uptake. Ecological validity remains bounded by the characteristics of a single ambulance service, one wearable platform, and the participating jurisdiction's rostering and case-mix profile

Within a shift, BP and RPE measures were more often missing during periods of high call volume, underscoring trade-offs between measurement intensity and operational burden. Although the protocol may be adaptable to other ambulance and emergency-service contexts, transferability is likely to depend on local rostering models, case mix, device availability, data-governance arrangements, and analytic capabilities.

Implications: Beyond paramedicine, the growing occupational health literature highlights that wearable sensor systems can improve exposure assessment precision and enable continuous monitoring of biomechanical and physiologic loads in real-world work settings, but they also face challenges around sensor placement, data processing, and user acceptance (Babangida et al., 2025). The protocol provides a template for occupational exposure research in other emergency services and shift working groups, where linking biometric and operational data is increasingly feasible. Embedding similar methodological frameworks in future etiologic and intervention studies may help standardize exposure measurement, improve reproducibility, and reduce research waste in paramedicine.

Future work should extend this approach to multi-service, multi-device cohorts and examine how protocol performance varies across organizational contexts.

CONCLUSION

This methodology article presents a replicable, EQUATOR-aligned protocol for integrating wearable biosensors, subjective workload ratings, and CAD data into paramedic occupational exposure research. Taken together, these findings address the study objective by showing that a multi-modal, shift-level monitoring protocol can be implemented within routine paramedic operations with acceptable completeness, manageable artifact rates, and successful integration of biometric and operational data. In conclusion, the principal contribution of this work is methodological: it provides a transparent and replicable framework for future occupational exposure research in paramedicine. It may help to inform health and wellness initiatives in ambulance services.

Conflicts of interest: The authors declare no conflicts of interest related to this study. The mention of specific devices, software, or manufacturers is for methodological transparency only and does not imply endorsement or a financial relationship.

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