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Soldier performance management: insights from boots on ground research and recommendations for practitioners

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ABSTRACT

Theoretically, the serial measurement of biomarkers to monitor physiological responses to military training could be used to mitigate musculoskeletal injury risk and better understand the recovery status of personnel. To date, the cost and scalability of these initiatives have impeded their uptake by defence organisations. However, advances in technology are increasing the accessibility of a range of health and performance biomarkers. This paper presents a synthesises of findings from the literature and discussions with informed stakeholders to provide contextually relevant advice for future efforts to monitor military personnel, together with key considerations to ensure actionable outcomes from the data captured. The aim of this review is, therefore, twofold; first, to demonstrate how wearable devices and biomarkers have been used in defence research to assess the context-specific, occupational demands placed on personnel; and second, to discuss their potential to monitor military workloads, optimise training programming and understand soldier adaptation to multi-stressor environments.

INTRODUCTION

Military personnel are at risk of negative long-term health outcomes if the workload is not appropriately managed across the life cycle of their career. Short-term implications of improperly managed workloads that exceed an individual's ability to adapt include decreased occupational performance and readiness and increased incidents of musculoskeletal injury[1] and illness.[2] In sporting contexts, a range of subjective (ie, measures of mood state) and objective measures (eg, resting or maximal heart rate) have been used to monitor adaptation, optimise performance potential and inform training programming.[3] However, the intent of this paper is not to provide an exhaustive list of available measures and techniques to monitor work and training loads in military settings.[4] Rather, the goal is to provide the rationale for why measures of training load or monitoring systems are required, share some empirical examples to highlight different military contexts (basic and specialist training) where these measures have been used and the practical considerations that need to be addressed before implementation can occur.

Historically, a biomarker referred to a biological molecule found in the blood, sweat, urine or tissues that was a sign of a normal or abnormal process or a disease. However, the term 'biomarker' is no longer restricted to these body fluids and can be used to encompass all data that can describe biological functions including sleep, movement and measures of well-being. At a general population level, advances in medical research and technology are increasing the awareness of health and performance biomarkers. Moreover, the use of wearables is supporting the delivery of more personalised medicine, while a combination of wearable sensors[5] and telehealth platforms are being explored to support the management of chronic health concerns remotely.[6] In comparison, biomarker monitoring for health and performance in military personnel is arguably in its infancy. We believe that the integration of screening and continuous monitoring methods (such as actigraphy for activity counts and sleep), coupled with robust analytical approaches, can provide novel insights for military leaders regarding health, performance and readiness outcomes during multi-stressor military training to mitigate against injury and/or ill-health.[7] The purpose of this narrative review is to provide an overview of how wearable devices and biomarkers have been used in defence research to

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Theoretically, soldiers' biomarker data could be used to assist military leaders and decision-makers with managing operational tempo, asset allocation and force readiness while enhancing the long-term health and career outcomes of military personnel.

WHAT THIS STUDY ADDS

⇒ This study underscores operational considerations for the implementation of soldier performance monitoring. Highlighting that with appropriate chain of command support, it is possible to collect biomarker data across a range of different military training environments.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This paper provides contextually relevant advice for future efforts to introduce serial monitoring of military personnel as well as some key considerations to ensure actionable outcomes from the data are captured. Ultimately, the success of leveraging biomarker data within these contexts will be dependent on the buy-in and perceived benefit from military stakeholders and leaders.

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assess the context-specific, occupational demands placed on personnel while discussing their potential to monitor military workloads, optimise training programming and understand soldier adaptation to multi-stressor environments.

BIOMARKERS IN MILITARY TRAINING

Biomarkers, as defined above, represent the next frontier in preserving and enhancing the health and performance of military personnel. For example, consider the basic military training (BMT). Representing the point of entry training for soldiers, this transition from a civilian to a military career is characterised by a multi-stressor environment of high physical activity volumes, controlled daily scheduling affecting sleep and nutrition and considerable psychological and cognitive stressors,[8] coupled with high injury rates[9] and commensurate high allostatic loads.[10] In this context, the goal is to increase physical capacity. However, the challenges are an increased risk of injury and compromised recovery and well-being. To help mitigate the risk of these negative training outcomes (ie, injury /attrition), many military organisations have enlistment physical fitness standards[11] to ensure that personnel can meet the job requirements. These measures of performance or fitness represent another source of biomarkers. Assessed at a single point in time such as the commencement and/or end of BMT, measures of physical fitness (eg, sit-ups, push-ups or aerobic capacity) are moderately effective (at best) in prospectively predicting maladaptive outcomes such as injury.[12] Various other measures of physical function and performance such as counter-movement jump (CMJ), functional movement screening and balance tests have also been investigated but have similarly shown unacceptable predictive utility from a baseline assessment in training environments.[12 13]

For military organisations, the complexity associated with mitigating negative training outcomes is further exacerbated by the fixed or grouped training programmes, which are typical of military training environments. To date, research efforts to deploy wearable devices and biomarkers in the context of BMT have demonstrated the utility of these approaches to monitor the allostatic load of recruits during training. And yet, while the ongoing measurement of biomarkers may support more individualised training to achieve better training outcomes for both the individual and the organisation, conventional military training environments have typically not been able to support individualised training like that seen in high-performance sports. Military training establishments may have hundreds to thousands of personnel to manage on any given day, with low staff-to-personnel ratios, modest training resources and compressed training schedules. This broad assessment is based on the current resourcing and personnel management common in BMT among western military organisations, which may be summarised as a 'one-size-fits-all' approach. In response to this challenge, the US Army has implemented a comprehensive Holistic Health and Fitness initiative that is providing greater resources, personnel, doctrine/guidance and funding to mirror the more personalised high-performance models observed in collegiate and professional sports (FM 7–22). This provides a template that other militaries may consider in the future.

Yet, even without significant resourcing, there are still opportunities to use wearable devices and short questionnaires to collect low-burden, high-return biomarker data from recruits, without impacting the daily training environment. For example, BMT typically involves changes to the sleeping environment, schedule and periods of deliberate sleep restriction throughout training.[14 15] As a result, insufficient sleep during BMT has been associated with compromised recruit recovery and signs of overtraining.[16] To quantify the magnitude of this demand on the personnel, the use of wrist-worn actigraphy to objectively measure overnight sleep has been deployed across the 12 week Australian Army BMT course.[17 18] Both Bulmer *et al*[17] and Larsen[18] independently reported that recruits had a mean nightly sleep duration of 6.3–6.4 hours, which is likely to negatively impact training outcomes. Combining both subjective and objective measures of sleep best explains the relationships between sleep metrics, stress, fatigue and recovery.[17] The research team concluded that if objective measures for monitoring sleep are not practical, subjective self-reported sleep quality was the best single-item measured that reflected changes in perceptions of fatigue, recovery and stress.[17]

Other low-cost measures that could be scaled across large formations include objective and subjective measures of workload such as ratings of perceived exertion[19 20] and multi-domain self-reported tools such as the MTDS or SRSS, both used by Bulmer *et al*.[21] Similarly, multiple research groups have now used actigraphy to quantify workloads across BMT.[17–21] These papers support the utility of actigraphy to provide data for the early identification of recruits at risk of injury, maladaptation or attrition. For example, Tait *et al*[22] collected a range of biomarkers from 46 recruits across a 12 week BMT programme. Higher perceived exertion, fatigue, stress, poor sleep quality and elevated cortisol levels (collected daily to weekly) were associated with an increased injury risk. Conversely, higher testosterone levels and better fitness on entry reduced the risk of injury and delays to completion time.[22] However, more work is required with chain-of-command support and buy-in from end users before these kinds of measures can be implemented without researchers support for the purpose of serial monitoring in BMT contexts.

Following BMT, soldiers will undertake additional training courses to acquire trade-specific qualifications, promotion or selection into specialised military roles (eg, officer training, airborne, reconnaissance, special forces). In this context, the goal is to develop role-specific cognitive and physical capacity; however again, there is an increased risk of maladaptive training responses and decreased preparedness and well-being. Such courses are typically described as 'arduous' as training aims to be harder or at least as hard as the demands expected to be faced on operations, with the mentality of 'train hard, fight easy'. What characterises a course as arduous in nature is typically the high proportion of course time devoted to field exercises performed in challenging conditions, conducted over several weeks. To prepare for these roles, courses are designed to train candidates to perform at a high level where the physical demands of training may be greater than seen in BMT[23] and may exceed the minimum Physical Employment Standards.[24]

As such, monitoring individuals and collecting accurate biomarker data during specialist training environments may help ensure that training-induced strain is tolerable and preserves human capability. However, this data collection can present challenges (concomitant to those mentioned above for BMT). For example, monitoring soldier responses to the arduous courses in the British Army has primarily been achieved via the integration of military and research teams.[25] Buy-in from senior commanders and course training teams is crucial, particularly when there are tangible outcomes that will influence policy changes. Regarding the data capture itself, a light-touch approach has been proven beneficial, whereby research teams have minimal interference with participants during training so as not to alter scenarios or change training programme activity, yet use methods (namely

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wearable devices) that enable high-quality longitudinal field data capture. Specifically, wearables that can be easily fitted (ie, quick to administer), are forgotten (ie, comfortable and don't need charging often) and are sufficiently robust to handle the environmental conditions will aid data quality and user-acceptability. Again, research-grade tri-axial accelerometers, which have been used extensively for the serial collection of physical activity and sleep data in military populations with minimal burden on participants,[17–20] represent an ideal solution. These devices provide a valid alternative to the gold-standard doubly labelled water (DLW) for prolonged training periods.[26] Using these devices, arduous British Army training courses have been characterised by high levels of moderate- to vigorous-intensity activity (thus, high daily energy expenditures), coupled with poor sleep patterns, resulting in negative energy balance and reduced body mass.[23–25]

Specialist courses also involve the performance of more role-specific tasks that exceed BMT activity demands, such as heavy load carriage or lifting heavy equipment. Collecting biomarker data that includes objective measures (eg, HR, GPS), and subjective data (eg, questionnaires or ergonomic analysis) during physically demanding courses may assist in classifying the physical requirements needed to successfully perform tasks in specialist roles. Indeed, programmes of work commissioned solely within specific military populations such as the US Rangers to document the enhanced physiological stressors using a range of physical tests and biomarker measures (eg, DLW, somatotrophic hormone[27]) can then provide continuity and opportunity to monitor the long-term impacts of training and intervention initiatives.[28] A complementary approach using marker-less motion capture, force plate technology and cluster analysis for CMJ has also been developed to monitor personnel. During US Marine Corps Officer Candidate School, Bird *et al*[29] identified three distinct clusters from CMJ movements that differed for musculoskeletal injury risk. These results support the potential utility of technology-driven approaches to mitigating injury risk.[13]

Similar to BMT, PT during in-service arduous military training courses sees cohorts complete grouped PT sessions, and/or complete lone PT. This additional training can exacerbate the already increased training load experienced on the course and lead to maladaptive responses (eg, blunted training adaptations, increased injury risk and overtraining).[30] While career courses often aim to replicate job demands, it is a snapshot of a potentially arduous career in these operational roles.[28] By understanding the physical demands placed on individuals during these training environments through the serial collection of biomarker data, these data can then inform the development of evidence-based course-specific selection criteria (ie, physical fitness tests), targeted pre-course physical preparation programmes and/or recovery strategies following periods of arduous training to improve course success, reduce injury rates and enhance readiness.

In contrast to conventional forces, many special operations forces have adopted more contemporary high-performance models involving embedded performance specialists such as strength and conditioning coaches, nutritionists, psychologists and physiotherapists; for example, the Tactical Human Performance Optimisation Rapid Rehabilitation and Reconditioning in the US Army Special Forces.[31] In these environments, technologies such as force plates, linear force transducers, accelerometers and continuous thermal load monitoring, are increasingly being used as training aids or sources of biomarker data to facilitate monitoring the high physical and mental loads synonymous with training and operating in this environment.[13 22 28] Similarly, off-the-shelf wearable devices that capture physical training loads, sleep and recovery offer an attractive approach to facilitate improved performance outcomes through the evaluation and adjustment of training practices for this population. However, clarity around the expectations of users' needs to be discussed and consideration given to the intended use of the biomarker data prior to implementation of any monitoring systems. It must also be noted that most commercially available devices have not been validated against 'gold standard' measures and use proprietary algorithms to provide health and performance insights. This is a major concern because inaccurate data may lead to incorrect observations and subsequent decisions regarding personnel management.[32] However, the use of these technologies appears to increase individual's self-awareness of factors influencing their health and performance, which may be sufficient justification for their use if desired behavioural changes occur as a result.

INTERNATIONAL CONGRESS ON SOLDIERS' PHYSICAL PERFORMANCE (ICSPP) PANEL FACILITATED AUDIENCE DISCUSSION

The interest in soldier performance monitoring was illustrated during the 2023 ICSPP. What follows is the synthesis of the facilitated discussion held at the authors thematic session at ICSPP. As such, these reflections highlight the collective appetite for the implementation of soldier performance monitoring by key partners including support staff and end-users. Several questions were posed to the panel, and audience members were encouraged to participate using MentiMeter. The qualitative data (ie, text responses) were analysed to identify common themes across all audience responses; the outcomes of these discussions are summarised below.

With regard to how human performance data could be used to augment soldier performance in the future, there were 27 responses from 25 audience members. Most comments reflected on the ability of this data to inform modifications to training prescription, specifically, the ability to gain insights on a soldiers' training state (ie, readiness or fatigue) and monitor the risk of near- or long-term injury; with the view that this could be achieved at both the individual and group levels, to inform evidence-based interventions. 32 members of the audience voted on what types of data might be important to collect. Data from wearables and subjective measures were ranked equally important (4.3/5), with circulating biomarkers still considered important (3.3/5). Arguably, a current barrier to the collection of circulating biomarkers is the lack of available real-time tests suitable for point-of-care testing.

Irrespective of the context, one of the ongoing challenges with the implementation of serial monitoring is who will be responsible for the collection, synthesis and interpretation of the data and how this will be managed.[33] 25 participants provided 53 text responses to this question. There was consistent support for embedded scientists or researchers, with other suggestions to include PT instructors. It was noted that personal wearable devices that automatically download would help reduce the burden of data collection, and this could be facilitated with a cloud-based dashboard or similar for commanders.

Key considerations included the need for user buy-in and usable outputs. Ultimately, the system needs to be efficient, with a timely data workflow to inform decision-making. Overwhelmingly, the group indicated that a dashboard was the best way for this data to be shared and support decision-making.

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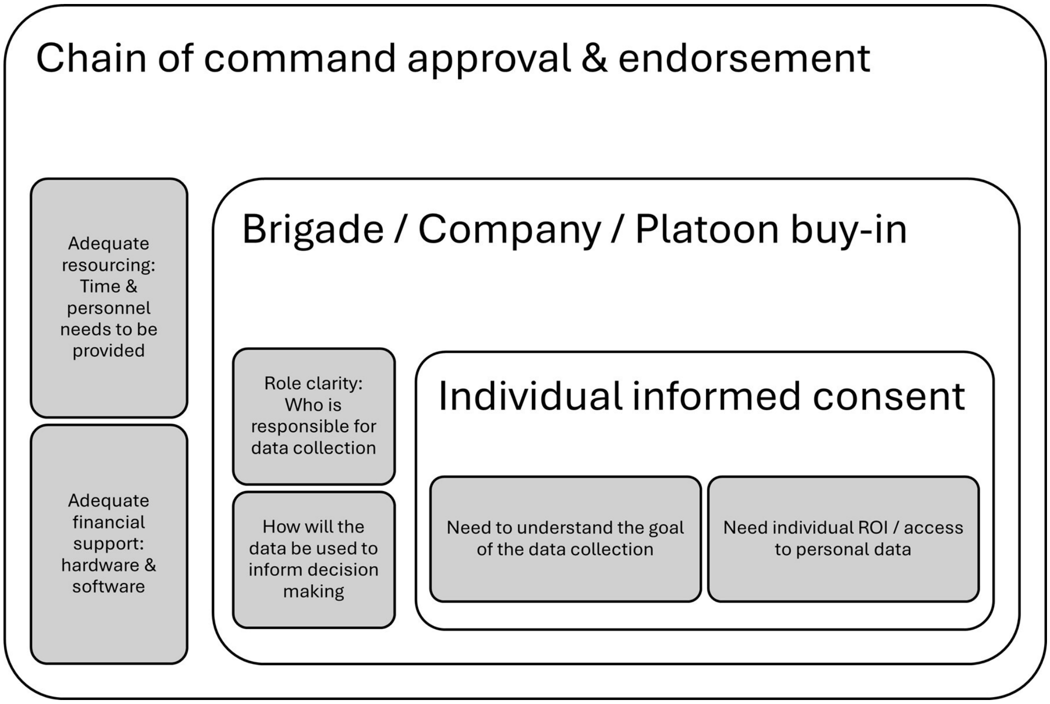

Figure 1 Operational considerations for the implementation of soldier performance monitoring.

Using infographics to provide higher-level summaries for both individual soldiers and group mean data for commanders and other users was recommended. Suggestions were also made for local and/or international databases with standardised measures; however, a range of ethical and security considerations would need to be resolved before this could occur. Indeed, privacy was one of the key challenges raised with regard to the collection of health and human performance data and an awareness of any relevant legislation related to this. Consideration is needed regarding the development of standard operating procedures to ensure consistency around data access and information use, specifically how will the data be stored and what security measures will be required to protect potentially sensitive health data. Other barriers identified included the additional burden or time impost and the need for resources to interpret the data to provide useful/usable insights.

ACTIONABLE INSIGHTS AND FUTURE RESEARCH DIRECTIONS

In synthesising the available literature and through the lens of the discussions summarised above, a conceptual framework is proposed to assist end-users in considering the factors that may be involved in the implementation of future soldier performance monitoring (Figure 1). Specific questions or pertinent points are posed at each level of this model to assist the decision-making process. Arguably this framework is overly simplistic; however, the authors hope that it provides some guidance to both researchers and practitioners working in this space.

Fundamentally, the operational capability of a military organisation is predicated on the psycho-physiological status of its workforce. While this is self-evident for land forces and, in particular, those in combat arms roles and special operations forces, this equally applies to those in the air and maritime domains, which may have lower physical demands but considerable cognitive demands. Additional stressors such as disrupted sleep further challenge individual resilience and occupational performance. That being the case, there are many lessons from both sports and medicine that military organisations can adopt to better manage the workforce and enhance organisational capability. However, the biomarkers of most relevance and/or impact are likely to vary between settings, and for military organisations to realise the potential benefits of biomarker monitoring, they must 'partner-in-depth' with researchers to identify candidate markers that can meaningfully inform decision-making processes. Conversely, a challenge for researchers is to better understand the military context and the specific use case for the application of biomarkers and/or a technology overlay. For biomarker monitoring to have an enduring impact, the research community needs to progress the large body of association-based research to assess the predictive accuracy of biomarkers with more veracity (eg, sensitivity and specificity). While understanding the associations between physical and psycho- physiological characteristics and risk profiles can potentially help to inform recruiting standards and training interventions (eg, preconditioning programmes, remedial programmes), to date the likelihood of an adverse event associated with risk thresholds has not shown better predictive ability than guessing. For military organisations to invest in staff, infrastructure and systems, they must be confident that the biomarker/s represents a materiel improvement over an existing practice.

CONCLUSION

This review has provided the rationale, practical implications and applications for the current state-of-the-science biomarker assessment illustrating the utility of the monitoring of physiological and psychological stressors during military training. The ultimate success for biomarker-focused research and development efforts will be the buy-in and benefit realised by military stakeholders and leaders. The approaches must use technology that is feasible, acceptable and suitable, and the return on investment must be significant and supported by science. Continued efforts should leverage the most feasible, acceptable and suitable technologies and the most relevant biomarkers for military readiness and resilience. A dashboard with a user interface that

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collects biomarker data in a field-expedient manner and can provide real-time/near real-time data will be most valuable for military application and use.

However, there are still considerable barriers associated with the systematic monitoring of soldiers en masse. Ignoring technological considerations (eg, validity, reliability, available measures), the authors suggest that it would be helpful for researchers to reach a consensus on a minimum suite of measures that can be used to make meaningful inferences about health and performance. Noting that while many variables are associated with potentially relevant indices of health or performance, more needs to be done to ensure that we can confidently predict outcomes with sufficient strength and accuracy. Further, we suggest that military organisations need to consider how they can embrace more contemporary data-informed processes to support personnel management.[30] Increased data gathered from soldiers will give us more detailed 'readiness scores', which may be helpful during training and deployments.

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