Five-day evaluation of the acceptability and comfort of wearable technology at four anatomical locations during military training

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ABSTRACT

Introduction Wearable sensor technologies enable Defence to optimise human performance, remotely identify physiological abnormalities and enhance medical support. Maximising the acceptability of devices will ensure they are worn alongside other equipment. This study assessed the acceptability and comfort of four devices at different anatomical locations during military training.

Method A cross-sectional pilot study during a live firing infantry exercise or adventurous training assessed four anatomical locations concurrently over 5 days: finger, wrist, upper arm and chest. Participants rated comfort, acceptability and preference using a standardised questionnaire after 12 hours and 5 days of wear.

Results Twenty-one regular British Army personnel soldiers participated, aged 24.4 (4.3) years. The upper arm location received the highest rating by participants for comfort, followed in order by wrist, finger and chest ($p=0.002$, $X^2=40.0$). The finger was most commonly identified as uncomfortable during specific activities (76%), followed by chest (48%), wrist (23%) and upper arm devices (14%). There was no significant difference in participant confidence in the devices to collect data or allow movement, but there was a trend towards greater confidence in upper arm and wrist locations to stay in position than the others ($p=0.059$, $X^2=28.0$). After 5 days of wear, 43% of participants said they preferred the upper arm for comfort, followed by wrist (36%), finger (24%) and chest (10%). 73% and 71% would wear the wrist and upper arm devices on deployed operations, compared with 29% and 24% for chest and finger devices, respectively.

Conclusion The upper arm location offered greater acceptability and comfort than finger, wrist or chest locations. It is essential to consider such findings from occupationally relevant settings when selecting wearable technology. A larger service evaluation in diverse settings is recommended to guide the choice of the most acceptable wearable devices across different equipment, roles and environments.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Harnessing wearable technology can benefit healthcare and Defence, following rapid recent developments in hardware and software.
⇒ Establishing acceptability and comfort is an essential precursor to using wearable devices, especially in military settings.

WHAT THIS STUDY ADDS

⇒ This was the first study to assess wearable technology at different locations over 5 days in an occupationally relevant military setting.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The greatest comfort and acceptability rated the upper arm location, followed in order by wrist, finger and chest.

INTRODUCTION

The future character of conflict is projected to present challenges to military medicine as the operating environments become more complex and diverse.[1] Military medical services need to be able to operate in an increasingly austere, expeditionary environment.[2] The UK's aspiration for an agile force capable of enhanced reach with reduced supporting mass increases the likelihood of prolonged timelines for medical care, requiring clinicians to manage patients in remote environments for longer, potentially with minimal support or supervision.[3 4] Wearable physiological monitoring putatively offers an enabler to expeditionary medicine, supporting clinicians to make timely, data-driven decisions at reach supported by the firm base.[5]

Wearable devices are used to measure movement and physiological parameters including HR and HR variability, skin temperature, RR and blood oxygen saturation.[2] Chest, arm and wrist-based HR monitors have demonstrated validity in military settings versus ECG.[6 7] Accelerometers tend to under-report energy expenditure, regardless of anatomical location.[6 8 9] Proprietary software claims to derive a diverse range of militarily or clinically relevant outcomes from wearable technology data, including training status, sleep quality, fitness, stress levels and ovulation.[10] Some have been validated for remote clinical use, for example, to detect arrhythmias.[11] Emerging uses include early detection of viral respiratory tract infection from HR changes[12] and identification of individuals at risk of heat injury from changes in HR and gait.[13]

The optimal employment of wearable technology for military personnel is contingent on high user acceptability. Devices must be comfortable enough not to distract the serviceperson, interoperable with their other equipment, and avoid hindering any of the multiplicity of technical and manual roles they undertake. Beeler *et al* assessed the comfort of wrist, arm, chest and hip devices in 27 male Swiss Army recruits over 12 hours of a typical working day during basic training.[14] The upper arm location was

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preferred, although all were positively rated. The application of these findings for trained soldiers undergoing high levels of physical activity while using typical military equipment is unknown. Therefore, we aimed to explore the preference of four common anatomical locations of monitoring devices (finger, wrist, upper arm and chest), over a 5-day period, in trained and equipped military personnel undergoing generalisable activities.

METHOD

Participants and setting

We undertook a service evaluation among regular soldiers and officers in the British Army. This was a convenience sample; no power calculation was undertaken. We aimed to capture personnel undergoing adventurous training and an armoured infantry exercise, since these represent relatively physically active and technical roles, interacting with equipment (eg, carrying rucksacks over long distances, or using weapons and armoured vehicles under manoeuvres) which could be expected to test the user acceptability of wearables. We therefore invited participants who were regular Army personnel conducting either Summer Mountain Foundation (MF) or a routine infantry exercise (EX).

The MF is a military adventurous training course, which involves carrying rucksacks over mountainous terrain in Snowdonia, UK for 5 days in September 2021. The assessment period took place over the first 5 days, when the MF cohort was carrying out daily hikes carrying rucksacks and navigation training. EX took place in Otterburn, UK, in October–November 2021, conducted on and off armoured vehicles and lasted 10 days. The EX cohort evaluation took place over the first 5 days, during a live firing range package, which involved handling a variety of weapons, entering and exiting vehicles, and living in field conditions sleeping in shelters next to vehicles.

Devices

We selected four devices at different anatomical locations which were reliable, cost-effective, available, already in use within UK Defence and do not geolocate (table 1). The Oura Ring Heritage (Oura Ring Oy, Oulu, Finland) uses photoplethysmography (PPG) as well as temperature and movement sensors and promoted as a sleep assessment tool.[15] The Oura Ring has been used in recent military research[16] and devices were available to the investigators following a study in the British Army. The GENEActiv (Activinsights, Cambridge, UK) measures movement, temperature and light, and has been extensively used in military studies[9 17–19] and has demonstrated better reliability than other commercial accelerometers.[9 19 20] While not technically a physiological monitor, it is of typical size, weight and form to watch-type HR monitors and, moreover, was already being used in a concurrent research study in the EX cohort. The Polar H10 chest strap (POLAR Electro, Kempele, Finland) uses ECG to detect R-R interval which is considered a gold standard.[21] The other common anatomical location for physiological sensors is the upper arm. The Polar Verity Sense uses PPG to detect HR and has demonstrated excellent reliability against the H10.[7] Both devices had been used in recent military research by our department. The device characteristics are shown in table 1.

Procedure

Wrist, upper arm, finger and chest devices were worn concurrently by each participant. Participants were given the devices and then advised on how to wear them correctly and charge them. All participants were asked to wear the devices from the first day of the study and the devices were collected 5 days later.

Oura rings were sized using an Oura sizing kit for the ring or middle finger (participant preferences), according to manufacturer's instructions. The Oura Ring, GENEActiv and Polar Verity Sense were positioned on the non-dominant middle or ring finger, wrist and upper arm, respectively. A single investigator confirmed that each device was placed correctly, and participants were reminded to keep devices clean and dry throughout the evaluation to minimise risk of irritation to the skin.

Questionnaire

A questionnaire assessing comfort and impact on performance was conducted at the end of 12 hours of wear, based on questions used by Beeler *et al*[14] and Tharion *et al*.[22] Participants were asked to rate the comfort of each device on a 7-point scale ranging from very uncomfortable to very comfortable. Participants were asked if they felt any device was uncomfortable during specific activities ('yes' or 'no', followed by free-text box), to rate how each device impacted on activity that day (extremely negative to no negative impact), and three questions on their confidence in the device to collect data, to stay in the correct position and to allow free movement (7-point scale from not very confident to very confident). Binary 'yes/no' questions assessed whether each device changed position, and whether participants would voluntarily wear the device for 8 hours or more or for 5 days or more.

Participants completed three further questions at the end of 5 days of wear: 'which device did you find most comfortable over the last 4 days?' (rating the devices from first to fourth place in order of comfort)', followed by two yes/no questions: 'would you wear the device for a week when deployed on operations?' and 'would you wear the device for a week when working in a remote location (not on operations)?'.

Table 1 Device characteristics

Device	Location worn	Sensor	Weight	Data interface	Battery life/ power source	Durability	Time worn
Oura Ring (Oura Health, Finland)	Middle or ring finger	Temperature, HR (PPG), triaxial accelerometry	8 g	Proprietary UI only	9 days	−10 to +54 C, WR100	Continuous except when showering
GENEActiv (Activinsights, UK)	Wrist	Triaxial accelerometry, temperature, light	30 g	Open data format (unfiltered), no UI	Up to 30 days	+5 to +40 C, WR10	Continuous
Polar H10 (Polar, Finland)	Chest strap	HR (ECG)	60 g	Open data format, proprietary UI	400 hours (disposable 3V lithium battery)	−10 to +50 C, WR30	Continuous except when showering
Polar Verity Sense (Polar, Finland)	Upper arm band	HR (PPG)	19 g	Open data format, proprietary UI	30 hours	−20 to +60 C, WR50	Continuous except when showering and charging

PPG, photoplethysmography; UI, user interface; WR, water resistant.

Table 2 Day 1 questionnaire (with reference to 12 hours of wear time)

Variable	Scale	Oura Ring (finger)	GENEActiv (wrist)	Polar H10 (chest)	Polar Verity Sense (upper arm)	
Wearing comfort	1–7	3.6 (1.3)	4.6 (1.8)	3.0 (1.8)	5.0 (1.9)	P=0.002, X^2=40.0
Uncomfortable during specific activities	% yes	76	23	48	14	
Which activities?	Free text	Day-to-day activities, getting caught on bags (2), wearing gloves (2), cycling, holding poles (2), grabbing things out of my bag, getting caught on different objects, catches on things too easily, feels large, running with my weapon system, handling weapon, when doing nothing and sat around you notice the ring, any activity using hands	Same as the ring (day-to-day activities), lifting objects	Uncomfortable in general, walking (2), felt restricted, restrictive and uncomfortable, moving body	None were specified	
Impact on activity today	1–4	3.0 (0.9)	3.6 (0.9)	2.7 (1.1)	3.6 (0.7)	P=0.045 X^2=17.2
Confidence in device to collect data	1–7	5.0 (1.7)	5.3 (1.9)	4.6 (1.7)	5.4 (1.7)	P=0.9
Confidence in device to stay in position	1–7	4.6 (1.8)	5.7 (1.0)	4.5 (2.0)	5.8 (1.4)	P=0.059 X^2=28.0
Confidence to move freely	1–7	4.8 (1.9)	6.0 (1.5)	4.1 (2.2)	6.0 (1.4)	P=0.15 X^2=24.0
Did the device change position?	% yes	48	33	61	28	
Wear the device for 8 hours or more?	% yes	48	48	39	83	
Wear the device for 5 days or more?	% yes	28	67	33	78	

Scale data are expressed as mean (SD).
For the specific activities identified, see main text.

The questions were reviewed by non-clinical British Army soldiers and officers for comprehension and understanding of the target audience. Participants were asked to complete questionnaires each evening, using REDCap online software (https://www.project-redcap.org/). An iPad (Apple, USA) was provided for participants who did not have access to a smart phone. Participants who were unable to tolerate a device remained in the evaluation and were asked to record the reason they removed the device via the questionnaire.

Statistical analysis

Data were assessed visually for normality before parametric statistics were used. Mean and SDs are reported. Likert scale data were compared using χ^2 tests. Statistical analysis was conducted using SPSS for Mac V.29.0.1 (IBM). Alpha was set at 0.05.

RESULTS

Participants

Twenty-one participants completed the evaluation (5 in MF, 16 in EX), with mean age 24.4 (SD 4.3, range 21.0–31.2) years. Their ranks were private (9, 43%), lance corporal (6, 29%), corporal (1, 5%), sergeant (1, 5%), second lieutenant (1, 5%) and major (3, 14%). One participant (5%, in EX cohort) was female.

Results of the questionnaire conducted on day 1 are shown in table 2. Of the four devices, the Polar Verity Sense was rated the most comfortable, followed in order by GENEActiv, Oura Ring and Polar H10. The device most participants found uncomfortable during specific activities was the Oura Ring (particularly, activity using hands), followed in order by Polar H10, GENEActiv and Polar Verity Sense. The activities are specified in table 2. The Polar H10 was identified to be the least impactful on daily activity. No significant differences were seen between devices in confidence in the device's data collection, to stay in position or to allow free movement. The Polar H10 was most frequently reported to change position, followed in order by Oura Ring, GENEActiv and Polar Verity Sense. A majority of participants said they would wear the Polar Verity Sense for 8 hours or 5 days or more, or the GENEActiv for 5 days or more.

The second questionnaire is shown in table 3. After 5 days of wear, the Polar Verity Sense was the preferred device for comfort, with just under half of participants placing it first choice, followed by GENEActiv. The majority of respondents would wear the Polar Verity Sense or GENEActiv on operations or in remote locations. Free-text comments highlighted that the ring was found to be too big, the Polar H10 was sometimes uncomfortable, and GENEActiv and Polar Verity Sense were comfortable and discrete; however, there was a diversity of opinion expressed on most of the devices.

DISCUSSION

This cross-sectional evaluation of wearable technology acceptability during regular British Army personnel found that an upper arm device was preferable over 12 hours, followed in order by a wrist device, ring device and chest device. This was the first study to assess wear time of 5 days in the military. Findings after 5 days were consistent with those after 12 hours: the majority of participants said they would prefer an upper arm or wrist-based device over a ring or chest strap. Anatomical location may be a greater consideration than size or weight, since the

Table 3 Day 5 questionnaire (with reference to 5 days of wear time)

	Order of preference for comfort	Would wear on operations (% yes)	Would wear in a remote location (% yes)	Free-text comments
Oura Ring (finger)		24	43	Ring is too big/bulky (2)
First choice	24%			Really comfortable (1)
Second choice	19%			The ring was quite uncomfortable
Third choice	38%			Ring device needs to be slimmed down on the sides so as to not interfere with putting fingers together
Fourth choice	19%			The ring was not charged, or I could not connect
GENEActiv (wrist)		73	73	Doesn't tell the time (2)
First choice	36%			The best because it's easy to access to take on and off
Second choice	57%			The most comfortable as you don't have to put other equipment over the top of it
Third choice	7%			When exercising it doesn't retain sweat like some of the other band devices
Fourth choice	0%			Out of the way compared with something like the ring
Polar H10 (chest)		29	29	Wearing the chest strap under body armour quite uncomfortable
First choice	10%			Really comfortable
Second choice	24%			Needs shoulder straps to stop the device falling down
Third choice	24%			Only any good when doing fitness in t-shirt and shorts so I believe not practical for military roles
Fourth choice	43%			
Polar Verity Sense (upper arm)		71	81	Most comfortable after a few hours of wearing
First choice	43%			Less comfortable during running
Second choice	19%			
Third choice	29%			
Fourth choice	10%			
General comments				All moderately comfortable
				The watch and ring are practical throughout working day doing everyday job
				No comments (10 respondents, 48%)

smallest and lightest device (Oura Ring, 9 g) was not the most widely accepted. This was also the first study to assess wearable technology comfort alongside military personal protective equipment, live weapon handling or undertaking adventurous training. Respondents identified a number of areas in which devices impeded activity, particularly the ring device getting caught and interfering with gloves and weapons and the chest strap proving restrictive. This perhaps explains why only 24% and 29% of participants said they would wear the Oura Ring and H10 chest strap on operations, respectively, in stark contrast to the upper arm and wrist-based devices (both over 70%). Technical and manual activities like vehicle and weapon handling are common in the military, so these findings are helpful for military researchers and clinicians considering which of the plethora of wearable technologies to employ in future.

Our findings are consistent with data from the Swiss Army[14] and others[23] who found an upper arm device was more comfortable than waist, wrist or chest devices over 12 hours. Given the manual nature of soldiering one, we anticipated that a ring device would not be tolerated well. It is perhaps surprising however that after 12 hours, the 'impact on activity today' was relatively low (mean score 3.0 out of 5), 48% of participants said they would wear the device for over 8 hours and after 5 days 24% rated it first in terms of comfort. These data underline the significant interindividual variability in perceptions of comfort. A chest-worn strap, which is frequently worn during physical activity and commonly used by elite athletes, was the least popular device after 5 days of wear, as has been reported elsewhere.[14 23] While chest strap-derived ECG is a gold standard in HR detection, the ergonomics might render the device completely ineffective if the majority of personnel do not wear it.

The free-text responses highlighted that acceptability may have been improved by devices providing more perceived usefulness to participants, for example, by telling the time. A similar observation was also made in Swiss recruits,[14] and in civilian adults aged over 50 years.[24]

In future, wearable technology is likely to become smaller, more capable and discrete. For example, Smith *et al* trialled a bespoke sensor measuring sweat electrolytes, single-lead ECG and temperature in a bra strap, in six female Army personnel crossing Antarctica.[25] They were successful in demonstrating the sensor's ability to assess physiological data remotely and transmit this to the UK, and good user acceptability. While not all data were captured, this demonstrated a proof of concept and possible direction of travel for future devices.

A wider evaluation of device acceptability is necessary to guide Defence uptake of wearables and should take a more granular approach to the interaction between wearables and military activity, equipment and environments. It is unlikely that one device will suit all. A database of devices and their acceptability for certain roles would be a key enabler to investment in this area. Correct choice of device is particularly important for arduous environments (eg, ground close combat, high altitude, heat and cold), where comfort and physiology are strained, making device acceptability (and the data they collect) paramount.

The strengths of this study are the occupationally relevant setting and duration of assessment, which was 4.5 days longer than previous military studies, and the selection of relevant anatomical locations for physiological monitoring devices. The design was intentionally simple (one device per anatomical location) to allow longer assessment duration and avoid the burden of multiple devices, which could have affected previous studies.[8 14 24] Finally, the questionnaire comprised items which have already been used in other studies of soldiers, allowing comparisons. Limitations include the small sample size and lack of female participants; future work should address the gender gap in particular. We were unable to compare EX and MF cohorts due to insufficient statistical power. The GENEActiv 'watch' is not a physiological monitor and was designed as an epidemiology research tool. However, it was used here because it was of similar size, weight and form to many activity watches. While the findings are generalisable, future studies should use watches with the kind of functionality likely to be employed in practice. Finally, it is possible that soldiers with a particular interest in wearable technology were more likely to volunteer for the study, which could have led to inclusion bias and a sample of personnel who are not representative of the wider military. Future studies should seek to address this by targeting broader service populations and establishing prior use of wearables.

CONCLUSION

Wearable physiological sensors and analytical approaches are emerging rapidly, and present an opportunity for Defence to understand, optimise and enhance human performance, and identify illness in remote and austere locations. However, if a device is not tolerated by the end user, no data will be collected. Our study identified poor acceptability of ring and chest strap devices during live firing infantry and mountaineering training, with participants stating they would be unlikely to endure these devices for 5 days or longer, compared with wrist and upper arm devices. Around 70% said they would wear any wearable technology on operations (upper arm or wrist devices) and 80% in a remote environment (wrist device). These findings are important to help inform the significant investment required for wearable technology in Defence. However, our results are preliminary and demonstrate wide variance in comfort and acceptability. More robust and role-specific evaluations are required prior to widespread rollout of wearable technology, since devices are unlikely to be used if they are uncomfortable or interfere with military activity.

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