

# Historical and Current Online Monitoring of Vital Parameters of Persons on Duty in Extreme Environments

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## Abstract

Collecting and recording physiological parameters and forwarding this data via telemedicine or remote surveys may significantly increase the health and safety of people working under extreme environmental conditions, like firefighters, mountain rescuers, disaster control employees, military personnel, etc. First, ruggedized systems, as small, lightweight, and flexible as possible, are needed to optimize the goal of increasing occupational health and safety of persons at risk and maximizing their performance during missions. Previous systems could only record a minimal number of parameters, and a few could forward the data online to return information to the user. Therefore, an extension of existing systems is required to record several meaningful, valid, and reliable physiological parameters synchronized. This review highlights this problem and gives an overview of the historical development and the actual status of the physiological systems available. In the end, a proven and promising solution is presented that can solve the problem and allow people to work more safely in extreme environments in the future.

**Keywords:** Performance; Prevention; Online monitoring; Smart textiles; Telemedicine; E-health

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## Introduction

Over 60 % of the world's population performs physical activity for less than 30 minutes per week. Well-known consequences of health-damaging everyday habits are obesity, decreasing performance, capability/resilience, and the occurrence of chronic secondary diseases [1-3]. This development is also reflected in the candidate selection or day-to-day military duties. However, health and fitness are currently the most discussed topics in society when lifestyle is concerned. Many manufacturers try to implement this new idea of all-day measuring of physiological data on the commercial market in order to show the users their activities so that one can deduce how to improve their nutrition and physical activity, including the sleep-wake rhythm in short, how to improve one entire behavior (consumer-oriented fitness and health offers) in the future. While some systems may stay on

standby until needed (e.g., pacemakers that detect arrhythmia), other data should be recorded permanently so that the user or a surveying person in a remote setting is informed online and can change the behavior in real-time [4]. The digitization of the health sector virtually moves from bottom to top. The consumers set the plan, with the increased health consciousness being the primary reason for this trend. More than 100,000 applications from the health and fitness areas are on the market and can be displayed on a smartphone [5]. In recent years, the so-called wearables (mainly as bracelets or integrated into a watch) were placed on the market. They can be operated autonomously or connected to a smartphone [6]. Wearables use simple physiological parameters (movement, heart rate) and convert them into distances covered and calories consumed utilizing specific algorithms. Thus, fitness apps and wearables constitute the interface between leisure time and health offers and are currently the growth engine of

the e-health market [7]. Previously, these opportunities were only available to chronically sick persons and top athletes [8-10]. Meanwhile, smartphones are even scheduled for diagnostic purposes, which is critical from a physician's point of view because it will be possible for amateurs to make examinations, which will not be evidence-based medicine [11,12].

In extreme environments where it may be very difficult or even impossible to provide medical assistance in the case of an emergency, telemedical systems that allow remote control of the person(s) are of particular interest. Such a setting may significantly increase health, safety, and performance, not only in the military but also in a civilian setting. Examples are firefighters who must handle extreme heat and the risk of hyperthermia or mountain rescuers who have to work in the cold, sometimes extremely cold (icy), environments and face rugged terrain, hypoxia, helicopter noise, and other stressors [13-17]. However, to increase health and safety in such situations, real-time monitoring is needed in contrast to the alarm systems mentioned above [18-23].

## Literature Review

### High responsible occupational fields in rugged environments

In aviation, various environmental and aircraft type-related factors impact the human organism, which is not tailored to these conditions from an evolutionary perspective. The said factors must be coped with either behavioral measures or technical solutions. Pilots and flying personnel are significantly affected by stress, especially when the military flight service is concerned [24,25]. Considering the job of a pilot acting in extreme flights as the operator of high-performance and agile military aircraft is characterized by high physical stress and mental and neuropsychological strain within the human-machine system [26]. This can have acute and chronic effects, thus also resulting in creeping exhaustion. And the stressors cannot be denied, not only in the actual situation but even during training [27-29]. Due to the high responsibility in this occupational field, a decline in or loss of operational capability constitutes an increased risk for the persons themselves and others (e.g., passenger transport). In addition to person-specific factors, the respective environmental conditions, which still need to be considered in most of the monitoring performed so far, are essential when evaluating stress situations where the different factors often coincide. There is a high physical and increasingly psychological, psychophysiological, and cognitive stress not only in jet aviation but also in modern fixed-wing aircraft used for transport and in helicopters [30-32]. This trend is additionally enhanced by an ever-increasing use of equipment (e.g., night vision goggles. Unmanned air vehicle pilots, who primarily have to cope with mental stress, must be addressed entirely [32-35]. Performing regular medical assessments and maintaining the fitness status through appropriate programs makes preserving and ensuring flight operations possible, but more is needed from today's point of view [36].

Therefore, physiological monitoring would be desirable for

various reasons. Literature research is only very fruitful from Russian publications [37]. In the library of the former Institute of Aviation Medicine (Königsbrück, German abbreviation: ILM), however, reports and treatises from the former East German National People's Army (Nationale Volksarmee, German abbreviation: NVA) could be found [38]. The paper stated: "The progressive development of aviation technology imposes very high requirements on flying personnel's psychological and physical performance capability" [39]. Thus, the responsibility of aviation medicine increases as well. In order to meet this responsibility, they must know the stress affecting flying personnel during flight and the response reactions triggered by the human organism. Undoubtedly, these factors can be determined most effectively utilizing corresponding examinations performed during flight combat training". Besides this, data are scarce, focusing on telemetric ECG recordings during flights [40-42]. The requirements imposed on the bio telemetric complex, i.e., telemeasuring of biophysical or physiological parameters, during which signal transmission is partly affected using radio or carrier frequency procedures, must include the following characteristics [43]:

- No impairment of flight safety and the activities of flying personnel
- Small dimensions and low weight
- No changes concerning aircraft engineering (except for attachment of the transmitter and the antenna as well as the power supply from the aircraft electrical system for the transmitter)
- Low operating and servicing effort
- No disturbing influences on airborne equipment and no corresponding disturbances of the biotelemetry device
- High stability concerning flight and environmental factors
- Relatively high transmitter power to bridge long distances, with high constancy of the transmission frequency

These aspects are still relevant today and serve as a basis for developing such systems or have already been implemented in the commercial wearables mentioned above. In the concluding remark, the biotelemetry device used is described as valid and operational. The expected assumptions and requirements have been fulfilled so that it has been possible to collect valuable aeromedical data for the purpose of evaluation and can be used as a monitoring system.

### Military operation's physiological monitoring

For decades, the American military sector (e.g., U.S. Army Research Institute of Environmental Medicine USARIEM) has been working on a technology to support soldiers medically in the theatre of operations or during training. The Future Force Warrior, formerly called Objective Force Warrior, was part of the Future Combat System project of the United States Army [44]. It enabled infantry members to participate in the Global Information Grid. It was designed to increase soldiers' survivability, robustness,

and networkability on the future battlefield, but it was stopped for political reasons. This program also included the so-called Warfighter Physiological Status Monitor (WPSM) subsystem [45]. The WPSM had sensors integrated into a suit to monitor each individual soldier's physiological and medical condition (pulse, body temperature, blood pressure, respiration, stress, and posture). If necessary, the WPSM could transfer the corresponding data to the military leaders or the medical personnel when the respective soldier was tired, wounded, or even fatally hit and should calculate a soldier's survival probability during combat [46]. But this seems to be more an evaluation and an estimation of military combat efficiency, not a caring approach. Work continues on parts of the former program, now called Brigade Combat Team Modernization. The project is subdivided into subareas, including the Early Infantry Brigade Combat Team Capability Package. The field units will be equipped with a Network Integration Kit to permit network-centric warfare. Later, additional elements of the Follow-On Incremental Capabilities are scheduled to supplement the Global Information Grid network; this program was planned to be operational by 2020 [47]. Due to their orientation towards physical performance optimization, cognitive performance, decision-making, and judgment, deployment health protection, heat and cold stress, high altitude, and pathophysiology, the two latter aspects, in particular, have determined the focal points. During their missions, the Americans mainly focus on heat stress and the significant failure rates that go with it. Due to these data on heat sicknesses or heat death, a parameter measurement has been introduced into the U.S. military, where intensive work has been performed (Thermal and Mountain Medicine, USARIEM).

In Europe, this approach has yet to attract much attention. Within the scope of a European Defence Agency project, it was attempted from 2010 to develop a new kind of biomonitoring and use it for military purposes, all under the slogan "Soldier Modernization Harmonization–Biosensor Information Demonstrator" [48]. All in all, it must be noted that this concept did not work, particularly concerning data transfer. Within the Bundeswehr, the "Future Infantryman/Infantrywoman" (German abbreviation: IdZ) project is the German modernization program for the infantry, which is affected in NATO under the slogan "Future Soldier" and serves the purpose of improving the "personal combat equipment of infantry in the Bundeswehr" [49]. The manufacturer's overall system responsibility lies with Rheinmetall Defence Electronics, based in Bremen. The current system status (2021) is IdZ-4, which was delivered to the Bundeswehr under the designation "Gladius" (implementation phase 2) in 2013. Although many components for the infantryman/infantrywoman have been incorporated into this system or are available, there is no mature physiological monitoring. However, it is obligatory for the employer and the executive personnel responsible to fully comply with their legally imposed overall care responsibility [50].

In contrast, telemedicine in the Bundeswehr already began before the year 2000 and is still employed successfully [51]. It is primarily used for transferring X-ray data and on sea-based units and medical facilities during missions abroad. The main purpose of telemedicine is to evaluate symptoms and abnormalities by

a medical specialist located in the home country, who can then help initiate the ensuing therapy or make recommendations. As early as 1997, such a system was established in the Bundeswehr and has been extended until now [52].

### Infield physiological sensor applications

In everyday clinical life, patients' instrumentation with sensors is a routine procedure [53,54]. The sensors used are well-established and function properly, and the measuring points are clearly defined and validated. When using sensors outside a clinic, it is vital that they have a high degree of safety, thus permitting valuable measurements. Sensors used in the field must be non-invasive mandatorily because the "carrier" does not accept any sensor insertion in most cases (compliance). Ideally, the sensors must not strain or disturb the "carrier"; it is best when they either do not feel the sensor at all or quickly forget it after the application [55]. Any disturbance could negatively affect the person concerned, resulting in additional physical and/or psychological stress (pain, mobility limitations, being permanently reminded of the sensor, etc.). If the sensor is an additional stressor, it adversely affects the measurement results and may negatively influence the interpretation [56].

Another consequence is that the actual measuring point may no longer be identical to the validated measuring point. It is possible to measure something almost anywhere on the human body, but the result and the interpretation are significantly affected by the measuring point. When it comes to evaluating an ECG, the places where it is derived are clearly defined and cannot be deviated from, particularly in diagnostics. However, they may be changed in the field, and a diagnostic interpretation is questionable or excluded. As far as respiration is concerned, there are limitations when it is intended to measure respiratory gases. Although it is indirectly possible to measure these gases at points on the skin (e.g., peripheral oxygen saturation), it must always be understood that the results of these measurements may differ from the actual values. As described in the introduction, wearables are thus usable to a minimal extent only. In most cases, they can merely show a trend, whereas the actual measurements should subsequently be performed using other, better sensors.

However, this sensor version is used sparingly; ingestible sensors have also been developed [57,58]. In the course of the corresponding procedure, a sensor as small as possible is ingested and will be excreted again, with the average intestinal transit time amounting to 3 days. Reusing such sensors is not recommended for hygienic reasons, making continuous measuring very expensive. So far, this method has only been possible to record very few parameters. These parameters are basically limited to temperature measurement, nevertheless, it has been tried to detect heart and lung parameters [59,60]. From a physiological point of view, such data must always be treated with caution. Thus, the dynamic measuring of parameters in a moving individual plays a particular part in the evaluation. Additional methods would include implantable sensors, which are primarily used in animals [61]. Such sensors can technically be applied in humans, but there are significant ethical concerns regarding their

application in healthy humans; however, these sensors already have clinical use [62].

### Mobile medical terminal wearables

Commercially available measuring instruments are often limited, but only one parameter can display individual measurements [63]. This is due mainly to the fact that an increase in parameters would considerably enhance the size of the system, which would thus not be attractive for the wearer any longer (mobility) [64]. In addition, an increase in the number of sensors makes instrumenting relatively comprehensive, negatively affecting user compliance and is also a disadvantage in extreme environments [65].

**POLAR®:** Beginning with the probably best-known solution, the POLAR® watch, a product offering monitoring via heart rate measurement, is available. Many customers have found this type of monitoring in popular sports, i.e., in amateur and semi-professional areas [66]. In long-distance track races, which are part of popular sports, the heart rate is recorded through a watch, albeit not 1:1, but in an averaged way to compensate for artifacts. This solution also offers GPS/GALILEO for the purpose of position determination. In connection with a smartphone, this can also be used for training on running tracks. In addition, the associated software promises lifestyle interpretation and a comprehensive physiological evaluation. From a scientific point of view, it hardly seems to be possible to make an evaluation and a valid statement based on one parameter. Thus, this monitoring type is obviously not suited for performing precise tracking with high requirements on the data. A heart variance analysis cannot be achieved by averaging the said data. Beat-to-beat data output is almost impossible without disturbances. The recording of this physiological parameter would be desirable, however, because it has been found that there is a measurable synchronization of the heart and breathing rhythms [67]. But the balance between these two rhythms disappears when an increased release of stress hormones accompanies reactions like stress, anger, or anxiety. In behavior therapy-oriented psychotherapy, the heart rate variability feedback has been used for quite some time in the form of coaching or a complementary medicine method. Studies in the USA show that this can positively influence depression, cardiac diseases, asthma, anxiety disorders, and sleeplessness [68]. These parameters would thus be an essential factor when employing military personnel.

**Vitaport:** The Vitaport-4 system reaches a somewhat more professional level [69]. According to the manufacturer, this portable recorder offers excellent recording quality and optimum convenience for the person to be measured during the EEG or PSG recordings. Due to the parameters, however, the device manufactured and marketed by the Dutch Temec Technologies B.V. company is only suitable for some areas requiring soldiers or flying personnel. The software offered makes some evaluations, but the display on a screen is impossible. Therefore, subsequent evaluation can be performed only. However, this is not suited for the area of application described above.

**Sense Wear:** Another device on the market is the Sense Wear® an

existing armband version [70,71]. The upper arm version is suited for the scientific level, whereas the watch has been produced for the commercial market. The data can be evaluated via Bluetooth or LAN, and the software calculates different results, which are difficult to interpret for an amateur. The following parameters can be recorded: Active energy expenditure, energy expenditure at rest, metabolic units, the overall number of steps, duration of physical activity, and sleep duration and activity. The device belongs to the so-called actometers, which can measure movement data non-invasively. Since the 1980s, actometers have also been used for evaluating human sleep [72]. Studies performed in young, healthy test persons comparing actimetry and polysomnography (PSG) concerning sleep data validation showed conformance of 91-93% [73]. This device is relatively inexpensive and comparatively uncomplicated. It is only suited for the parameters and cannot cover other required physiological parameters [74]. In addition, the (data) transfer through Bluetooth is not done for monitoring over long distances.

**Equivaltal Hidalgo:** The Equivaltal™ Physiological Monitor System, a fieldable system offered by the English Hidalgo company, Cambridge, is on the market. According to the manufacturer, this system is a product that permits the measurement of individual physiological parameters. The company states on its homepage that the system is used in the scientific area, sports, and clinical science [75,76]. In Pubmed, there are four entries regarding this system and even one military application in Afghanistan [77]. The software permits a 1:1 display of the data on a (hand-held) screen, even for several persons simultaneously (Military Black Ghost Training System). All sensors are in a breast strap (heart and respiration rate, skin, "core body temperature", accelerometry with fall alert, skin conductance, and even O<sub>2</sub>-saturation all in one). As far as wearing comfort is concerned, this is a convenient solution, but the measuring point must be questioned critically [78].

**Zephyr:** The Zephyr™ Performance system pursues a similar approach, which is marketed by an American supplier (Medical). The evaluation system resembles that of Equivaltal™. On the homepage, it is possible to have a look at the list of customers and users; they include the space agencies and the military. The USARIEM does not have any publications on this system. In Pubmed, there is also a low number of publications [79,80].

**Sensor Mobile SM 100:** Regarding professional medical devices, the Sensor Mobile SM 100 device was developed by TMS–Telemedizinische Systeme GmbH (current name: Vitasystems GmbH) and was certified and approved in 2002. It belongs to the tele-ECG devices that can record an ECG and transfer it to a switching and exchange center or directly to a physician. The patient autonomously records one or several ECGs, sends the corresponding data to a receiving center, and waits for feedback. The transmitting device can be a mobile or fixed-line telephone that receives and sends the data by infrared or acoustic transmission. During transmission by infrared to the cellular phone, the evaluation center's number is automatically dialed by the mobile telephone [81]. Such systems can transfer data but not field physiology because there is no appropriate infrastructure.

## Smart textiles

This term describes various characteristics of textiles [82-85]. On the one hand, it comprises clothing worn in sports and is intended to positively influence an athlete's temperature regulation. Thus, a sportswear supplier has developed an innovative, prize-winning new training jacket for soccer players. In this case, dynamic temperature regulation is affected through the athlete's movement, i.e., inserts in the textile open and thus cool in case of activity. In contrast, they close again during rest periods, keeping the athlete warm. Such textiles are called performance textiles, and there is a growing market for innovations like that. However, because of this paper's subject, integrating sensors and cables into clothing is the most crucial aspect of this textile type [86]. The Sensatex® company offers a smart shirt system. The prototype was manufactured after long-term development and research work at the Georgia Institute of Technology and is called a "wearable motherboard". Following a revision of the design, it is now commercially marketed as a smart shirt. The device concerned comes from the research area of wearable computing.

While the smart shirt is worn, the wearer's vital parameters, e.g., body temperature, pulse rate, respiration, or transpiration degree, are perceived by sensors [84]. The collected data can be stored in a small box located on the shirt's underside and transmitted later via Bluetooth, WLAN, or a cellular phone modem. The sensors are integrated into a woven mesh in electro-optical fibers, comparable with a plug-and-play bus. Due to this, any number of sensors can be added with little effort, so there are various application areas for the smart shirt [85]. It would be conceivable, for example, to use "intelligent" shirts for Special Weapons and Tactics (SWAT) teams or elite troops. Thus, it could be checked at any time whether the vital functions of all persons involved are in the normal range, mainly when a person concerned can no longer make an emergency call [86]. A similar situation exists for fire departments in case of large fires. A smart shirt worn under the overall can permanently measure the temperature or respiratory activity. This means that, in any situation where direct eye contact with the emergency forces is not possible, the use of intelligent clothing is reasonable. This may also fit Astronauts, chronically sick or older persons, or top athletes [87]. This approach is downright positive, although it is still challenging to implement at present [88,89]. For permanent monitoring of data and to keep the noise levels of data at a minimum, it is essential that all sensors have permanent and good contact with the skin. Therefore, the textile should be highly elastic to fit perfectly with the body.

## Progression of telemedicine

Telemonitoring is not a new issue. Dr. Einthoven demonstrated in 1906 the transmission of an electrocardiogram (ECG) data from a hospital to a laboratory using a telephone line [90]. For astronautics, the first time in history that the medical data transfer principle was applied on a large scale was situation-related. The Russian Space Agency (Roskosmos) and the US-American

Space Agency (NASA) started medical telemetry programs at the end of the 1950s in order to check the physiological functions of Astronauts and to transmit data to Earth [91]. At that time, television technology was used.

1964, the first interactive T.V. telemedicine project started, permitting medical care using a secure T.V. link between a psychiatric ward in Nebraska and a Norfolk clinic. Due to the enormous expenditure and lack of financial profitability, such projects were terminated at the beginning of the 1970s. Only the emergence of digital communications technology and the strongly criticized medical care of cosmonauts/astronauts led to another increase in research work in the early 1990s. With the development of new mobile communications technologies like infrared, Bluetooth, LTE, and 5G, telemedicine has become a growing market and will presumably remain in the future [92]. Image digitization and data compression procedures permitted video data transmission via low-bandwidth lines. With the World WideWeb introduced into the Internet by Tim Berners Lees in 1993, data files stored on different computers could be interconnected [93]. This enabled second-generation telemedicine to provide medical knowledge in otherwise medically inaccessible regions, i.e., aviation and sea travel and areas like the Arctic, Antarctic, or Space [94,95].

All examinations performed in the laboratory must prove whether the results are valid for daily life circumstances a problem already emphasized by Nathan Zuntz at the beginning of the twentieth century. His primary interest was to explore the physiology of animals and humans in stressful situations (physical labor, physical exercise, stays in high-altitude places) in laboratory and field studies or during high-altitude balloon flights [96-101]. He developed mobile measuring systems and even included meteorological conditions in his interpretation. His motto was: "The knowledge of the relations between climate and humans [...] provides us with the basis for evaluating human performance capability [...] (and) also with the foundation of human activity under extreme climatic conditions" [102]. After his death, this approach faded into obscurity. In physiological studies, no significant relationships existed between heart rates measured in the laboratory and the field, whereas other studies yielded different or only minor associations [103-105]. In a multimodally conceived comparison between laboratory and field, no significant predictability of the reactions could be found, leading to the far-reaching conclusion of relative independence of field data [106]. So, it can be assumed that data collected in the laboratory are probably valid for some, but not all, daily life situations, i.e., they can hardly be generalized.

For the reasons mentioned above, it is stated that the advantages of field research, on the one hand, and the questionable external or ecological validity and reliability of test and laboratory findings, on the other hand, have long since been discussed in the literature. However, empirical field studies can only sometimes be found [41]. This is primarily due to the lack of methodical experience or the need for more suitable equipment.

The transferability of examination results from the laboratory to everyday life is considered critical.

For decades, examining humans freely moving during their activities under natural conditions was impossible. Therefore, humans were primarily examined at rest before or after their activities or possibly in their actions, but this needed interruptions. Consequently, active human physiology primarily developed into rest physiology or the physiology of recovery [107,108]. During the transition from rest to activity, the organism's fundamental adaptation processes during the entire training and transition from activity to rest could not be recorded under natural conditions [109]. Moreover, the data's significance decreases as time passes between stress and measurement. Therefore, a more precise and, thus, more significant measurement of physiological framework data must be performed on-site. With all conventional methods, the subjects must be connected to the point of registration through hoses and wires, resulting in a significant number of activities remaining elusive for exact measurement [110]. Also, measurements where the examiner can't be together with the proband or where the examiner's presence may be perceived as disturbing will have an impact on the data (e.g., the "white coat effect") [111].

Moreover, the mental situation impacts the data [112]. Physical and psychological stress are intertwined; thus, it is not astonishing that permanent stress also results in clinical abnormalities [113]. This is also true the other way around. These relationships are scientifically edited within the studies' scope on psychophysical connections, show a distinct correlation, and attract attention [114]. However, laboratory studies are performed in an idealized way, i.e., excluding disturbing influences that exist in the real world. These studies simulate stress situations, and the influencing environmental factors are systematically standardized or eliminated. Yet, this causes problems when these results are transferred to reality; some examples are listed below:

- Examinations of the working and performance capability are performed using conventional, i.e., clinical standards [115]. The used equipment consists of medical devices and is thus validated but mostly inaccurate for field equipment [116].
- Functional diagnoses are made based on short-time examinations, which have little to do with the proper working environment regarding the temporal aspect [106].
- Physiological stress indices are generated statically. They constitute the mathematic-functional correlation between a few characteristic physiological parameters [117], which cannot be generally transferred to the natural, dynamic situation [118].
- Studies are mainly conducted with a few persons with limited statistical power. In addition, "idealized persons" are recruited, i.e., primarily young men aged between 20 and 30 years, sporty, with average weight, etc. However, the results are then extrapolated and transferred to all other persons. However, the transfer can be applied to neither all age groups (age physiology) nor genders (gender physiology).
- In the natural human environment, numerous additional influences significantly impact performance capability and resilience [119]. In this context, the combination of temperature, altitude (oxygen pressure), wind, radiation, precipitation, pressure changes, noise disturbances, etc., must be mentioned [120]. The complexity of these factors is not taken into account in the laboratory.
- In the future, more reliable indices will have to include more parameters on the one hand and take into account intra-individual dynamic factors, e.g., sleep deficit, inadequate food intake, beginning or healing infectious diseases, or influences due to the unique environment (family, friends, etc.) [121]. "Dynamic" in this context primarily means weighting the individual parameters, which may sometimes impact the person in the respective situation, sometimes more or less intensively [122].

Mobile systems for professional use need advanced properties for data transfer (distance, obstacles, data volume). This and data safety (personal rights, military service, etc.) are still problematic, even with radio or LAN. The German Aerospace Center (German abbreviation: DLR) has assumed a crucial role in this context (telemedicine in the Bundeswehr Medical Service for the purpose of operational support). This technology will be extended further in existing and future projects (teleneurosurgery, intraoperative teletutoring) [123-125]. However, this only applies to stationary data transfer, which must be ensured through a mature infrastructure. The primary challenge is the data transfer of several mobiles and located persons in areas with an insufficient structure [126].

### The new path of infield physiological monitoring

The HealthLab system, which is a core component of the mobPhysioLab® (KORA Industrial Electronics GmbH, Hambühren, Germany) and has been under development in Germany for several decades, is a mobile physiological system intended to examine stress situations affecting humans in various working environments. It permits both physiological data collection and the conduct of specific studies on persons in extreme stress situations under the conditions directly prevailing on-site [127].

Contrary to conventional procedures, this system permits continuous, non-invasive, and synchronized physiological data measurements through innovative medical technology. It consists of flexible individual components that connect psychophysiological measuring methods with collecting environmental parameters through information technology. This system's current development status integrates and combines physiological measuring procedures in a flexible, mobile, and relatively small device. This device is based on a multiprocessor system combining a network of satellites with a master. The satellite elements have a respective "intelligence" of their own (i.e., a separate BUS). The satellite elements communicate via a bus with the central processing unit. In principle, this first seems to be more complex than developing one single measuring unit with four channels and particularly one processor only, but it has several advantages:

- The analog and digital measuring techniques are distributed among several small units and can, for example, be placed in a vest.
- The connection of unique measuring methods (e.g., core body temperature, heart rate, fundamental vocal frequency, etc.) is possible due to the development of a corresponding satellite, which can be used directly on the system without further settings.
- The central processing unit automatically recognizes the respective satellites and immediately records the data with the satellite's signal-specific parameters.
- With the help of the software and hardware provided, users can also develop satellites and programs of their own.
- Moreover, the system can monitor the data online and thus already evaluate them.

The described modularity and the versatile applicability regarding adaptation options and the system's mobility have yet to be commercially available in this form. The freely programmable software applications give users various modification options depending on the special applications and requirements. Thus, only the individual wearer's appropriate parameters are recorded, making the system extremely flexible and lighter (Figures 1-4).



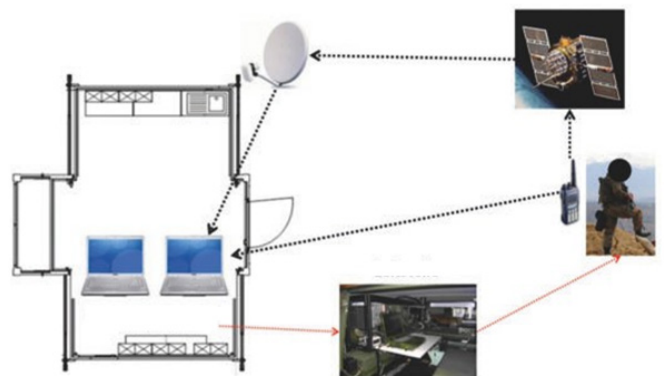
**Figure 1** A fieldable mobile physiological laboratory (mobPhysioLab®) was used in the abovementioned studies. Source: Wehrwissenschaftliches Institut für Schutztechnologien (WIS)–ABC-Schutz [Bundeswehr Research Institute for Pro-TECTIVE Technologies and Chemical, Biological, Radiological, and Nuclear Protection], Munster.



**Figure 2** Space suitable mobPhysioLab® is currently used at the International Space Station (ThermoLab). Source: Dr. Andreas Werner.



**Figure 3** Prototype of a sensor suite (smart textile) used for recording skin temperature at the extremities, skin moisture, respiration rate, and heart rate. Source: Wehrwissenschaftliches Institut für Werk und Betriebsstoffe (WIWeB) [Bundeswehr Research Institute for Materials, Fuels, and Lubricants], Erding.



**Figure 4** Data transfer via radio system or satellite, data evaluation by medically trained personnel and transmission to the control center for further mission planning source: Dr. Andreas Werner.

It has been possible to employ the system in terrestrially extreme environments successfully (i.e., in salt mines at a depth of 1,450 m [occupational medicine], in water applications [therapy], at high altitudes [military] and in the [civilian and military] flying service, even in Space [ESA and NASA, ThermoLab]; IBMP [MARS500, Russia]):

- The double sensor (Tcore®, Draeger, Germany) is a non-invasive device to continuously monitor core temperature in humans on Earth and in Space [128-132].
- Metabolic and physiological changes in the human organism during overwintering in the Antarctic [133]
- Monitoring of vital parameters in a real-world environment using a flexible modular telephysiological System [134]

- Oxygen supply for parachutists at operational altitudes laboratory studies and their benefits in an extreme and real-world environment [135]
- Heat exposure of jet pilots during air traffic [136]
- Mars500 project–Circadian rhythm and body core temperature in humans during long-term isolation and confinement [137]
- The role of exercise in synchronizing the circadian timing system during 60 days of bed rest [138]
- Core body temperature changes during long-duration space flights [139]
- Currently, this system is advanced by miniaturization, insertion of sensors into a smart textile, and data transfer via radio, with the focus being on the following requirements:
- Provision of emergency functions and algorithms [140]

## Discussion

In the future, physiological monitoring to determine people's performance, load, and stress status in extreme environments will be an essential means of considering the caring and health aspects [141-143]. Given increasingly specialized workplaces, which can only be depicted by fewer and fewer people, human resources are increasingly important in this context [144,145]. In addition, monitoring during an assignment or operation is a tool with which management tasks can be better supported, especially when deciding whether an individual or a group can still carry out an assignment [146-148]. In addition, monitoring can be used to recognize dangerous situations in time and to derive adequate action [149]. If damage occurs, essential prehospital physiological data can be used to initiate significantly better care of the person [150,151]. However, there is no claim to provide medical, diagnostic, or therapeutic support for even treatment decisions, which should be reserved for clinical monitoring [152]. Therefore, according to medical device ordinances or laws, physiological monitoring should not become a medical device. However, it must comply with the regulations that application to humans is possible.

The available physiological data obtained in this article could be more suitable to meet the claim made [153]. On the one hand, the monitoring systems must be ideal for the field so that they are not susceptible [154]. Furthermore, the systems must be able to record many physiological parameters, especially synchronized, which can be realized inadequately with the presented monitoring systems, except for the mobPhysioLab<sup>®</sup>. The sensor application must be made as simple as possible. Therefore, the integration of sensor technology into a textile (smart textile) is essential (instrumentation while clothing) [155]. The smart textile and its sensors must be designed in such a way that they do not influence the wearer and do not sense the sensor technology because any disturbance influences the physiological parameters, so a reliable evaluation cannot be achieved [156]. This could harm the intended decision-making and guidance of individuals. In addition

to optimizing the smart textile, weighing the physiological data obtained to generate meaningful parameterization [157,158] will be a task yet to be mastered. In addition, a head of operations cannot be expected to display all the physiological data collected on a monitor. The accounting of the data must result in a simple scoring with trend analysis within the framework of development so that an overview of the overall situation is created as quickly as possible [159].

- Development of built-in test functions to ensure operation through monitoring of all necessary functions, including power supply
- Algorithms regarding the trend statement of vital parameters during missions
- Recording of system parameters
- Safety functions for the mission duration (reliability)
- Unique algorithms for processing large and complex data quantities with low demand for computing power, yielding a valid diagnostic value
- Data safety (especially for military use) and person's privacy

## Conclusion

In the future, it can be expected that a measuring system will have a far-reaching influence on the physiological parameters to be recorded in the field [160,161]. The benefit of this development is that the results obtained in the laboratory can be reproduced within the scope of a field trial [162,163]. Thus, the simulation can advance, resulting in a more realistic depiction [164,165]. The presented solution approach (mobPhysioLab<sup>®</sup>) significantly improves the collection of field physiological data. However, the authors are aware that there is still much research to fully cover the many application scenarios that achieve the optimal results in each situation.

## Declarations

### Contributor ship

AW and H-CG contributed to their own studies in conceptualization, methodology, software, validation, formal analysis, investigation, data curation, project administration, and funding acquisition. AW: writing original draft preparation, review, and editing. H-CG: writing, reviewing, and editing. TK contributes with his own research, review, and editing. All authors have read and agreed to the published version of the manuscript.

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The authors declared no potential conflicts of interest concerning this article's research, authorship, and/or publication.

### Ethical approval

This work is not a clinical study. Thus, ethical approval is not required. Informed Consent Statement: Informed consent was obtained from all subjects involved in each named and listed their own investigations.



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