NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(HFM-260)TP/927

www.sto.nato.int

STO TECHNICAL REPORT **TR-HFM-260**

Enhancing Warfighter Effectiveness with Wearable Biosensors and Physiological Models

(Amélioration de l'efficacité du combattant à l'aide de biocapteurs portatifs et de modèles physiologiques)

Final Report of Task Group HFM-260.

Published January 2020

Distribution and Availability on Back Cover

NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(HFM-260)TP/927

www.sto.nato.int

STO TECHNICAL REPORT **TR-HFM-260**

Enhancing Warfighter Effectiveness with Wearable Biosensors and Physiological Models

(Amélioration de l'efficacité du combattant à l'aide de biocapteurs portatifs et de modèles physiologiques)

Final Report of Task Group HFM-260.

The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

The content of this publication has been reproduced directly from material supplied by STO or the authors.

Published January 2020

ISBN 978-92-837-2252-6

Table of Contents

List of Figures

HFM-260 Membership List

Mr. Bertil VEENSTRA
Ministry of Defense / CLAS
NETHERLANDS
Email: bj.veenstra.01@mindef.nl

Dr. Reed HOYT
US Army
UNITED STATES
Email: reed.w.hoyt.civ@mail.mil

MEMBERS

Commander James A. BALCIUS
United States Marine Corps
UNITED STATES
Email: james.a.balcius@usmc.mil

Mr. Mark BULLER
US Army
UNITED STATES
Email: mark.j.buller.civ@mail.mil

Dr. Mounir CHENNAOUI
Institut de Recherche Biomédicale des Armées (IRBA)
FRANCE
Email: mounirchennaoui@gmail.com

Ms. Jessica CONRADI
Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE)
GERMANY
Email: Jessica.conradi@fkie.fraunhofer.de

Dr. Simon Keith DELVES
Institute of Naval Medicine
UNITED KINGDOM
Email: NAVYINM-EMSAP3@mod.uk

Prof. Gianluigi FERRARI
University of Parma
ITALY
Email: gianluigi.ferrari@unipr.it

Col Karl FRIEDL
US Army
UNITED STATES
Email: friedlke@gmail.com

Dr. Kari KALLINEN
Finnish Defence Research Agency FDRA
FINLAND
Email: kari.kallinen@mil.fi

Dr. Ryan LOVE
Defence Research & Development Centre (DRDC) – Toronto
CANADA
Email: Ryan.Love3@forces.gc.ca

Major Rachel MORRELL
Canadian Forces Environmental Medicine Establishment
CANADA
Email: rachel.morrell@forces.gc.ca

Mr. Richard C. MURDOCK
US Air Force (USAF)
UNITED STATES
Email: richard.murdock.2@us.af.mil

Mr. Philip NEWTON
Canadian Armed Forces
CANADA
Email: philip.newton@forces.gc.ca

Dr. Jeffrey PALMER
MIT Lincoln Laboratory
UNITED STATES
Email: jspalmer@ll.mit.edu

Mr. Christian PLEGGE
Fraunhofer FKIE
GERMANY
Email: christian.plegge@fkie.fraunhofer.de

Dr. Kok-Yong SENG
Defence Medical & Environmental Research Institute
SINGAPORE
Email: skokyong@dso.org.sg

Dr. Stergio STERGIOPOULOS
Defence Research & Development Centre (DRDC) – Toronto
CANADA
Email: stergios.stergiopoulos@drdc-rddc.gc.ca

Ms. Wendy SULLIVAN-KWANTES
Canadian Forces Environmental Medicine Establishment
CANADA
Email: wendy.sullivan-kwantes@drdc-rddc.gc.ca

Ms. Hilde Kristin TEIEN
Forsvarets Forskningsinstitutt
NORWAY
Email: hilde-kristin.teien@ffi.no

Dr. Jason Kai WEI LEE
Defence Medical & Environmental Research Institute
SINGAPORE
Email: kaiwei@dso.org.sg

Dr. Thomas WYSS
Federal Department of Defence
SWITZERLAND
Email: thomas.wyss@baspo.admin.ch

Mr. Ertan ZAFEROGLU
Turkish Aerospace Industries – TAI
TURKEY
Email: ezaferoglu@tai.com.tr

PANEL/GROUP MENTOR

Dr. John Tangney
Office of Naval Research
UNITED STATES
Email: John.f.tangney@navy.mil

Enhancing Warfighter Effectiveness with Wearable Biosensors and Physiological Models

(STO-TR-HFM-260)

Executive Summary

Physiological monitoring has many potential applications for the military where actionable real-time health and performance status of individual soldiers can be provided to the individual, leaders, and medical personnel. This panel advanced the science of wearable physiological monitoring technology applications for protection and enhancement of soldier performance. The results of four years of research discussion, coordination, and direct multinational collaborations were evident in three demonstrations and numerous peer-reviewed publications. The impact of the panel can be measured by comparing accomplishments to the state-of-the-art in a predecessor panel, RTG HFM-132 (June 2010), where concepts and sensor technologies were described and research applications were just beginning. Specifically, RTG HFM-260 took this to the next level with coordination of national efforts in physiological monitoring applications, two multinational field research experiments, and three Cooperative Demonstrations of Technology. A frequently asked question from military leaders is why can't troops be equipped with the latest wearable monitoring technology available in the commercial sector? The answer is simple: raw heart rates, sleep history, and activity levels are interesting but not useful information by themselves; however, actionable information relevant to military applications can be derived through development of physiologically-based algorithms and iterative testing with soldiers in realistic field environments. This leaves it to the military to fill critical gaps in the design and application of sensor systems and to obtain relevant intelligence on our own soldiers. The resulting system design, sensors, and algorithms are likely to be selected by industry and commercialized for the wider civilian market, not the other way around. A current example is the core temperature algorithm developed by Mark Buller from the US Army that accurately estimates elevation in core temperature from time series heart rate, rather than having to swallow core temperature pills every day. This algorithm has been licensed to commercial companies to also estimate core temperature increases in the civilian community.

Major accomplishments of this panel were:

- Information exchanges on technologies and use cases for wearable monitoring technologies;
- Synchronized national wearable monitoring efforts with exchange of best practices and lessons learned;
- Establishing a common approach to real-time thermal strain monitoring in the field, now proposed as a new RTG to include development of a STANREC;
- Shared mature national efforts on alertness monitoring and aircrew rest scheduling techniques (FRA);
- Explored the state-of-the-art in sensor technologies to fill specific monitoring needs such as: boot inserts for ground reaction forces (NLD, USA), Inertial Measurement Units (IMUs) for inertial navigation (ITA), and skin temperature monitoring in cold environments (CAN, NOR, USA), and load monitoring (energy expenditure) during daily military routine (CAN, CHE, GBR, NLD, USA);
- Disseminated findings from national and multinational studies through relevant conferences and symposia, including annual IEEE Body Sensor Networks conferences;

- Conducted and reported results of two multinational studies led by Switzerland;
- Developed monitoring systems for applications in training safety for recruits (GBR, NLD, SCH, USA), highlighted in a Cooperative Demonstration of Technology (CDT) led by GBR; and
- Engaged in joint research efforts (NOR-CAN, USA-CAN, USA-GBR, USA-GBR-NLD-CHE).

Amélioration de l'efficacité du combattant à l'aide de biocapteurs portatifs et de modèles physiologiques

(STO-TR-HFM-260)

Synthèse

Le monitorage physiologique a de nombreuses applications potentielles chez les militaires, car l'état de santé et les performances en temps réel de chaque soldat peuvent être fournis à l'individu, aux chefs et au personnel médical, ce qui permet d'intervenir. La présente commission a fait progresser la science des applications de la technologie portative de monitorage physiologique visant à protéger et améliorer les performances des soldats. Les résultats de quatre années de discussions, de coordination et de collaboration multinationale directe de recherche ont été manifestes lors de trois démonstrations et de nombreuses publications à comité de relecture. L'effet de la commission peut être mesuré en comparant les résultats de la technique de pointe d'une commission précédente, le RTG HFM-132 (juin 2010), dans laquelle les concepts et technologies de détection ont été décrits alors que les applications de recherche commençaient tout juste. Plus précisément, le RTG HFM-260 a franchi une autre étape en coordonnant les travaux nationaux sur les applications de monitorage physiologique et en menant deux expériences multinationales de recherche sur le terrain et trois démonstrations en coopération des technologies. Les responsables militaires demandent fréquemment pourquoi les troupes ne peuvent pas être équipées de la dernière technologie de monitorage portative disponible dans le commerce. La réponse est simple : la fréquence cardiaque brute, l'historique de sommeil et les niveaux d'activité sont des informations intéressantes, mais inutiles en soi. En revanche, il est possible de déduire des informations utiles à des applications militaires en développant des algorithmes et des essais itératifs basés sur la physiologie avec des soldats dans des environnements de terrain réalistes. Il incombe par conséquent aux militaires de combler les lacunes critiques de conception et d'application des systèmes de capteurs et d'obtenir des renseignements pertinents sur nos propres soldats. Le modèle de système, les capteurs et les algorithmes en résultant sont susceptibles d'intéresser l'industrie et d'être commercialisés sur le marché civil, et non l'inverse. L'algorithme de température centrale en est actuellement un exemple. Élaboré par Mark Buller, de l'armée des États-Unis, il estime l'élévation de la température centrale à partir d'une série chronologique de fréquences cardiaques, plutôt qu'à l'aide d'un thermomètre en pilule avalé chaque jour. Cet algorithme a été concédé sous licence à des entreprises commerciales pour estimer également la hausse de la température centrale chez les civils.

Les grandes réussites de cette commission ont été :

- L'échange d'informations sur les technologies et les cas d'utilisation des technologies portatives de monitorage ;
- La synchronisation des travaux nationaux de monitorage portatif avec l'échange des meilleures pratiques et des enseignements ;
- L'établissement d'une démarche commune de monitorage de la contrainte thermique en temps réel sur le terrain, maintenant proposée comme nouveau RTG pour inclure l'élaboration d'un STANREC ;
- Le partage des travaux nationaux matures sur le monitorage de la vigilance et les techniques de programmation du repos des équipages aériens (FRA) ;

- L’étude de l’état de la technologie des capteurs pour répondre à des besoins de monitorage spécifiques tels que : les inserts dans les bottes des forces d’intervention terrestres (NLD, USA), les centrales inertielles (IMU) pour la navigation inertielle (ITA), le monitorage de la température cutanée dans les environnements froids (CAN, NOR, USA) et le monitorage de la charge (dépense d’énergie) pendant la routine militaire quotidienne (CAN, CHE, GBR, NLD, USA) ;
- La diffusion des conclusions d’études nationales et multinationales à travers des conférences et colloques pertinents, notamment les conférences annuelles « Body Sensor Networks » de l’IEEE ;
- La réalisation de deux études multinationales menées par la Suisse et le compte rendu des résultats ;
- Le développement de systèmes de monitorage pour des applications de sécurité dans la formation des recrues (SCH, NLD, USA, GBR), mis en lumière par une démonstration en coopération des technologies (CDT) menée par le Royaume-Uni ;
- L’implication dans des travaux de recherche communs (NOR-CAN, USA-CAN, USA-GBR,, USA-GBR-NLD-CHE).

ENHANCING WARFIGHTER EFFECTIVENESS WITH WEARABLE BIOSENSORS AND PHYSIOLOGICAL MODELS

1.0 SUMMARY OF ACCOMPLISHMENTS

1.1 Background

This group was formed on the basis of interest generated by a workshop organized by Dr. Brian Telfer (MIT Lincoln Labs) on military applications of physiological monitoring at the IEEE Body Sensor Networks 2014 symposium in Zurich, Switzerland. The concept gained traction after Dr. Jeffrey Palmer briefed senior US scientific leadership and the RTG was established shortly thereafter. This project built on the work of a previous HFM task group (RTG HFM-132, "Real-Time Physiological and Psycho-Physiological Status Monitoring") chaired by Dr. Reed Hoyt. The group rapidly formed because of existing affiliations, initial international collaborations, and associations through the annual IEEE Body Sensor Networks symposium.

Physiological monitoring has many potential applications for the military where the real-time health and performance status of individual soldiers can be provided to the individual, leaders, and medical personnel. This is comparable to the dashboard settings in a vehicle, where engine speed and temperature, oil and gas levels, and other readouts on the maintenance and performance status are provided to the driver. A key difference is that individuals generally need actionable health state information that may not be self-evident, or special alerts to others when an individual is impaired.

A frequently asked question from military leaders is why can't their troops be equipped with all the latest wearable monitoring technology that is available in the commercial sector? The answer is simple: raw heart rates, sleep history, or activity levels are interesting but generally do not constitute actionable information; other information promised with commercial systems at this time, such as hydration status and mental status, generally have not been rigorously developed or validated. Currently available commercial systems generally do not provide the performance monitoring capabilities needed by the military, as performance predictions are not regulated and industry is not incentivized to conduct the research and development of valid algorithms. Medical monitoring and predictive algorithms for casualty care are more complex but these monitoring systems are largely confined to medical centers and industry has little incentive to create diagnostic algorithms for use in remote triage and medical management.

This leaves it to the military to fill critical gaps in our understanding and visibility of the readiness states of our own soldiers, and the system designs and algorithms developed will likely be later picked up by industry and commercialized for the wider civilian market. A current example of this is the Estimated Core Temperature (ECTemp) algorithm developed by the Army to estimate core temperature from an accurate time series heart rate. This algorithm has now been licensed to commercial companies for use in the civilian community.

1.2 Objectives

The mission of the Human Factors and Medicine Panel is to provide the science and technology base for optimizing health, human protection, well-being and performance of the human in operational environments with consideration of mission effectiveness and affordability. This involves understanding and ensuring the physical, physiological, psychological and cognitive compatibility among military personnel, technological systems, missions, and environments. This is accomplished by exchange of information, collaborative *experiments and shared field trials.* From the 2018 Collaborative Programme of Work (CPoW), 10 January 2018, Collaboration Support Office, NATO (AC/323-D(2018)0001).

This panel successfully fulfilled the stated goals of an HFM group as described more than four years ago in the original Technical Activity Proposal (TAP**)** (see Annex A).

1.3 Accomplishments

Over four years, this panel advanced the science of physiological monitoring technology applications for the military. The impact of the panel can be measured by comparing to the state-of-the-art in a predecessor panel, RTG HFM-132, where concepts and sensor technologies were described and research applications were just beginning. RTG HFM-260 took this to the next level with coordination of national efforts in physiological monitoring applications, two multinational field research experiments, and three Concept Demonstration projects. A narrowly focused follow-on panel will be proposed for the purpose of developing a NATO STANREC for the use of physiological monitoring in exertional heat illness prevention along with related applications in accelerated heat acclimatisation.

The major accomplishments of this panel have been the following:

- Accomplished information exchanges on technologies and use cases for wearable monitoring technologies;
- Synchronized national wearable monitoring efforts with exchange of best practices and lessons learned;
- Established a common approach and basis for real-time thermal strain monitoring in the field, now proposed as a new RTG to include development of a STANREC;
- Shared mature national efforts on alertness monitoring and crew rest scheduling techniques (FRA);
- Explored the state-of-the-art in sensor technologies to fill specific monitoring needs such as boot inserts for ground reaction forces (NLD, USA), IMUs for inertial navigation (ITA), and skin temperature monitoring in cold environments (CAN, NOR, USA);
- Disseminated findings from national and multinational studies through relevant conferences and symposia, including annual IEEE Body Sensor Networks conferences;
- Conducted and reported results of two multinational studies led by Switzerland;
- Developed monitoring systems for applications in training safety for recruits (GBR, NLD, SCH, USA), highlighted in a CDT led by GBR; and
- Engaged in joint research efforts (NOR-CAN, USA-CAN, USA-GBR, USA-GBR-NLD-CHE).

1.4 Organization of This Report

This report summarizes highlights of each group meeting, including relevant material from/with associated conferences (Chapter 2) and includes a comprehensive list of key reports, publications, and presentations from the group members, relevant to this activity. Full references at the end are organized by meetings and conferences in which publications were discussed and presentations were made.

Some of these reports, publications, and presentations are reproduced in the appendices. All of these materials are/were available to country panel members.

A complete set of minutes summarizing each of the eight formal meetings was collated and distributed only to each of the country panel members who were current in June 2019.

2.0 SUMMARY OF SEMI-ANNUAL MEETINGS

Panel HFM-260 was formed in 2015 with a three-year charter, and a one-year extension (ending June 2019). Formal meetings occurred twice per year, usually scheduled in conjunction with relevant technical conferences or technology demonstrations. Relevant technical conferences included the following:

- International IEEE Body Sensor Networks meetings (BSN2015, BSN2016, and BSN2017);
- 6th International Conference on the Physiology and Pharmacology of Temperature Regulation (PPTR2016);
- 4th International Congress on Soldier Physical Performance (ICSPP 2017); and
- International Conference on Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM 2019).

Three Cooperative Demonstrations of Technology (CDTs) included:

- Sleep and alertness monitoring and enhancement (Paris, France, 2015);
- Inertial navigation and Inertial Management Unit (IMU) technology (Parma, Italy, 2016); and
- Applications of wearable physiological monitoring (Lympstone, Great Britain, 2018).

This section summarizes the themes and specific tasks accomplished at each meeting.

2.1 First Meeting: Thermal-Work Strain Monitoring Systems and Models

Date:	June 8 – 12, 2015
Theme:	Thermal-work strain monitoring systems and models
Host:	Jeffrey Palmer, MIT Lincoln Laboratories
Location:	MIT Beaverworks, Cambridge, Massachusetts
Associated Conference:	IEEE Body Sensor Networks 2015, MIT Media Lab, Cambridge, MA

The group met in a collaboration meeting space provided by MIT, the MIT Beaverworks, in Cambridge Massachusetts. The meeting was opened by LtCol Frank Wessels, the CSO Executive Secretary who outlined the goals and rules for a NATO HFM technical panel. The group reviewed each country activity and interests in the area of wearable monitoring (see Figure 1). The team was introduced to Swiss and Dutch concepts of workload monitoring in recruits to reduce injury rates; the Norwegian Skjold Study 2015 involving thermal monitoring in Norwegian ski troops; Canadian research program (2011 – 2015) involving integrated physiological monitors and wearable ECG suits for the Canadian Space Agency; British monitoring studies and field data collection in Operation Telic and Operation Herrick, including wearable temperature monitoring devices; and French research on vigilance monitoring and microsleeps in long haul French Air Force pilots, and sleep/wake patterns in French submariners. The meeting also included participation of bioengineers from Lincoln Laboratories, MIT, with presentations on current efforts in boot insole / shoe insert sensing. COL Deydre Teyhen was a guest presenter (and keynote speaker at the BSN 2015 meeting), discussing monitoring of health habits using the FitBit wrist-worn device in soldiers. An element of the thesis work of Mark Buller was presented, illustrating the use of real-time physiological monitoring to provide feedback every 2 minutes from modelled performance optimization for the completion of a prescribed task involving completing a timed run/walk and remaining and ending as cool and functional as possible. This represents an early trial in human pacing optimization, or "technological doping."

Figure 1: Wearable EEG Device.

Relevant references provided (associated with country presentations): Ref. [1], [2], [3], [4], [5], [6].

NATO member participation in BSN 2015 conference: Ref. [7], [8], [9], [10].

2.2 Second Meeting: Alertness Monitoring and Fatigue Interventions

Date:	December 8 – 11, 2015
Theme:	Alertness monitoring and fatigue interventions
Host:	Mounir Chennaoui, IRBA
Location:	Val de Grace and Percy Hospital, Paris, France
Cooperative Demonstration of Technology (CDT)	Presentations by the IRBA sleep team including Fabien Sauvet, Arnaud Rabat, and the Rythm team in sleep labs at Hôpital Percy

This meeting focused on sleep and alertness monitoring, with a demonstration of wearable sleep, alertness, and acoustic enhancement of sleep technologies. The main meeting was held in an executive conference room organized at the Val de Grace French military medical training center in Paris (Figure 2). A field trip was organized to the sleep labs at Hôpital Percy, and a brief tour of the sleep labs in Hôtel Dieu was also provided.

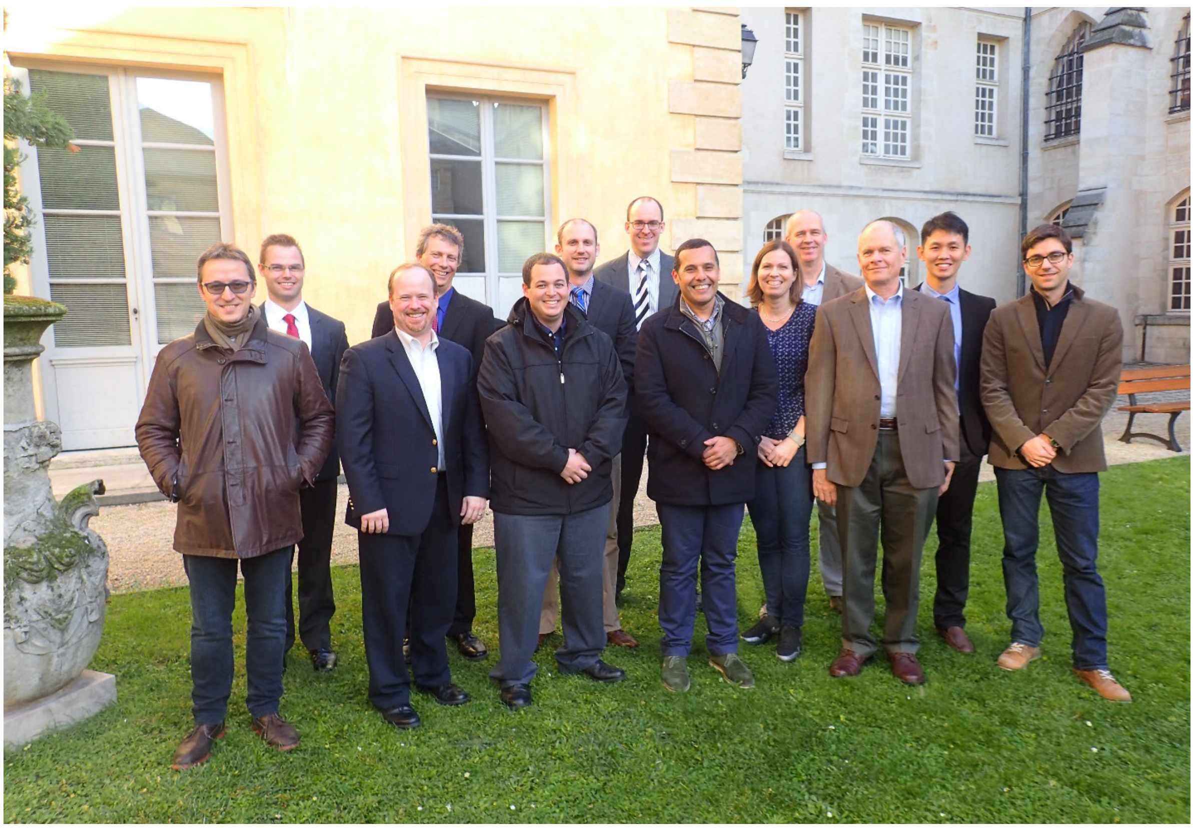


Figure 2: RTG HFM-260 Team at Val de Grace, Paris.

Note: Pictured from left to right: Gianluigi Ferrari (ITA), Ryan Love (CAN), Jeffrey Palmer (USA), Mark Buller (USA), Craig Murdock (USA), Simon Delves (GBR), Christian Plegge (DEU), Mounir Chennaoui (host)(FRA), Hilde Teien (NOR), Bertil Veenstra (NLD), Reed Hoyt (USA), Jason Lee (SGP), Thomas Wyss (CHE). (Friedl took the picture).

A significant technology development effort had focused on wearable EEG monitoring including single channel wearable systems used in aviators on long haul flights to detect micro sleeps and to develop better sleep-work schedules, as well as a partnership with a commercial firm Rythm in the development and application of dry electrode wearable sleep EEG and acoustic stimulator system (Figure 1).

CDT supporting references: Ref. [11], [12].

User scenarios for wearable monitoring were written before the meeting and presented by the Netherlands, Switzerland, United Kingdom, United States, Singapore, Norway and Canada. Each of these further defined concepts of operation/use cases for wearable physiological monitoring to help the group exchange information on current efforts and goals, to refine some common themes in thermal and workload monitoring. Current research data collection technologies were compared and discussed.

The UK, Swiss, and Dutch scenarios outlined concepts that evolved into actual testbed opportunities with future studies and demonstrations including the "March in March" multinational studies of Swiss recruits and the Collaborative Demonstration of Technology (CDT) involving Royal Marine Commandos wearing a multinational array of wearable physiological sensors.

New ideas were introduced by four new contributors with Ryan Love (CAN) presenting on current efforts in Canadian field studies; Christian Plegge (DEU) describing his work at Fraunhofer on monitoring for Urban Operations; Gianluigi Ferrari (ITA) presenting activities of the Wireless Ad Hoc and Sensor Networks (WASN) lab at the University of Parma; and Craig Murdock (USA) describing the performance monitoring research at the Air Force Research Lab, notably sweat sensing technologies.

2.3 Third Meeting: Estimation of Activity Energy Expenditure (AEE) and the "March in March" Cooperative Study

Date:	June 15 – 17, 2016
Theme:	Estimation of Activity Energy Expenditure (AEE) and accelerometry
Location:	Marine Memorial Club, San Francisco, California
Host:	Karl Friedl, USARIEM and University of California, San Francisco
Guest presenter (uncompensated):	Dr. Kong Chen, NIDDK/NIH, accelerometry and estimation of energy expenditure
Associated Conference:	IEEE Body Sensor Networks, UCSF Mission Bay Conference Center, San Francisco, California, USA, 14 – 17 June 2016

In the RTG HFM-260 meeting, Kong Chen presented a review of body worn systems and how machine learning techniques have been used to improve predictions for specific populations and against criterion measures. He described standardization efforts for accelerometry techniques and he summarized the NHANES dataset that will eventually be released for analysis [13], [14], [15].

Federico Parisi described his thesis work in Gianluigi Ferrari's lab on ambulatory monitoring of Parkinson's patients, with summaries from several papers to be presented at the BSN 2016.

Kok-Yong Seng (SGP) presented a preview of his testing and validation of the ECTemp algorithm for thermal strain prediction applications.

Ryan Love (CAN) described a national effort involving purchase of 20,000 fitness trackers for Canadian Forces. He requested review assistance with a new technical report on wearable monitoring [16].

Friedl (USA) presented a new summary technical report on physiological monitoring in the US Army [17].

NATO interests were well integrated with the conference agenda because Friedl and Buller were lead organizer and chair of the scientific committee, respectively. Conference participation included a special session on the RTG HFM-260 effort; a session on related efforts for wearable monitoring for military working dogs and police horses; and direct roles in physiological monitoring in extreme environments (presentations and themed posters).

NATO group member presentations at IEEE BSN 2016: [18], [19], [20], [21], [22], [23], [24], [25], [26], [27].

The "March in March" multinational study of Swiss recruits had already been organized and was "shoe horned" into the BSN 2016 agenda, including brief podium time and three posters (see Figure 3, Figure 4, and Figure 5.) from Refs. [25], [26], [27].

2.4 Fourth Meeting: Inertial Navigation and IMU Technology

Dates:	December 1 – 3, 2016
Theme:	Inertial navigation and IMU technology and technology demonstration (funding from NATO CSO)
Location:	University of Parma, Parma, Italy
Host:	Gianluigi Ferrari, Department of Engineering and Architecture, University of Parma
Collaborative Demonstration of Technology (CDT):	On inertial navigation
Associated Conference:	6th International Conference on the Physiology and Pharmacology of Temperature Regulation (PPTR), Ljubljana, Slovenia, 5 – 8 December 2016

This meeting included a range of guest presentations from Gianluigi Ferrari's WASN group on topics related to Internet of Things (IoT), wireless networking strategies (e.g., architectures; hybrid networks) and technologies (e.g., video processing-based systems; fast echo channel equalization), and other aspects of signal processing – all relevant to field wearable systems, especially in remote and austere environments and in contested environments (see Figure 6) [28], [29], [30], [31], [32], [33], [34].

With modest funding support from NATO CSO, Nicolo Strozzi was able to provide a demonstration of a state-of-the-art IMU system, comparing inertial navigation to GPS within and around the structure of the building in which we were meeting while this was projected real-time for the RTG HFM-260 panel (summary illustration, below) [28], [29], [30], [31]. Gianluigi Ferrari outlined future applications.

UNCLASSIFIED – Disclaimer: The views expressed are those of the authors and do not reflect official policy.

NATO Panel HFM-260: Enhancing Soldier Effectiveness with Wearable Biosensors & Physiological Models

Validity of Wrist Based Heart Rate Monitors for the Physiological Assessment of Swiss Army Recruits

Mark J. Buller,[1] Jacqueline Bitterle[2], Simon K. Delves,[3] Bertil J. Veenstra,[4] Lilian Roos,[2] Nadja Beeler,[2] Thomas Wyss,[2]
[1]United States Army Research Institute of Environmental Medicine, Natick, USA
[2]Swiss Federal Institute of Sport Magglingen SFISM, Magglingen, Switzerland
[3]Institute of Naval Medicine, Alverstoke, Gosport, United Kingdom
[4]Institute of Training Medicine & Training Physiology, MOD/TGTF, Utrecht, the Netherlands

INTRODUCTION

Heart rate (HR) is an informative physiological measure that has long been utilized to assess work rate, energy expenditure, and fitness. Recent algorithms, that primarily use heart rate, have shown promise in estimating body core temperature,[3] assessing circadian rhythms,[4] and are often used in prescribed training regimes. Heart rate derived from electrocardiograms (ECG) using wearable chest straps are a mature technology from circa 1980 that provide reliable and valid measures.[8] Many chest based HR monitoring systems have been shown to have high correlations (r>0.9) when compared to standard medical ECG devices, along with minimal bias (within +/- 3 bpm), and small standard deviations (SD) (+/- 11 bpm).[8] However, chest belt HR systems can be problematic for long term wear (>12 h). The belts tend to move lower over time – increasing errors, they can be seen as constrictive and cause skin irritation,[10] which contribute to reducing wear compliance over time.[7]

Recently wrist-based activity trackers have been incorporating heart rate measures derived from photo-plethysmography (PPG). These wrist-based systems offer an advantage of increased comfort and user compliance over long wear times. The Swiss Army has been developing a simple low cost monitoring system to track recruits and help them utilize a better training regime.[11,12] One component of this system is a wrist-based PPG HR monitor (Fig 1).

Figure 1: Mio Fuse wrist based PPG heart rate monitor.

However, because these devices rely primarily on PPG, movement artifacts are thought to be a problem and anecdotes also suggest a lack of accuracy.[9] This study aimed to examine whether an example of a wrist based PPG HR device (Mio Fuse, Mio Global Inc., Vancouver) would provide accurate heart rate data across a long duration militarily relevant task.

METHODS

Fifty three Swiss Army recruits (male; age 20±1 y; height 1.79±0.07 m; body mass 75.7±10.0 kg) took part in a 35 km road march over approximately eight hours. Soldiers carried their equipment and backpack (~25 kg). In addition to the Mio Fuse, participants wore a chest belt ECG HR monitor (EQ-02, Hidalgo Ltd. Cambridge UK) as a for criterion validation.

Wrist size, arm hair, and skin type were recorded as possible confounders of accurate HR from the wrist.

The hair on the forearm was categorized into two groups, one group with little or no hair and the other with moderate to a lot of hair. The separation of the two groups was made by two example images (Fig 2).

Figure 2: Example images to categorize: Hairy (left) & Smooth (right)

Skin type was assessed using the Fitzpatrick-Scale[6] (Fig. 3) and wrist size was categorized (S, M, & L) by the number of holes remaining in the Mio Fuse band.

The Fitzpatrick Scale
Type 1 Type 2 Type 3 Type 4 Type 5 Type 6

Figure 3: The Fitzpatrick Scale of Skin Types

The performance of the Mio Fuse was assessed by calculating the Pearson correlation coefficient (R) and Root Mean Square Error (RMSE) for each participant. A high correlation coefficient (>0.9) and low RMSE (< 11) would characterize good performance similar to ECG chest based systems.

RESULTS

Mean HR for the Mio Fuse (126 ± 10 bpm) was significantly lower than the mean HR (130 ± 10 bpm) for the EQ-02 (t = −4.87, p<0.001) but only by about 4 bpm. Overall RMSE was 14.3 ± 7.0 bpm. The mean correlation coefficient was 0.65 ± 0.27 (Fig. 4).

Frequency
0 5 10 15
0 0.2 0.4 0.6 0.8 1
R

Figure 4: Histogram of correlation coefficients where approximately 60% of participants show reasonable correlations (>0.7).

A multiple linear regression (F = 7.012, p = 0.002) was found where R could be predicted by wrist size (p = 0.001) and BMI (p = 0.005): R = 0.039 BMI − 0.243 Wrist Size + 0.173. However, this equation only explains about 23% of the variability observed in the data. Of all the input factors only wrist size had a significant (R = − 0.30, p<0.05) albeit moderate correlation. No significant differences were found between R and RMSE for skin types, wrist size, and skin hair.

DISCUSSION / CONCLUSIONS

The difference in means between the HR monitors is quite small and initially appears to suggest that the wrist PPG is a good substitute for the chest ECG systems.

Δ HR (bpm) (Est. - Mea.)
100 50 0 -50 -100
60 80 100 120 140 160 180
Mean HR (bpm) (Mea. and Est.)

Figure 5: Bland Altman plot of all the comparison data. Overall, there is small negative bias of −3.6 bpm (solid horizontal line) with limits of agreement of ± 31.1 bpm (dashed horizontal line).

However, mean HR computed across the length of road march masks the poorer performance of the Mio Fuse as indicated by the larger RMSE, and the fairly poor average R value. The systematic negative bias and fairly large limits of agreement also indicate poorer performance than when compared with chest ECG systems and other comparisons of wrist based systems on less rigorous tasks.[13] Similar to other wrist PPG validation studies,[14] it appears that the Mio Fuse worked well for about 60% of the Soldiers where R > 0.7 and RMSE <14.5. The only significant factor that was correlated with performance was wrist size. This suggests that the pre-formed and fairly rigid watch band does not match the anthropometry well of some wrist sizes especially larger sizes.

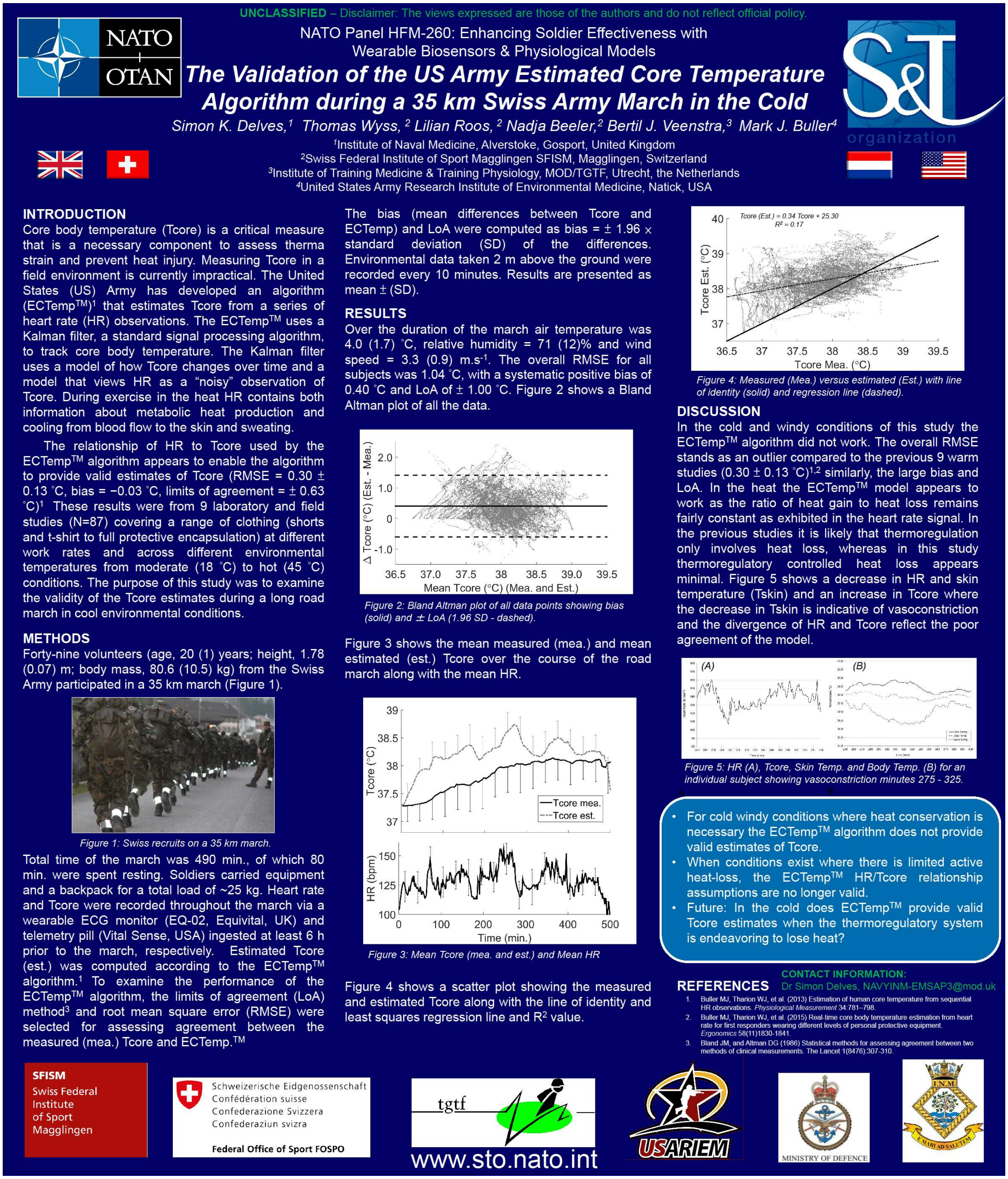
- For many the Mio Fuse provided valid HR data.
- For some the Mio Fuse provided inaccurate HRs.
- Wrist based PPG HR systems should be used with caution. Performance appears person dependent.
- Future Work:
  - ➢ Reliability – Once fit correctly does a wrist based system continue to work well?
  - ➢ Are errors predominantly from fit and wrist anthropometrics?

REFERENCES

CONTACT: Mark Buller: mark.j.buller.civ@mail.mil

1. Beidelman BA, Hoyt RW, Pearce FJ et al. (2003) User Acceptability of Design Concepts for a Life Sign Detection System. Natick MA, USARIEM Technical Report T04-02.
2. Beidelman BA, Tharion WJ, Buller MJ, Hoyt RW, Freund BJ (2004) Reliability and Validity of Devices for a Life Sign Detection System. Natick MA, USARIEM Technical Report T05-01.
3. Buller MJ, Tharion WJ, et al. (2013) Estimation of human core temperature from sequential HR observations. *Physiological Measurement* 34:781–798.
4. Sim SY, Joo KM, Kim HB, et al. (2016) Estimation of circadian body temperature rhythm based on heart rate in healthy, ambulatory subjects. IEEE J Biomed Health Inform. (epub ahead of print).
5. Bland JM, and Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurements. *The Lancet* 1(8476):307-310.
6. Fitzpatrick, T.B. (1988). The validity and practicality of sun reactive skin types I through VI. *Arch Dermatol* 124, 869-871.
7. Forrest A, Gustafson-Storms M, Gale B, et al. (2004) Subject compliance using digital activity log, accelerometer and heart rate monitor to record physical activity. FASEB J. 18:A112.
8. Leger L and Thivierge M (1988) The reliability of heart rate monitors. *Science and Sports* 3(3):211-221.
9. Metz R (2015). The Struggle for Accurate Measurements on Your Wrist. MIT Technology Review, June 22 , 2015: URL: https://www.technologyreview.com/s/538416/the-struggle-for-accurate-measurements-on-your-wrist/ Accessed: 5/25/2016
10. O'Toole M (1998) Use of heart rate monitors by endurance athletes: lessons from triathletes. *J. Sports Med. Phys. Fitness* 38:181-187.
11. Wyss T, Scheffler J, Mader U. Ambulatory physical activity in swiss army recruits. *Int J Sports Med.* 2012;33(9):716-22. doi:10.1055/s-0031-1295445.
12. Wyss T, Roos L, Hofstetter MC, Frey F, Mader U. Impact of training patterns on injury incidences in 12 Swiss Army basic military training schools. *Mil Med.* 2014;179(1):49-55.
13. Parak J, Korhonen I (2014) Evaluation of wearable consumer heart rate monitors based on photopletysmography. Conf Proc IEEE Eng Med Biol Soc. doi: 10.1109/EMBC.2014.6944419.
14. Stahl SE, An HS, Dinkel DM, et al. (2016) How accurate are the wrist-based heart rate monitors during waling and running activities? Are they accurate enough? BMJ
15. Open Sport Exerc Med 2:e000106 doi:10.1136/bmjsem-2015-000106

Figure 3: Validity of Wrist Based Heart Rate Monitors for the Physiological Assessment of Swiss Army Recruits [25].



UNCLASSIFIED – Disclaimer: The views expressed are those of the authors and do not reflect official policy.

NATO Panel HFM-260: Enhancing Soldier Effectiveness with Wearable Biosensors & Physiological Models

The Validation of the US Army Estimated Core Temperature Algorithm during a 35 km Swiss Army March in the Cold

Simon K. Delves,[1] Thomas Wyss,[2] Lilian Roos,[2] Nadja Beeler,[2] Bertil J. Veenstra,[3] Mark J. Buller[4]

[1]Institute of Naval Medicine, Alverstoke, Gosport, United Kingdom
[2]Swiss Federal Institute of Sport Magglingen SFISM, Magglingen, Switzerland
[3]Institute of Training Medicine & Training Physiology, MOD/TGTF, Utrecht, the Netherlands
[4]United States Army Research Institute of Environmental Medicine, Natick, USA

INTRODUCTION

Core body temperature (Tcore) is a critical measure that is a necessary component to assess therma strain and prevent heat injury. Measuring Tcore in a field environment is currently impractical. The United States (US) Army has developed an algorithm (ECTemp™)[1] that estimates Tcore from a series of heart rate (HR) observations. The ECTemp™ uses a Kalman filter, a standard signal processing algorithm, to track core body temperature. The Kalman filter uses a model of how Tcore changes over time and a model that views HR as a "noisy" observation of Tcore. During exercise in the heat HR contains both information about metabolic heat production and cooling from blood flow to the skin and sweating.

The relationship of HR to Tcore used by the ECTemp™ algorithm appears to enable the algorithm to provide valid estimates of Tcore (RMSE = 0.30 ± 0.13 ˚C, bias = −0.03 ˚C, limits of agreement = ± 0.63 ˚C)[1] These results were from 9 laboratory and field studies (N=87) covering a range of clothing (shorts and t-shirt to full protective encapsulation) at different work rates and across different environmental temperatures from moderate (18 ˚C) to hot (45 ˚C) conditions. The purpose of this study was to examine the validity of the Tcore estimates during a long road march in cool environmental conditions.

METHODS

Forty-nine volunteers (age, 20 (1) years; height, 1.78 (0.07) m; body mass, 80.6 (10.5) kg) from the Swiss Army participated in a 35 km march (Figure 1).

Figure 1: Swiss recruits on a 35 km march.

Total time of the march was 490 min., of which 80 min. were spent resting. Soldiers carried equipment and a backpack for a total load of ~25 kg. Heart rate and Tcore were recorded throughout the march via a wearable ECG monitor (EQ-02, Equivital, UK) and telemetry pill (Vital Sense, USA) ingested at least 6 h prior to the march, respectively. Estimated Tcore (est.) was computed according to the ECTemp™ algorithm.[1] To examine the performance of the ECTemp™ algorithm, the limits of agreement (LoA) method[3] and root mean square error (RMSE) were selected for assessing agreement between the measured (mea.) Tcore and ECTemp.™

The bias (mean differences between Tcore and ECTemp) and LoA were computed as bias = ± 1.96 x standard deviation (SD) of the differences. Environmental data taken 2 m above the ground were recorded every 10 minutes. Results are presented as mean ± (SD).

RESULTS

Over the duration of the march air temperature was 4.0 (1.7) ˚C, relative humidity = 71 (12)% and wind speed = 3.3 (0.9) m.s^{-1}. The overall RMSE for all subjects was 1.04 ˚C, with a systematic positive bias of 0.40 ˚C and LoA of ± 1.00 ˚C. Figure 2 shows a Bland Altman plot of all the data.

Figure 2: Bland Altman plot of all data points showing bias (solid) and ± LoA (1.96 SD - dashed).

Figure 3 shows the mean measured (mea.) and mean estimated (est.) Tcore over the course of the road march along with the mean HR.

Figure 3: Mean Tcore (mea. and est.) and Mean HR

Figure 4 shows a scatter plot showing the measured and estimated Tcore along with the line of identity and least squares regression line and R^2 value.

Figure 4: Measured (Mea.) versus estimated (Est.) with line of identity (solid) and regression line (dashed).

DISCUSSION

In the cold and windy conditions of this study the ECTemp™ algorithm did not work. The overall RMSE stands as an outlier compared to the previous 9 warm studies (0.30 ± 0.13 ˚C)[1,2] similarly, the large bias and LoA. In the heat the ECTemp™ model appears to work as the ratio of heat gain to heat loss remains fairly constant as exhibited in the heart rate signal. In the previous studies it is likely that thermoregulation only involves heat loss, whereas in this study thermoregulatory controlled heat loss appears minimal. Figure 5 shows a decrease in HR and skin temperature (Tskin) and an increase in Tcore where the decrease in Tskin is indicative of vasoconstriction and the divergence of HR and Tcore reflect the poor agreement of the model.

Figure 5: HR (A), Tcore, Skin Temp. and Body Temp. (B) for an individual subject showing vasoconstriction minutes 275 - 325.

- For cold windy conditions where heat conservation is necessary the ECTemp™ algorithm does not provide valid estimates of Tcore.
- When conditions exist where there is limited active heat-loss, the ECTemp™ HR/Tcore relationship assumptions are no longer valid.
- Future: In the cold does ECTemp™ provide valid Tcore estimates when the thermoregulatory system is endeavoring to lose heat?

REFERENCES

CONTACT INFORMATION:
Dr Simon Delves, NAVYINM-EMSAP3@mod.uk

1. Buller MJ, Tharion WJ, et al. (2013) Estimation of human core temperature from sequential HR observations. *Physiological Measurement* 34:781–798.
2. Buller MJ, Tharion WJ, et al. (2015) Real-time core body temperature estimation from heart rate for first responders wearing different levels of personal protective equipment. *Ergonomics* 58(11)1830-1841.
3. Bland JM, and Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurements. The Lancet 1(8476):307-310.

SFISM Swiss Federal Institute of Sport Magglingen
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Federal Office of Sport FOSPO
www.sto.nato.int

Figure 4: The Validation of the US Army Estimated Core Temperature Algorithm During a 35 km Swiss Army March in the Cold [26].

UNCLASSIFIED – Disclaimer: The views expressed are those of the authors and do not reflect official policy.

NATO Panel HFM-260: Enhancing Soldier Effectiveness with Wearable Biosensors & Physiological Models

A Comparison of Algorithms Estimating Distance Covered on Foot by Soldiers over Graded Terrain

Bertil J. Veenstra,[1] Simon K. Delves,[2] Mark J. Buller,[3] Thomas Wyss,[4] Lilian Roos,[4] Nadja Beeler[4]

[1]Institute of Training Medicine & Training Physiology, MOD/TGTF, Utrecht, the Netherlands

[2]Institute of Naval Medicine, Alverstoke, Gosport, United Kingdom

[3]United States Army Research Institute of Environmental Medicine, Natick, USA

[4]Swiss Federal Institute of Sport Magglingen SFISM, Magglingen, Switzerland

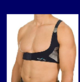
INTRODUCTION

Through NATO Panel HFM-260 a collaborative study was established between Switzerland, the Netherlands, the United States of America and the United Kingdom. This poster presents preliminary results of a comparison of different devices and algorithms used in the Swiss and Netherlands Armed Forces to estimate distance covered on foot by soldiers. The accuracy of the Swiss (CHE) and Dutch (NLD) monitoring systems were investigated during a 35 km road march over graded terrain undertaken by Swiss soldiers.

METHODS

The total time of the march was 490 minutes, of which 80 minutes were spent resting. Soldiers were carrying their equipment (webbing, helmet, weapon) which weighed 7.0 kg and an additional backpack of 17.8 kg. The march started at 562 m above sea level and ended at 370 m above sea level. The distance of the march was measured using maps.geo.admin.ch.

Swiss monitoring system:
Mio FUSE, PARTwear, and GT1M



Dutch monitoring system:
Hidalgo Equivital EQ-02

The following 3 models were compared:

1. CHE algorithms[1] to estimate walking speed:

   Walking speed = 0.705*step.s^{-1} for speeds below 1 m.s^{-1}
   Walking speed = 1.675*step.s^{-1} – 1.464 for speeds above 1 m.s^{-1}

2. NLD algorithm[2] to estimate walking speed:

   Walking speed= 1.083*(step.s^{-1})^2 + 0.173*count.s^{-1} + 0.025*height – 0.011*body mass + 0.145* shoe type – 3.450
   (speed in km.h^{-1}, height in cm, body mass in kg, shoe type: sport shoes = 0; military boots = 1)

3. Mio FUSE algorithm to estimate walking speed:

   Algorithm not known.

RESULTS

A total of 51 soldiers (age 20±1 y; height 1.79±0.07 m; body mass 75.7±10.0 kg) participated. In Table 1 the results over the total march for the three models are shown.

Table 1: Estimated distances for the different devices over the total march (34.2 km)

n=51	CHE model	NLD model	Mio FUSE
Estimated distance (km) mean (sd) min – max Coefficient of variation (%)	 38.5 (2.8) 33.3-44.9 7.3%	 36.2 (1.9) 32.2-40.0 5.2%	 34.9 (2.3) 31.3-40.0 6.6%
% difference with measured distance: mean (sd)	12.6% (8.3%)	5.9% (5.6%)	1.9% (6.6%)
Number of steps mean (sd)	44552 (1869)	45478 (1916)	-
Step length (cm) mean (sd)	86.3 (2.9)	79.7 (2.3)	-

To investigate the influence of the graded terrain on the accuracy of the prediction models, separate analyses were performed for level walking, uphill walking and downhill walking (Figure 1 & Table 2).

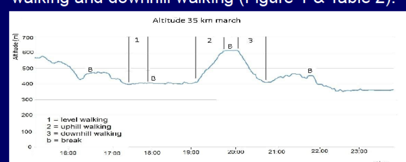


Figure 1: Altitude during the march

Since the Mio FUSE only shows cumulative data, only the CHE and the NLD model could be compared.

Table 2: Estimated distances for level walking, uphill walking and downhill walking by the CHE and the NLD models

n=44	**Level walking** Distance: 3090 m Time: 35 min		**Uphill walking** Ascending 200 m Distance: 3100 m Time: 42 min Mean slope: 6.5%		**Downhill walking** Descending 200 m Distance: 3650 m Time: 42 min Mean slope: 5.5%	
	CHE	**NLD**	**CHE**	**NLD**	**CHE**	**NLD**
Mean Estimated distance (m)	3311*	3099	3577*	3438*	4023*	3749*
Sd	291	210	302	190	344	211
% difference	**7.1%**	**0.3%**	**15.4%**	**10.9%**	**10.2%**	**2.7%**
Mean speed (km.h^{-1})	5.3		4.4		5.2	
Mean steps.min^{-1}	109		104		111	
Mean step length (cm)	81		71		78	

The estimation of distance is most accurate for level walking. Compared to level walking, downhill walking increases the error by 2.4-3.1% and uphill walking by 8.3-10.6%. The mean step length during uphill walking was 10 cm shorter compared to level walking.

Figure 2 shows boxplots of the estimated distances for the total march, level walking, uphill walking and downhill walking.

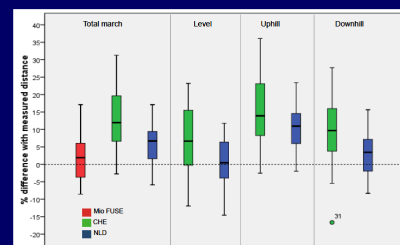


Figure 2: Boxplots for the percentage difference with the measured distances. For the total march, 51 soldiers were included. For the boxplots of level, uphill and downhill walking, 41 soldiers were included.

Correlation coefficients between body height and the residuals of the different algorithms (CHE -0.62; NLD -0.43, Mio FUSE -0.54) suggest that all algorithms were more accurate for taller people.

CONCLUSIONS

- Estimating walking distance with a single accelerometer, without individual calibration, can be accurate for military activity.
- A model only based on step frequency (CHE) is less accurate than a model including body height and body mass (NLD).
- Walking downhill increases the step frequency by 2 steps.min^{-1} and decreases the step length by 3 cm compared to level walking. Walking down a 5.5% slope leads to an overestimation in distance of 2.4-3.1%.
- Walking uphill decreases the step frequency by 5 steps.min^{-1} and decreases step length by 10 cm compared to level walking. Walking up a 6.5% slope leads to an overestimation in distance of 8.3-10.6%.
- When predicting distance in graded terrain, a correction should be made for uphill and downhill walking.
- The effects of graded terrain on the Mio FUSE estimation needs further investigation.

REFERENCES

1. Wyss, T., Scheffler, J. & Mäder, U. (2012). Ambulatory Physical Activity in Swiss Army Recruits. International Journal of Sports Medicine, 33: 716-722.
2. Kaaden van der L. (2012) A new model to estimate walking and running speed from anthropometric measures and accelerometer data. Unpublished master thesis.

CONTACT INFORMATION
Bertil Veenstra: bj.veenstra.01@mindef.nl

SFISM Swiss Federal Institute of Sport Magglingen

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Federal Office of Sport FOSPO

tgtf

www.sto.nato.int

USARIEM

MINISTRY OF DEFENCE

I.N.M. MARI AD SALUTEM

Figure 5: A Comparison of Algorithms Estimating Distance Covered on Foot by Soldiers in Consideration of Graded Terrain [27].

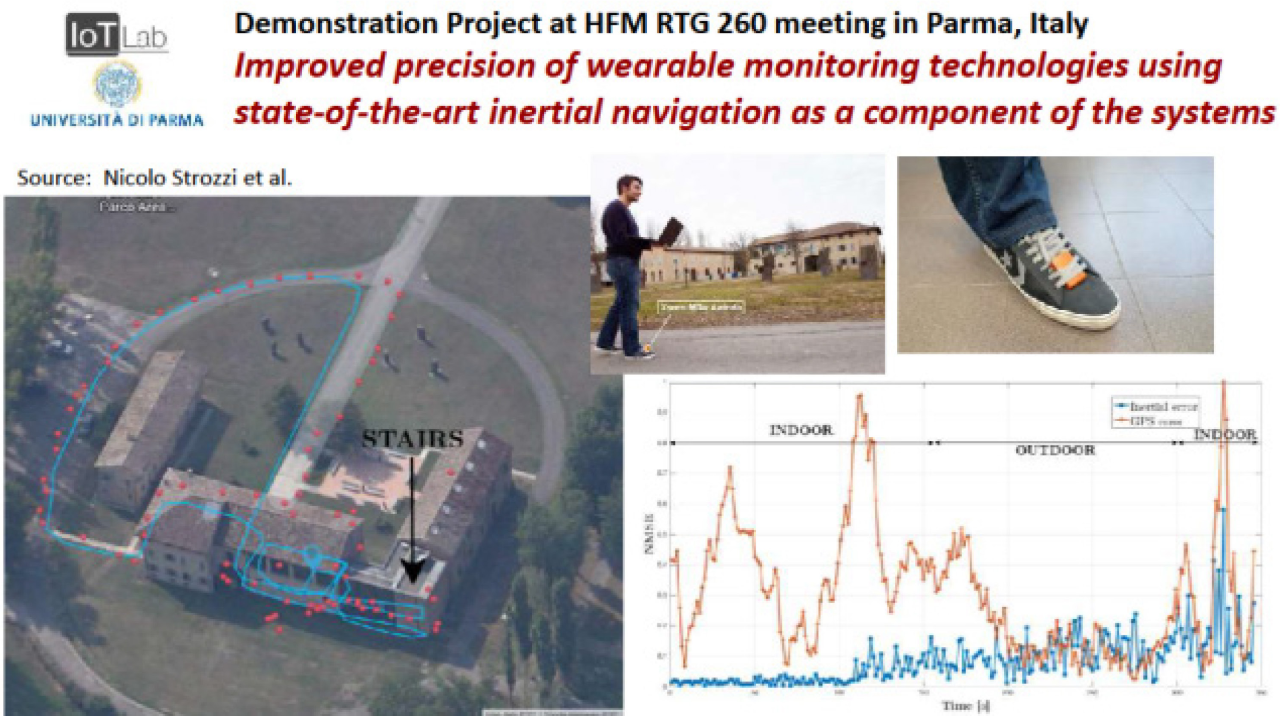


Figure 6: Demonstration Project at RTG HFM-260.

The RTG HFM-260 meeting included detailed and extensive country updates on wearable efforts and projects either planned or underway. Wendy Sullivan-Kwantes (CAN) outlined her field research work on monitoring freezing cold injury in Canadian Forces, using glove and boot temperature monitoring to understand the risk factors for cold weather injury in the Arctic. Mark Buller (USA) outlined concepts for an “adaptive PSI” involving an adjustment of the core temperature set point from differences in core temperature to skin temperature gradients. Jason Lee initiated discussion about a tropical thermal test for Singapore vs. the Israeli Defence Forces heat tolerance test which does not distinguish heat injured and control Singaporeans. A second multinational study led by Switzerland was outlined. Progress in the development of the Dutch ARMOR system was outlined including description of the very interesting load sensing boot insert. Craig Murdock (USA) presented a detailed outline of US Air Force initiatives with industry collaborations to develop a smart shirt and used of ECTemp with the Zephyr system at Lackland Air Force Base to monitor heat strain in basic recruits. An effort to organize a survey of researcher opinions on acceptable/required precision for physiological parameter predictions, based on the survey done by Sean Notley (Wollongong University), was discussed by the group and later discussed with Notley at the Slovenia PPTR meeting – with a plan to solicit responses at the ICSPP meeting in Melbourne, Australia, at the end of the year.

2.5 Fifth Meeting: Training Load Assessment

Date:	May 2017
Theme:	Training load assessment and the 2nd "March in March" cooperative study
Location:	Kromhoutkazerne, Utrecht, the Netherlands (Figure 7)
Host:	Bertil Veenstra, Institute of Training Medicine and Training Physiology, MOD/TGTF
Guest Presenters: (Uncompensated)	Brian Telfer (oximetry) and Joe Lacrignola (boot inserts)
NATO Inter-Panel Presenter:	Hein Daanen (RTG HFM-266)
Associated Conference:	14th International IEEE Body Sensor Networks, Philips High Tech Campus Eindhoven, Eindhoven, Netherlands, May 9 – 12, 2017

Hein Daanen, chairman of RTG HFM-266, presented a summary on "3D scanning for clothing fit and logistics" and discussed common interests in form-fitted wearable electronics; the group produced a STANREC on recommended procedures and applications.

Figure 7: RTG HFM-260 Team at Kromhoutkazerne, Utrecht, Netherlands.

Note: Pictured from left to right: Reed Hoyt (USA), Bertil Veenstra (host) (NLD), Craig Murdock (USA), Simon Delves (GBR), Karl Friedl (USA), Mark Buller (USA), Nicolo Strozzi (ITA), Brian Telfer (USA), Jeffrey Palmer (USA), Joseph Lacrignola (USA), Jason Lee (SGP), Roy Vigneulle (USA), Mounir Chennaoui (FRA), Hilde Teien (NOR), Ertan Zaferoglu (TUR), Lkol Leon Jans (NLD), Hein Daanen (NLD).

Guest presentations previewed BSN 2017 presentations from MIT Lincoln Labs on instrumented footwear inserts (Joe Lacirignola) and wearable oximetry in extreme environments (Brian Telfer).

Country updates included new sleep and alertness research on drone operators in Mali (FRA); monitoring temperature thresholds appropriate to tropical environments (SGP); US-UK joint thermal monitoring and heat acclimation acceleration with monitoring (UK); Skjold 2017 studies involving the Actical accelerometer (NOR); and continued analysis of the "March in March" data (CHE, NLD).

Plans were made for presentations in four main thematic sessions for the ICSPP 2017 in Melbourne, Australia.

A new representative from Turkey outlined an interest in pilot health monitoring using near fNIRS technology.

Relevant publication (discussed in the group): Ref. [35]. NATO group member presentations and organizer roles at IEEE BSN 2017 (Eindhoven, Netherlands): [36], [37], [38], [39], [40], [41] (Figure 8), [42] (Figure 9).

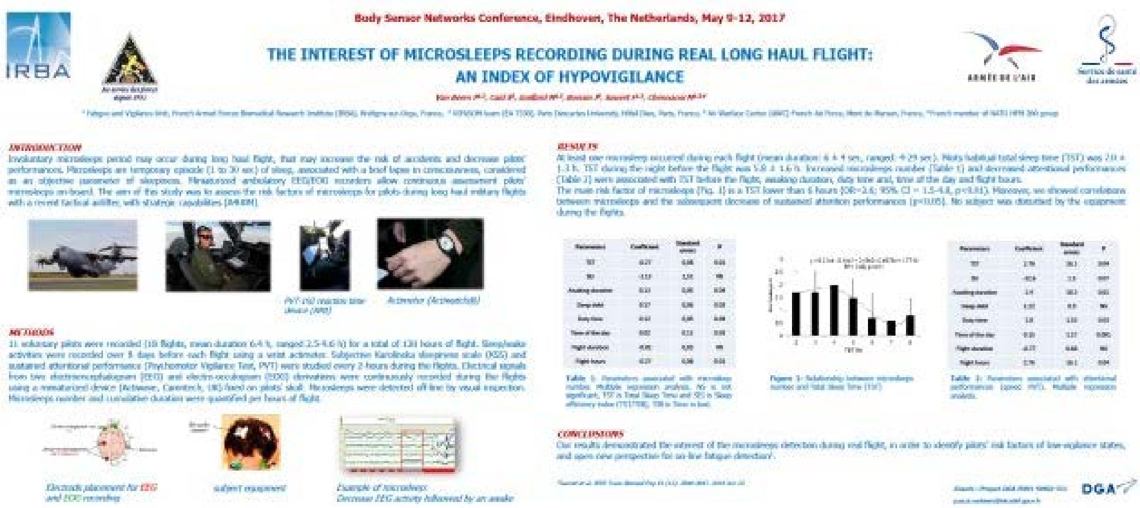


Figure 8: The Interest of Microsleeps Recording During Real Long Haul Flight [41].

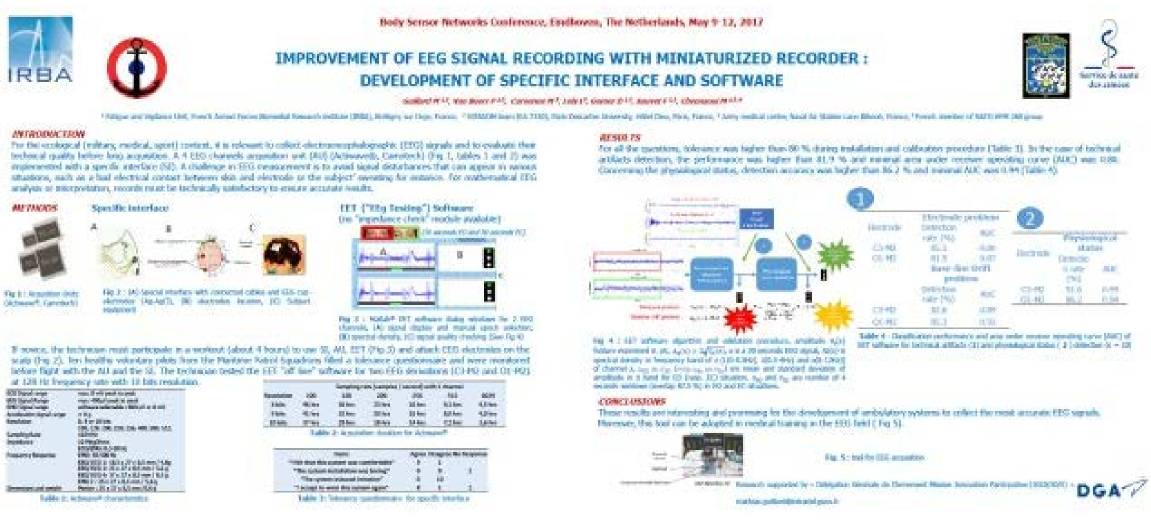


Figure 9: Improvement of EEG Signal Recording with Miniaturized Recorder [42].

2.6 Sixth Meeting: Military Applications of Wearable Physiological Monitoring

Dates:	November 29, 2017
Theme:	Military applications of wearable physiological monitoring
Location:	Melbourne Conference Centre, Melbourne, Australia
Host Support:	DSTG/4th ICSPP conference organizers
Associated Conference:	4th International Congress on Soldier Physical Performance, Melbourne, Australia, November 30–December 3, 2017

The RTG HFM-260 group meeting considered country updates and then focused on the ICSPP program which highlighted the efforts of RTG HFM-260, sharing this information with the broader international military biomedical research community (Abstracts in Annex C).

Country updates included: field validation of the heat strain algorithm of Kok-Yong Seng in Singaporean infantry route marching (SGP); the EEG Dreem headband system was further validated for slow wave sleep detection and accurate closed-loop auditory stimulation (FRA); the Brunei jungle warfare instructor course thermal monitoring study and evaluation of ECTemp was advancing (GBR); actigraphy data is being collected in a study of Norwegian Army Special Forces using the ActiGraph (NOR); studies with applications of heat strain monitoring and use cases in basic training for Air Force and Army continue (USA); new efforts to use accelerometry to monitor factors such as speed and stride length to model gait asymmetries and other indicators of fatigue and impending musculoskeletal injury (USA); results of the 2nd multinational study on Swiss recruits involving wearing comfort and accuracy of the Everion device were previewed (CHE); involvement of RTG HFM-260 members in the Trident Juncture Exercise 2018 (TJE-2018) were considered but considered likely premature demonstrations of cold monitoring (CAN); near final developmental stages of ARMOR system were outlined (NLD); a new warfighter performance study with comprehensive monitoring of physical, psychological, cognitive workload has been commissioned by the Finnish Defence Forces (FIN); plans for the precision survey of ICSPP participants were discussed; preparation for the CDT with Royal Marine Commandos was also discussed.

Thematic sessions with presentations related to NATO HFM-260 included six presentations on wearable monitoring; five presentations in a thematic session on potential use of wearable monitoring for performance enhancement ("technological doping"); and a keynote talk on NATO efforts in wearable monitoring: see Refs. [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57].

2.7 Seventh Meeting: Collaboration Demonstration of Technology (CDT) on Wearable Military Applications

Dates:	May 21 – 25, 2018
Theme:	Collaboration Demonstration of Technology (CDT) on Wearable Military Applications
Location:	Portsmouth Naval Base, Portsmouth, United Kingdom
Host:	Simon Delves, Institute of Naval Medicine
Key Activity:	CDT at Commando Training Centre, Royal Marines, Lympstone, United Kingdom

RTG HFM-260 members were updated on current national projects (22, 25 May) and then participated in the CDT at the Commando Training Centre, Royal Marines, Lympstone (23 – 24 May) (Agenda in Annex D) (Figure 10). The CDT involved presentations to the Cadre and other invited VIPs on selected efforts by RTG HFM-260 members and then involved a real-time physiological monitoring exercise with wearable sensor systems from multiple countries.

Figure 10: RTG HFM-260 Team at the Marine Commando Training Centre, Lympstone, UK.

Note: Pictured from left to right: Gianluigi Ferrari (ITA), Nicolo Strozzi (ITA), Jeffrey Palmer (USA), Karl Friedl (USA), Bertil Veenstra (NLD), Simon Delves (host)(GBR), Mark Buller (USA), Thomas Wyss (CHE), Craig Murdock (USA), Hilde Teien (NOR), Jessica Conradi (DEU), Philip Newton (CAN).

Country updates included: a new study of the Norwegian Defence Cyber Academy involving actigraphy as a key monitoring tool (NOR); plans for a large-scale heat strain monitoring study to collect data on the few heat stroke cases that are likely to occur, with emphasis on identifying early changes in neuromotor coordination that may permit earlier identification of serious thermal injury (USA); development of new mobile training applications for Swiss recruits preparing for military service with information from monitoring data on specific physical workload and fitness requirements for various military occupations (CHE); development of WiFi mesh networking for monitoring systems, an ultrawide band system for localization in indoor environments, and exploration of smartphone IMU estimation of real-time path (ITA); initial field studies of physical workload effects on cognition with Jaeger Brigade SERE training in Sodankyla, Finland (FIN); summary of the work on DFIT fitness testing and related programs in Canada (CAN); advances in the development of the ARMOR system, and new workload monitoring studies on security guards and military police (NLD). A special presentation was made by Jessica Conradi on the work of the Frounhofer Institute (FKIE) on secure mobile communications engineering (DEU).

Presentations made to the audience at Commando Training Centre, Royal Marines, Lympstone, UK, and CDT agenda: (Annex D) [58], [59], [60], [61], [62], [63], [64], [65].

CDT summary as a news item on the NATO CSO website: (see Figure 11).

NATO STO Panel HFM-260
"Enhancing Warfigher Effectiveness with Wearable Biosensors and Physiological Models"
Cooperative Demonstration of Technology (CDT)
Royal Marine Commando Training Centre, Lympstone, UK

NATO STO Panel HFM-260 conducted a very successful demonstration of current wearable physiological monitoring concept systems with a group of Royal Marine Commandos who provided voluntary consent to wear the systems while conducting their normal training, including a speed march. This Concept Demonstration highlighted the feasibility of non-invasive ("wear and forget") systems that can provide real-time actionable information to leaders during intensive training. Near term applications of wearable physiological monitoring technologies in training involve thermal strain and musculoskeletal/workload fatigue and injury risk. This has been a focus of the panel, along with continuous coordination on development of wearable, accurate, reliable devices, and coordinated multinational research. The CDT included network-integrated systems from the US and UK providing personal, local, and remote presentation of heat injury mitigation technology, and subsets of Royal Marines wore the Royal Netherlands Army Physical Demands ARMOR system, the Swiss Axiamo PADIS 2.0, or the University of Parma Dead Reckoning System.

Pictured: Simon Delves from the Institute of Naval Medicine briefs visitors on the real-time thermal-work strain data transmitted from Royal Marines during a speed march (left); Royal Marines with boot-worn inertial measurement units that provide dead reckoning information and movement patterns for soldiers operating in urban environments (right).

Figure 11: CDT Summary as a News Item on the NATO CSO Website.

2.8 Eighth Meeting: Accelerometry

Dates:	June 25, 2019
Theme:	Accelerometry and behavioral monitoring
Location:	Maastricht, Netherlands (Figure 12)
Host:	Bertil Veenstra
Associated Activity:	6th International Conference on Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM), Maastricht, Netherlands (26 – 28 June 2019)

Figure 12: RTG HFM-260 Team at the Maastricht City Hall.

Note: Pictured from right to left, front to back: Thomas Wyss (CHE), Bertil Veenstra (NLD)(front); Reed Hoyt (USA), Karl Friedl (USA), Simon Delves (GBR), Philip Newton (CAN) (middle); Mounir Chennaoui (FRA), Kok-Yong Seng (SGP), Hilde Teien (NOR), Mark Buller (USA) (back). Kari Kallinen, Craig Murdock present at the meeting but not pictured.

Country presentations and updates included: current work and objectives in thermal strain predictions and monitoring in Singaporean Forces (SGP) [66]; current progress in the multiyear Canadian program for freezing cold injury monitoring in Canadian Forces during Arctic exercises and opportunities to improve hand and foot protective equipment (CAN) [67]; update on the French sleep monitoring and intervention tools including the Dreem headband [68]; update on analyses and publications from the "March in March" studies (CHE) [69], [70], [71], [72], [73]; Dutch advances in development and procurement of the ARMOR" system to monitor recruits during their basic training (NLD); new initiatives in Norwegian soldier research including a new program on performance in the cold (NOR); invaluable data obtained from six monitored heat stroke cases as they evolved during the monitoring of hundreds of US and UK soldiers / Royal Marines in training is expected to yield new insights into critical thermal strain warnings (GBR/USA); new work for Craig Murdock was presented on decontamination of major equipment systems and aircraft in a CBRNE environment, which will inevitably require physiological monitoring and outward sensing systems for the aircrew (USA); opportunities to monitor mental status from accelerometry (behavior) and other sensor data was briefly discussed in the context of the upcoming EMBC meeting in Berlin (USA).

The group was asked by Bertil Veenstra for a self-assessment of the panel in terms of return on the investment (members' travel, time, and costs) in productivity and value to each country, and how well our panel planning and strategy worked. There was a general consensus that this has been very productive. The facilitation by CHE for multinational research permitted studies that no one country had sufficient equipment and resources to accomplish alone. The GBR field model with humid heat training in Brunei provided another experimental testbed and opportunity for more than one country. The three CDT (concept demonstrations) involving novel concepts in wearable EEG and sleep intervention devices (FRA), state-of-the-art inertial navigation (ITA), and military applications wearables in Royal Marine training (GBR) were valuable opportunities for panel participants to explore the state-of-the-science in wearable monitoring. The CDTs were also valuable in calling attention to the fact that focused military applications in this area of science and technology are being actively worked on and that the military allies have a unique acquired expertise in this panel.

The group discussed follow-on opportunities that will fall primarily in three thrust areas:

- Proposed follow-on RTG that will complete the work **on thermal monitoring systems and applications focused on thermal monitoring in hot environments**, notably personalized monitoring for safer and more effective training, and with the goal of producing a STANREC summarizing the concepts to be developed and refined in the lead countries. SGP expressed their interest in also continuing with the NATO countries and CHE. A new TAP has been prepared and will be submitted through the Dutch country representative and proposed mentor. Aspects of workload monitoring for training effectiveness and to prevent musculoskeletal injury risk are also considerations in this effort.
- New RTG 310 (**Protection and performance in the cold**), led by Wendy Sullivan-Kwantes will include follow-on efforts in physiological monitoring for:
    1) Associations with freezing cold injury and hypothermia;
    2) To improve the effectiveness of protective equipment; and
    3) To monitor mental status and performance in the cold. CAN, GBR, NOR, SWE have joined and USA, FIN have expressed specific interests in this effort.
- ET 179 (**Biomedical basis of fatigue interventions**) has prepared the TAP for a new proposed RTG on Mental Endurance. A key component of this effort will include development and validation of field monitoring systems and algorithms for mental status (fatigue and alertness) and performance. FRA, USA are proposed leads, with a mentor from BEL.

The ICAMPAM conference agenda was briefly discussed, including two poster presentations and a podium presentation from panel members. Associated conference presentations: [74], [75], [76] (Figure 13).

Disclaimer: The views expressed are those of the authors and do not reflect official policy.

The Feasibility of Ambulatory Physical Activity Monitoring Devices in Studies on Soldiers

SFISM
Swiss Federal Institute of Sport Magglingen

Thomas Wyss[1], Lilian Roos[1], Karl Friedl[2], Mark Buller[2], Simon K. Delves[3] & Bertil Veenstra[4]

[1]Swiss Federal Institute of Sport SFISM, Magglingen, Switzerland
[2]United States Army Research Institute of Environmental Medicine, Natick, MA, USA
[3]Institute of Naval Medicine, Alverstoke, Hampshire, United Kingdom
[4]Institute of Training Medicine & Training Physiology, TGTF, Royal Netherlands Army, Utrecht, The Netherlands

Figure 1: Investigated monitoring devices

Introduction

Today's Armed Forces are using data about their soldiers' physical demands for decision making processes, injury and dropout prevention and training quality management. Increasing amounts of monitors, which can be used for this purpose, are becoming available. To choose the most appropriate device, information about the measurement accuracy, wearing comfort and feasibility is key. It was the aim of an international collaboration study, within the NATO panel HFM 260, to investigate these parameters for different devices used in military organizations worldwide to assess heart rate (HR) and energy expenditure (EE) among soldiers. On the present poster, data on the feasibility part are presented.

Method

The investigated monitoring devices are shown in Figure 1. Presented data are based on the hard- and software versions available as of January 11th 2017. Human resources were determined by the average time needed for sensor preparation, calibration, fitting on subject, data download and export. Wearing comfort was assessed among 32 volunteers from a Swiss Army infantry training school by questionnaire after wearing each system for one working day, as approved by the local ethics committee (Beeler et al. 2018). For determination of the devices' measurement time, an epoch time of 30 seconds was set. It was noted if the systems were able to provide real-time data synchronization with a receiver system within a 30 m range, and if they provided raw data. The devices were ranked by their values within each assessed category. The strength and weaknesses of each system are displayed in radar charts (Figure 2).

Results

The GENEActive device (208 USD and 2 min per subject) needed the fewest monetary and human resources, followed by fēnix 3, Axiamote and Everion (449 to 820 USD and 5-11 min per subject). The most cost and time expensive devices were ActiHeart, EQO2 and Blue Thunder (1054 to 1533 USD and 13 to 22 min per subject). Wearing comfort was rated highest in Axiamote followed by fēnix 3, Everion and ActiHeart. ActiHeart, Aximote and GENEActive provided a measurement duration of 7 days or more. EQO2 and Everion provided a measurement duration of at least 24 hours, while fēnix 3 and Blue Thunder batteries lasted only 20 and 6 hours, respectively. In EQO2, Everion and Blue Thunder real-time tracking with a receiver system on site was available. Only fēnix 3 and ActiHeart did not provide raw data. The greatest overall feasibility score was found in Everion, Axiamote and GENEActive with 16 to 18 ranking points compared to 26 to 30 ranking points in the other devices (Figure 2).

Discussion

Together with information about measurement accuracy of such monitoring devices, the present study helps decision makers to choose appropriate systems for ambulatory physical activity monitoring in soldiers. However, they have to keep in mind, that hard- and software of the investigated devices might have changed since January 2017 and newer measurement systems are now available on the market.

Reference

Beeler, N., Roos, L., Delves, SK., Veenstra, BJ., Friedl, K., Buller, MJ., and Wyss, T. (2018). The Wearing Comfort and Acceptability of Ambulatory Physical Activity Monitoring Devices in Soldiers. IISE Transactions on Occupational Ergonomics and Human Factors.

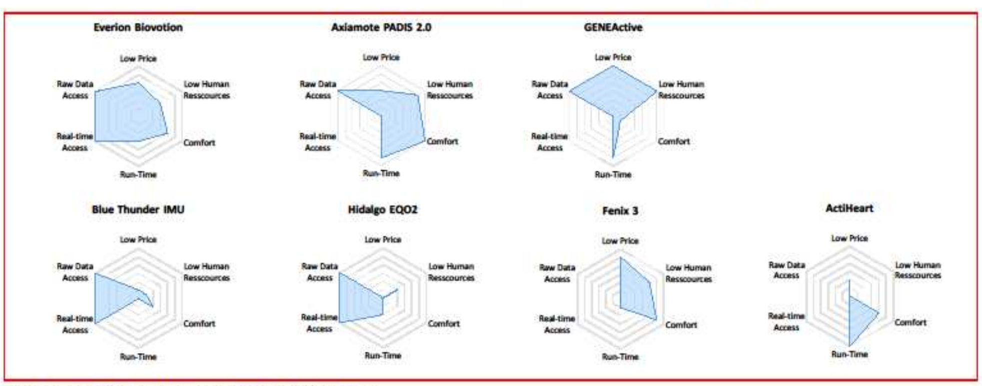


Figure 2: Feasibility of investigated monitoring devices

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Office of Sport FOSPO

Figure 13: The Feasibility of Ambulatory Physical Activity Monitoring Devices in Studies on Soldiers [76].

3.0 SUMMARY POINTS

3.1 Focus of the Group

RTG HFM-260 considered the state-of-the-art in military applications of physiological monitoring and ultimately focused on the most promising near term uses, in this order:

1) Prevention of heat injury in training;
2) Monitoring of workload to prevent musculoskeletal injury in recruit training;
3) More effective scheduling of pilots and drone operators based on wearable sleep monitoring;
4) High-precision wearable satellite-based location module with embedded IMU and various wireless connectivities (LoRaWAN, WiFi, BLE); and
5) Improvement of cold weather equipment and training based on hand and foot temperature monitoring in the Arctic.

A variety of other uses, including monitoring of mental status and mood were examined and specific types of sensor technologies were discussed and considered (e.g., varieties of boot inserts and load cells; IMUs; accelerometers; and oximeters) along with mathematical models to interpret patterns of response to provide actionable information for soldiers. Electronic communications, cybersecurity, information management, and human factors considerations were necessarily part of the discussions concerning transition of useful systems to soldiers.

3.2 Follow-On Efforts, Including Proposed New HFM Panels

Three new or proposed HFM efforts are expected to continue to build on the work of this panel.

3.2.1 New RTG HFM-327, Based on RTG HFM-260: Development of a NATO STANREC for Physiological Status Monitoring to Mitigate Exertional Heat Illness

Proposed follow-on RTG will complete the work on thermal monitoring systems and applications focused on thermal monitoring in hot environments, notably personalized monitoring for safer and more effective training. Key questions remaining include algorithms that will provide better information about actual heat injury risk (e.g., gait wobble index), more accurate personalized information (e.g., adjusted PSI), development of use cases (e.g., risk stratification), field validation across a range of soldier populations and circumstances, and optimization of practical and scientific considerations in wearable systems (e.g., wrist is too inaccurate for sensing and chest may not be universally accepted). This panel proposes to generate a STANREC summarizing the concepts developed and refined by the group. A new TAP has been prepared and will be submitted through the Dutch country representative, who is also the proposed mentor.

3.2.2 New RTG-310: Human Performance and Medical Treatment and Support During Cold Weather Operations

A recently approved RTG-310, focused on performance and protection in the cold and led by Wendy Sullivan-Kwantes (CAN), will include follow-on efforts in physiological monitoring for:

1) Associations with freezing cold injury and hypothermia;
2) To improve the effectiveness of protective equipment; and
3) To monitor mental status and performance in the cold. CAN, GBR, NOR, SWE have joined and USA, FIN have expressed specific interests in this effort.

3.2.3 Proposed New RTG, from HFM-ET-179 (Biomedical Bases of Mental Fatigue and Military Fatigue Countermeasures): Psychobiology and Management of Warfighter Mental Endurance

HFM-ET-179 (Biomedical basis of fatigue interventions) met twice in 2018 – 2019 and prepared a TAP for a new proposed RTG on Mental Endurance. A key component of this effort will include development and validation of field monitoring systems and algorithms for mental status (fatigue and alertness) and performance. FRA, USA are proposed leads, with a mentor from BEL.

3.3 Impact

RTG HFM-260 was established with an ideal balance of expertise that included physiologists, bioengineers, practical field researchers, vigilance and sleep, cold weather operations, recruit training and psychology, network and communications experts, and others. This optimal multidisciplinary mix contributed to thoughtful multinational deliberations and experiments that advanced the science of military wearable applications within the group. At the same time, members of the group were able to communicate within their own countries and military organizations about the efforts of the group, moderating the typical enthusiasm for commercially available "bright shiny toys" and building enthusiasm for productive paths to implementation of systems that may actually provide important and useful (i.e., actionable) information to address military needs. Members of the group helped to spread the word through publications, conference presentations, and even invited keynote lectures on wearable monitoring in soldiers (see References section in this report, including Ref. [77] to [111]). Meetings synchronized with national and international science conferences permitted the RTG HFM-260 to have a maximum impact on shaping the thinking of other scientists to help solve problems of importance to the military (e.g., explaining the soldier problems and how somebody's bioengineering technology could be redirected to solutions for those problems). The interaction with other NATO panels (e.g., RTG HFM-266, 3D Body Scanning Technologies for Clothing Fit; RTG-269, Physical Employment Standards) ensured dissemination of expertise and findings across related efforts. The true value and impact of RTG HFM-260 will only become apparent in the next few years with the successful adoption of wearable monitoring technologies.

4.0 REFERENCES

First Meeting – Relevant Publications

[1] (FRA) Trousselard, M., Leger, D., van Beers, P., Coste, O., Vicard, A., Pontis, J., Crosnier, S.N., and Chennaoui, M., Sleeping Under the Ocean: Despite Total Isolation, Nuclear Submariners Maintain Their Sleep and Wake Patterns Throughout Their Undersea Mission. PloS One 2015;10:e0126721.

[2] (FRA) Dussault, C., Jouanin, J.-C., Philippe, M., and Guezennec, C.Y., EEG and ECG Changes During Simulator Operation Reflect Mental Workload and Vigilance. Aviat Space Environ Med 2005;76:344-51.

[3] (FRA) Sauvet, F., Bougard, C., Coroenne, M., Lely, L., van Beers, P., Elbaz, M., Guillard, M., Leger, D., and Chennaoui, M., In-Flight Automatic Detection of Vigilance States Using a Single EEG Channel. IEEE Trans Biomed Eng 2014;61:2840-7.

[4] (NOR) Castellani, J.W., Spitz, M.G., Karis, A.J., Martini, S., Young, A.J., Margolis, L.M., Karl, J.P., Murphy, N.E., Xu, X., Montain, S.J., and Bohn, J.A., Cardiovascular and Thermal Strain During 3 – 4 Days of a Metabolically Demanding Cold-Weather Military Operation. Extr Physiol Med 2017;6:2.

Guest Presenter Papers

[5] (USA) Teyhen, D.S., Aldag, M., Edinborough, E., Ghannadian, J.D., Haught, A., Kinn, J., Kunkler, K.J., Levine, B., McClain, J., Neal, D., and Stewart, T., Leveraging Technology: Creating and Sustaining Changes for Health. Telemed e-Health 2014;20:835-49.

[6] (USA) Teyhen, D.S., Aldag, M., Centola, D., Edinborough, E., Ghannadian, J.D., Haught, A., Jackson, T., Kinn, J., Kunkler, K.J., Levine, B., and Martindale, V.E., Incentives to Create and Sustain Healthy Behaviors: Technology Solutions and Research Needs. Mil Med 2014;179:1419-31.

IEEE BSN 2015 Conference: Meeting Participation by NATO RTG HFM-260 Members

[7] Buller, M.J., Welles, A.P., Stevens, M., Leger, J., Gribok, A., Jenkins, O.C., Friedl, K.E., and Rumpler, W., Automated Guidance from Physiological Sensing to Reduce Thermal-Work Strain Levels on a Novel Task. In: Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference, 2015 June 9. IEEE.

[8] Williamson, J.R., Dumas, A., Hess, A.R., Patel, T., Telfer, B.A., and Buller, M.J., Detecting and Tracking Gait Asymmetries with Wearable Accelerometers. In: Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference, 2015 June 9. IEEE.

[9] Williamson, J.R., Dumas, A., Ciccarelli, G., Hess, A.R., Telfer, B.A., and Buller, M.J., Estimating Load Carriage from a Body-Worn Accelerometer. In: Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference, 2015 June 9. IEEE.

[10] Friedl, K.E., What Can Sleep Activity Measures Tell Us About Health and Disease? 3rd International Symposium on Automated Sensor Based Mobility Analysis for Disease Prevention and Treatment. Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference, 2015 June 9, MIT Media Lab, Cambridge, MA, 2015 June 12.

Second Meeting – Relevant Publications

[11] Sauvet, F., Bougard, C., Coroenne, M., Lely, L., van Beers, P., Elbaz, M., Guillard, M., Leger, D., and Chennaoui, M., In-Flight Automatic Detection of Vigilance States Using a Single EEG Channel. IEEE Transactions on Biomedical Engineering 2014;61:2840-7.

[12] Debellemaniere, E., Chambon, S., Pinaud, C., Thorey, V., Dehaene, D., Léger, D., Chennaoui, M., Arnal, P.J., and Galtier, M.N., Performance of an Ambulatory Dry-EEG Device for Auditory Closed-Loop Stimulation of Sleep Slow Oscillations in the Home Environment. Frontiers in Human Neuroscience 2018;12:88.

Third Meeting – Relevant Publications

Guest Presenter Papers

[13] Chen, K.Y., and Sun, M., Improving Energy Expenditure Estimation by Using a Triaxial Accelerometer. Journal of Applied Physiology 1997;83:2112-22.

[14] Chen, K.Y., Acra, S.A., Majchrzak, K., Donahue, C.L., Baker, L., Clemens, L., Sun, M., and Buchowski, M.S., Predicting Energy Expenditure of Physical Activity Using Hip- and Wrist-Worn Accelerometers. Diabetes Technology and Therapeutics 2003;5:1023-33.

[15] Rothney, M.P., Apker, G.A., Song, Y., and Chen, K.Y., Comparing the Performance of Three Generations of ActiGraph Accelerometers. Journal of Applied Physiology 2008;105:1091-7.

Technical Reports/Reviews

[16] Burrell, C., Love, R.J., and Stergiopoulos, S., Integrated Physiological Monitoring. Scientific Report DRDC-RDDC-2016-R207. DRDC Toronto Centre, Defence Research and Development Canada, Toronto, Canada. October 2016.

[17] Friedl, K.E., Buller, M.J., Tharion, W.J., Potter, A.W., and Hoyt, R.W., Real Time Physiological Status Monitoring (RT-PSM): Accomplishments, Requirements, and Research Roadmap. Technical Note 16-02. US Army Research Institute of Environmental Medicine, Natick, MA. 2016.

IEEE BSN 2016 – Meeting Participation by NATO RTG HFM-260 Members

Session 2: “Non-Human Biomonitoring and Protection (session chair: Karl Friedl)

[18] Williamson, J.R., Hess, A.R., Smalt, C.J., Sherrill, D.M., Quatieri, T.F., and O’Brien, C., Using Collar-Worn Sensors to Forecast Thermal Strain in Military Working Dogs. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14 (pp. 281-286). IEEE [USARIEM funded collaboration, directed by Reed Hoyt].

Session 3: “Wearable Sensor Applications in Extreme Environments” (session chair: Mark Buller)

[19] Teien, T., Physiological Monitoring in Cold Weather Operations. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14.

[20] Seng, K.-Y., Chen, Y., Chai, K.M., Wang, T., Fun, D.C., Teo, Y.S., Tan, P.M., Ang, W.H., and Lee, J.K., Tracking Body Core Temperature in Military Thermal Environments: An Extended Kalman Filter Approach. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14 (pp. 296-299). IEEE.

[21] Strozzi, N., Parisi, F., and Ferrari, G., On Single Sensor-Based Inertial Navigation. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14 (pp. 300-305). IEEE.

[22] Ludlow, L.W., and Weyand, P.G., Estimating Loaded, Inclined Walking Energetics: No Functional Difference Between Added and Body Mass. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14 (pp. 306-311). IEEE. [USARIEM funded collaboration].

[23] Wyss, T., Veenstra, B., Delves, S., and Buller, M., Monitoring Thermal Strain During Recruit Training. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14.

Session 3: "Wearable Biomechanics" (session chair: Kong Chen)

[24] Udofa, A.B., Ryan, L.J., and Weyand, P.G., Impact Forces During Running: Loaded Questions, Sensible Outcomes. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14 (pp. 371-376). IEEE. [USARIEM funded collaboration].

Presentations from the "March in March" International Study of Swiss Recruits

[25] Buller, M.J., Delves, S.K., Veenstra, B.J., Roos, L., Beeler, N., and Wyss, T., Validity of Wrist Based Heart Rate Monitors for the Physiological Assessment of Swiss Army Recruits. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14. (Poster).

[26] Delves, S.K., Wyss, T., Roos, L., Beeler, N., Veenstra, B.J., and Buller, M.J., The Validation of the US Army Estimated Core Temperature Algorithm During a 35 km Swiss Army March in the Cold. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14. (Poster).

[27] Veenstra, B.J., Delves S.K., Buller, M.J., Wyss, T., Roos, L., and Beeler, N., A Comparison of Algorithms Estimating Distance Covered on Foot by Soldiers in Consideration of Graded Terrain. In: 2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2016 June 14. (Poster)

Fourth Meeting – Relevant Publications

[28] Strozzi, N., Pedestrian Inertial Navigation. Doctoral Dissertation, Università degli studi di Parma. Dipartimento di Ingegneria e architettura. 2019.

[29] Strozzi, N., Parisi, F., and Ferrari, G., A Multifloor Hybrid Inertial/Barometric Navigation System. In: 2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN) 2016 October 4 (pp. 1-5). IEEE.

[30] Strozzi, N., Parisi, F., and Ferrari, G., A Novel Step Detection and Step Length Estimation Algorithm for Hand-Held Smartphones. In: 2018 International Conference on Indoor Positioning and Indoor Navigation (IPIN) 2018 Sep 24 (pp. 1-7). IEEE.

[31] Strozzi, N., Parisi, F., and Ferrari, G., Impact of On-Body IMU Placement on Inertial Navigation. IET Wireless Sensor Systems, Special Issue on Body Sensor Networks 2018;8:3-9. doi: 10.1049/iet-wss.2017.0087.

[32] Davoli, L., Cilfone, A., Belli, L., and Ferrari, G., Design and Experimental Performance Analysis of a BATMAN-Based Double Wi-Fi Interface Mesh Network. Future Generation Computer Systems 2019;92:593-603.

[33] Abrardo, A., Martalò, M., and Ferrari, G., Information Fusion for Efficient Target Detection in Large-Scale Surveillance Wireless Sensor Networks. Information Fusion. 2017 November 1;38:55-64.

[34] Tripodi, C., Ferrari, G., Pighi, R., and Raheli, R., A Novel Weight Reset Strategy for the LMS Algorithm Subject to Abrupt Channel Variations. In: 2015 IEEE International Symposium on Power Line Communications and Its Applications (ISPLC) 2015 March 29 (pp. 131-136). IEEE.

Fifth Meeting – Relevant Publication

[35] Binsch, O., Banko, M., Veenstra, K., Bertil J., and Valk, P., (2015). Examining the Relationship Between Mental, Physical, and Organizational Factors Associated with Attrition During Maritime Forces Training. Journal of Strength and Conditioning Research / National Strength and Conditioning Association.
29 Suppl. 11. S187-S191. 10.1519/JSC.0000000000001117.

IEEE BSN 2017 – Meeting Participation by NATO RTG HFM-260 Members

Session 4: "Metabolic and Environmental Monitoring" (session chair: Karl Friedl)

[36] Welles, A.P., Looney, D.P., Rumpler, W.V., and Buller, M.J., Estimating Human Metabolic Energy Expenditure Using a Bootstrap Particle Filter. In: 2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2017 May 9 (pp. 103-106). IEEE.

[37] Telfer, B., Hoyt, R., Lacirignola, J., Patel, T., Siegel, A., Swiston, A., Singh, N., Trebicka, R., Weston, C., and Williamson, J., Wearable Oximetry for Harsh Environments. In: 2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2017 May 9 (pp. 107-110). IEEE.

[38] Lacirignola, J., Weston, C., Byrd, K., Metzger, E., Singh, N., Davis, S., Maurer, D., Young, W., Collins, P., Balcius, J., and Richter, M., Instrumented Footwear Inserts: A New Tool for Measuring Forces and Biomechanical State Changes During Dynamic Movements. In: 2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2017 May 9 (pp. 119-124). IEEE.

1st International Symposium on Hydration Monitoring Technologies (full program in Annex B)

[39] Friedl, K.E., (Workshop co-chair and presenter). Blue Skies Concepts and Technologies for Personal Hydration Monitoring Applications. 1st International Symposium on Human Hydration Monitoring Technologies, at the 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN 2017), Eindhoven, Netherlands. 12 May 2017.

[40] Hoyt, R.W., Principles and Pitfalls of Fluid Monitoring for Hydration Management. 1st International Symposium on Human Hydration Monitoring Technologies, at the 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN 2017), Eindhoven, Netherlands. 12 May 2017.

Poster Session

[41] van Beers, P., Caid, S., Guillard, M., Sauvet, F., and Chennaoui, M., The Interest of Microsleep Recording During Real Long Haul Flight: An Index of Hypovigilance. In: IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2017. (Poster).

[42] Guillard, M., van Beers, P., Coroenne, M., Lely, L., Sauvet, F., and Chennaoui, M., Improvement of EEG Signal Recording with Miniaturized Recorder: Development of Specific Interface and Software. In: IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN) 2017. (Poster).

Sixth Meeting

4th ICSPP – Meeting Participation by NATO RTG HFM-260 Members

[43] Delves, S., Fallowfield, J., Hoyt, R., and Buller, M., Using Real-Time Physiological Monitoring to Enable Training Adjustments to Avoid Heat Illness. Journal of Science and Medicine in Sport 2017;20:S145-6.

4th ICSPP Session 18 – Military Applications of Wearable Physiological Monitoring

[44] Veenstra, B., and Friedl, K., Featured Science Session 18 – Military Applications of Wearable Physiological Monitoring: From Concept to Implementation. Journal of Science and Medicine in Sport. 2017;20:S133-6.

[45] Wyss, T., Roos, L., Beeler, N., Veenstra, B., Delves, S., Buller, M., and Friedl, K., The Comfort, Acceptability and Accuracy of Energy Expenditure Estimation from Wearable Ambulatory Physical Activity Monitoring Systems in Soldiers. Journal of Science and Medicine in Sport. 2017 November 1;20:S133 4.

[46] Chennaoui, M., van Beers, P., Caid, S., Guillard, M., Boissin, J., and Sauvet, F., Microsleep and Alertness Monitoring in French Air Force Long Haul Pilots. Journal of Science and Medicine in Sport 2017;20:S134.

[47] Teien, H.K., Castellani, J.W., Martini, S., and Pasiakos, S.M., Physiological Monitoring During Multi-Day Norwegian Ski Patrols in the Arctic. Journal of Science and Medicine in Sport 2017;20:S134-5.

[48] Veenstra, B., Schwietert, H.R., Goll, R., and van Beijnum, B.J.F., Development of an Integrated Physiological Monitoring System for the Royal Netherlands Army. Journal of Science and Medicine in Sport 2017;20:S135.

[49] Lacirignola, J., Davis, S., Young, W., Weston, C., Collins, P., Balcius, J., Richter, M., and Palmer, J., Mobility and Biomechanics Inserts for Load Evaluation (MoBILE): Measuring Load and Terrain Based Gait Changes. Journal of Science and Medicine in Sport 2017;20:S135.

[50] Tharion, W., Buller, M., and Hoyt, R., Implementation of Physiological Status Monitoring in Weapons of Mass Destruction – Civil Support Teams (WMD-CSTs) to Enhance Performance and Ensure Safety of Soldiers. Journal of Science and Medicine in Sport 2017;20: S135-S136.

4th ICSPP Session 14 – Non-Pharmacological Military Performance Enhancement Technologies (Technological "Doping"): Karl Friedl and Mark Buller (co-chairs)

[51] Friedl, K., and Buller, M., Non-pharmacological Military Performance Enhancement Technologies. Journal of Science and Medicine in Sport. 2017 November 1;20:S93.

[52] Delves, S., and Buller, M., A Novel Individual Heat Acclimatisation Dosimeter Concept. Journal of Science and Medicine in Sport 2017;20:S93.

[53] Buller, M., Welles, A., Stevens, M., Leger, J., Gribok, A., Looney, D., Friedl, K., Rumpler, W., and Hoyt, R., Physiologically-Based Real-Time Pacing Algorithms. Journal of Science and Medicine in Sport 2017;20:S94.

[54] Seng, K.-Y., Fan, W.P., Lee, S.H.M., Ong, J. Tan, P.L., Law, Y.L.L., and Lee, K.W.J. Subject-Specific Prediction of Body Core Temperature Using Nonlinear Population Modelling. Journal of Science and Medicine in Sport 2017;20:S133-4.

[55] Beidleman, B., Welles, A., and Buller, M., Predicting Individual Risk of Altitude Illness Using Real-Time Monitoring of Accumulated Hypoxic Debt. Journal of Science and Medicine in Sport 2017;20:S94-5.

[56] Arnal, P.J., Debellemaniere, E., El-Kanbi, K., Pinaud, C., Thorey, V., Chambon, S., Galtier, M., Léger, D., and Chennaoui, M., Auditory Closed-Loop Stimulation to Enhance Sleep Quality. Journal of Science and Medicine in Sport 2017;20:S133-4.

Keynote Presentation and Invited Paper on Wearable Physiological Monitoring

[57] Friedl, K.E., Military Applications of Soldier Physiological Monitoring. Journal of Science and Medicine in Sport 2018;21:1147-53.

Seventh Meeting – CDT Presentations

[58] Delves, S., Introduction to Presentations and Concept Demonstration. Institute of Naval Medicine, UK. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[59] Friedl, K.E., The Past, Present and Future of Wearable Technology. US Army Institute of Environmental Medicine, USA. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[60] Wyss, T., Monitoring of Physical Demands for Injury Prevention in the Swiss Army. University of Magglingen, Switzerland. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[61] Murdock, R.C., Data Management and Visualization System for Military Training and Operations. US Air Force, USA. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[62] Veenstra, B., The Use of Monitoring Tools During Basic Military Training in the Netherlands. Netherlands Army, Netherlands. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[63] Palmer, J., Central Nervous System (CNS) Dysfunction and Gait Asymmetry Analysis. Lincoln Laboratory, MIT, Lincoln, MA, USA. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[64] Buller, M., "ECTemp" Validation Data. US Army Institute of Environmental Medicine, USA. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

[65] Delves, S., Plan for Concept Demonstration. Institute of Naval Medicine, UK. Concept Demonstration Symposium, Commando Training Centre Royal Marines, Lympstone, Exmouth, United Kingdom. 23 May 2018.

Eighth Meeting – Relevant Publications

[66] Guo, J., Chen, Y., Fan, W.P., Lee, S.H.M., Ong, J., Tan, P.L., Law, Y.L.L., Lee, K.W.J., and Seng, K.-Y., Kalman Filter Models for the Prediction of Individualized Thermal-Work Strain. pp. 370-431. In: Ginalber Luiz Serra (ed.), Kalman Filters: Theory for Advanced Applications. IntechOpen Ltd: London. 2018.

[67] Sullivan-Kwantes, W., Moes, K., Limmer, R., and Goodman, L., Finger Cold-Induced Vasodilation Test Does Not Predict Subsequent Cold Injuries: A Lesson from the 2018 Canadian Forces Exercise. Temperature 2019;6:142-9

[68] Arnal, P.J., Thorey, V., Ballard, M.E., Hernandez, A.B., Guillot, A., Gourde, H., Harris, M., Guillard, M., van Beers, P., Chennaoui, M., and Sauvet, F., The Dreem Headband as an Alternative to Polysomnography for EEG Signal Acquisition and Sleep Staging. bioRxiv preprint first posted online June 10, 2019. doi: http://dx.doi.org/10.1101/662734.

Original Articles from the "March in March" Studies

[69] Beeler, N., Roos, L., Delves, S.K., Veenstra, B.J., Friedl, K., Buller, M.J., and Wyss, T., The Wearing Comfort and Acceptability of Ambulatory Physical Activity Monitoring Devices in Soldiers. IISE Transactions on Occupational Ergonomics and Human Factors 2018;6(1):1-10.

[70] Veenstra, B.J., Wyss, T., Roos, L., Delves, S.K., Buller, M., and Beeler, N., An Evaluation of Measurement Systems Estimating Gait Speed During a Loaded Military March Over Graded Terrain. Gait Posture 2018;61:204-9.

[71] Gilgen-Ammann, R., Buller, M., Bitterle, J.L., Delves, S.K., Veenstra, B.J., Roos, L., Beeler, N., and Wyss, T., Evaluation of Pulse Rate Measurement with a Wrist Worn Device During Different Tasks and Physical Activity. Current Issues in Sport Science 2018;3:011. doi: 10.15203/CISS_2018.011.

[72] Oeschger, R., Roos, L., Beeler, N., Buller, M., Delves, S., Veenstra, B., and Wyss, T., (pending), Influence of Aerobic Fitness on Core Temperature, Heart Rate, Energy Expenditure and Energy Intake During a Loaded 35-km Road March of Swiss Army Soldiers. Military Medicine in press, 2019.

[73] Roos, L., Beeler, N., Delves, S.K., Veenstra, B.J., Buller, M.J., Friedl, K., and Wyss, T., (pending), Validation of Ambulatory Monitoring Devices to Measure Heart Rate and Energy Expenditure in a Military Setting. in press, 2019.

ICAMPAM – Meeting Participation by NATO HFM RTG HFM-260 Members

[74] Buller, M., Gait Irregularity as a Predictive Marker of Exertional Heat Stroke. 6th International Conference on Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM), Maastricht, Netherlands. 26 – 28 June 2019.

[75] Williamson, J.R., Bobrow, J., Weed, L., Claypool, K.T., Telfer, B.A., and Friedl, K.E., Comparison of Raw Accelerometry from Four Research Grade Devices. 6th International Conference on Ambulatory

Monitoring of Physical Activity and Movement (ICAMPAM), Maastricht, Netherlands. 26 – 28 June 2019. (Poster).

[76] Wyss, T., Roos, L., Friedl, K., Buller, M., Delves, S.K., and Veenstra, B., The Feasibility of Ambulatory Physical Activity Monitoring Devices in Studies on Soldiers. 6th International Conference on Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM), Maastricht, Netherlands. 26 – 28 June 2019. (Poster).

Other RTG HFM-260 Relevant Presentations (alphabetical listing)

[77] Beeler, N., Wyss, T., Roos, L., Buller, M., Delves, S., and Veenstra, B., A Comparison of Military-Specific Sensor-Systems to Estimate Energy Expenditure in Soldiers. 9th Sportwissenschaftliche Gesellschaft der Schweiz (9th Annual SGS/4S-Conference), Zurich. Book of Abstracts. 09 – 10/02/2017.

[78] Friedl, K.E., Martin, B.J., and Rempel, D.M., (Invited lecture). Future Workforce: Personal Physiological Monitoring in the Military Workplace. 3rd International Conference on Physical Employment Standards. University of Portsmouth, Portsmouth, Hampshire, United Kingdom, 19 July 2018.

[79] Friedl, K.E., (Invited keynote speaker). Human Augmentation: The Basis for Technological Enhancement of Human Performance. NATO Allied Command Transformation (ACT) on "Disruption Technologies: Influencing the Conduct of War" as part of the International Concept Development and Experimentation Conference, Wembley Hilton, London, 10 – 12 October 2017.

[80] Friedl, K.E., (Invited keynote speaker). Monitoring of Sleep and Other Neurophysiological Parameters Outside of the Laboratory Setting. 5th International Conference on Ambulatory Monitoring of Physical Activity and Movement (ICAMPAM), Natcher Auditorium, National Institutes of Health, Bethesda, MD. 21 – 23 June 2017.

[81] Friedl, K.E., (Invited speaker and session co-chair with M. Chennaoui, "Le sommeil de l'extrême"). Sleep in Extreme Environments [Le sommeil en conditions extrêmes]. Le Congrès du Sommeil, Parc Chanot, Marseille, France, 23 – 25 November 2017.

[82] Murdock, R.C., and Hagen, J.A., Soldier Safety and Performance Through Wearable Devices. p.106391A. In: Micro- and Nanotechnology Sensors, Systems, and Applications, 8 May 2018 (Vol. 10639). International Society for Optics and Photonics.

[83] Sauvet, F., (Invited presenter, "Le sommeil de l'extrême"). Le sommeil des militaires: des sous-marins à l'aéronautique. Le Congrès du Sommeil, Parc Chanot, Marseille, France, 23 – 25 November 2017.

[84] Williamson, J.R., Dumas, A., Ciccarelli, G., Hess, A.R., and Buller, M.J., Using Gait Dynamics to Estimate Load from a Body-Worn Accelerometer. MIT Lincoln Laboratory Lexington, MA; 5 February 2016.

Other RTG HFM-260 Relevant Publications and Patents (alphabetical listing)

[85] Ammann, R., Taube, W., and Wyss, T. Accuracy of PARTwear Inertial Sensor and Optojump Optical Measurement System for Measuring Ground Contact Time During Running. Journal of Strength and Conditioning Research 2016;30:2057-63.

[86] Beeler, N., Roos, L., Delves, S.K., Veenstra, B.J., Friedl, K., Buller, M.J., and Wyss, T., The Wearing Comfort and Acceptability of Ambulatory Physical Activity Monitoring Devices in Soldiers. IISE Transactions on Occupational Ergonomics and Human Factors 2018;6:1-10.

[87] Bougard, C., Gomez-Merino, D., Rabat, A., Arnal, P., van Beers, P., Guillard, M., Léger, D., Sauvet, F., and Chennaoui, M., Daytime Microsleeps During 7 Days of Sleep Restriction Followed by 13 Days of Sleep Recovery in Healthy Young Adults. Consciousness and Cognition 2018;61:1-2.

[88] Buller, M.J., inventor; US Secretary of Army, assignee. Estimation of Human Core Temperature Based on Heart Rate System and Method. United States patent application US 15/449,943. 2017 August 24.

[89] Buller, M.J., inventor; US Secretary of Army, assignee. System and Method for Determining an Adaptive Physiological Strain Index. United States patent application US 16/072,815. 2019 January 31.

[90] Buller, M.J., Tharion, W.J., Duhamel, C.M., and Yokota, M., Real-Time Core Body Temperature Estimation from Heart Rate for First Responders Wearing Different Levels of Personal Protective Equipment. Ergonomics. 2015;58:1830-41.

[91] Buller, M.J., Welles, A.P., and Friedl, K.E., Wearable Physiological Monitoring for Human Thermal-Work Strain Optimization. Journal of Applied Physiology 2017;124:432-41.

[92] Candell, L.M., Ferraiolo, C., Shaw, G.A., Siegel, A.M., Zogbi, G., McClung, H.L., and Hoyt, R.W., inventors; Massachusetts Institute of Technology, assignee. Systems, Apparatus, and Methods Related to Modeling, Monitoring, and/or Managing Metabolism. United States patent application US 15/835,049. 2018 May 10.

[93] Castellani, J.W., Spitz, M.G., Karis, A.J., Martini, S., Young, A.J., Margolis, L.M., et al., Cardiovascular and Thermal Strain During 3 – 4 Days of a Metabolically Demanding Cold-Weather Military Operation. Extreme Physiology & Medicine 2017;6:2.

[94] Delves, S.K., and Buller, M.J., inventors. Individual Heat Acclimatisation Training Tool. Joint UK/US patent application. November 2019.

[95] Delves, S., Fallowfield, J., Hoyt, R., and Buller, M., Using Real-Time Physiological Monitoring to Enable Training Adjustments to Avoid Heat Illness. Journal of Science and Medicine in Sport 2017;20:S145-6.

[96] Friedl, K.E., Hixson, J.D., Buller, M.J., and Lo, B., Guest Editorial-13th Body Sensor Networks Symposium. IEEE Journal of Biomedical and Health Informatics 2018;22:3-4.

[97] Gilgen-Ammann, R., Koller, M., Huber, C., Ahola, R., Korhonen, T., and Wyss, T., Energy Expenditure Estimation from Respiration Variables. Scientific Reports 2017;7:15995.

[98] Hunt, A.P., Buller M.J., Maley, M.J., Costello, J.T., and Stewart, I.B., Validity of a Noninvasive Estimation of Deep Body Temperature When Wearing Personal Protective Equipment During Exercise and Recovery. Military Medical Research 2019;6:2.

[99] Klucken, J., Friedl, K.E., Eskofier, B.M., and Hausdorf, J.M., Guest Editorial: Enabling Technologies for Parkinson's Disease Management. IEEE Journal of Biomedical and Health Informatics. 2015;19:1775-6.

[100] Kuddoos, H., Seng, K.-Y., Law, Y.L.L., and Teo, Y.N.E., Optimizing Firefighters' Performance with Wearable Technology and Predictive Data Analytics. IEEE Journal of Biomedical and Health Informatics. 2019;4:105-11.

[101] Looney, D.P., Buller, M.J., Gribok, A.V., Leger, J.L., Potter, A.W., Rumpler, W.V., Tharion, W.J., Welles, A.P., Friedl, K.E., and Hoyt, R.W., Estimating Resting Core Temperature Using Heart Rate. Journal for the Measurement of Physical Behaviour 2018;1:79-86.

[102] Looney, D.P., Buller, M.J., Welles, A.P., Leger, J.L., Stevens, M., Gribok, A., Rumpler, W.V., and Hoyt, R.W., Accuracy of the Estimated Core Temperature (ECTemp) Algorithm in Estimating Circadian Rhythm Indicators. Technical Report T17-08, US Army Research Institute of Environmental Medicine, Natick, MA. April 2017.

[103] McClung, H.L., Kehayias, J.J., Zientara, G.P., and Hoyt, R.W., Direct and Indirect Measures of Dietary Intake Use of Sensors and Modern Technologies. pp. 163-183. In: Advances in the Assessment of Dietary Intake. CRC Press: Boca Raton, FL. 2017.

[104] O'Brien, C., Karis, A.J., Tharion, W.J., Sullivan, H.M., and Hoyt, R.W., Core Temperature Responses of Military Working Dogs During Training Activities and Exercise Walks. US Army Medical Department Journal 2017; October-December:71-78.

[105] Pihlainen, K., Santtila, M., Häkkinen, K., Lindholm, H., and Kyröläinen, H., Cardiorespiratory Responses Induced by Various Military Field Tasks. Military Medicine 2014;179:218-224.

[106] Roos, L., Taube, W., Beeler, N., and Wyss, T., Validity of Sports Watches When Estimating Energy Expenditure During Running. BMC Sports Science, Medicine and Rehabilitation 2017;9:22.

[107] Sawka, M.N., and Friedl, K.E., Emerging Wearable Physiological Monitoring Technologies and Decision Aids for Health and Performance. Journal of Applied Physiology 2018;124:430-431.

[108] Sims, N.M., Colquitt, N., Wollowitz, M., Hickcox, M., Dempsey, M., and Buller, M.J., inventors; General Hospital Corp, US Secretary of Army, assignee. Life Sign Detection and Health State Assessment System. United States patent US 9,687,195. 2017 June 27.

[109] Stamford, J.A., Schmidt, P.N., and Friedl, K.E., What Engineering Technology Could Do for Quality of Life in Parkinson's Disease: A Review of Current Needs and Opportunities. IEEE Journal of Biomedical and Health Informatics 2015;19:1862-72.

[110] Udofa, A.B., Clark, K.P., Ryan, L.J., and Weyand, P.G., Running Ground Reaction Forces Across Footwear Conditions Are Predicted from the Motion of Two Body Mass Components. Journal of Applied Physiology 2019;126:1315-25.

[111] Welles, A.P., Xu, X., Santee, W.R., Looney, D.P., Buller, M.J., Potter, A.W., and Hoyt, R.W., Estimation of Core Body Temperature from Skin Temperature, Heat Flux, and Heart Rate Using a Kalman Filter. Computers in Biology and Medicine 2018;99:1-6.

ANNEX A – TECHNICAL ACTIVITY PROPOSAL (TAP)

ACTIVITY TITLE: Enhancing Warfighter Effectiveness with Wearable Biosensors and Physiological Models.

BACKGROUND AND JUSTIFICATION (Relevance to NATO):

The use of sensing technologies has been common and widespread in the military for decades, providing detailed information on the operational status and maintenance of sophisticated vehicles and systems. There is also great interest in applying soldier monitoring capabilities in near term future soldier systems but to-date only location information has been implemented. A previous NATO HFM panel, HFM-132, outlined biosensor development efforts in several countries and explored their potential in protection of soldiers. Advances in engineering and computing technologies now permit low Size Weight and Power (SWaP) systems that are finally practical for wearable monitoring for dismounted soldiers. Prototype Commercial Off The Shelf (COTS) physiological monitoring systems, originally informed and inspired by military physiological research, are being used by several NATO countries for research on training and operational application. Measurement of physiological strain during training can protect soldiers from serious overuse training injuries and thermal injuries, and train soldiers and cadre to understand limits of performance. Other studies in Iraq and Afghanistan have provided the first objective data on thermal-work strain limits during military patrols and provided valuable information on more effective pacing strategies. Other applications have included assessment of the effectiveness of new materiel such as hot weather uniforms by objectively quantifying the physiological responses of the soldiers wearing the uniforms during field tests. The proliferation of wearable monitors in the commercial marketplace are interesting as motivational tools for fitness behaviors but lack sophistication and ruggedization in terms of accuracy, appropriate tactical communications considerations, and most importantly the validated algorithms or models to convert simple data such as activity measures or raw heart rates into predictive, tactically relevant actionable information that a soldier or commander can use. Further advances in this area are likely to come primarily from military research activities.

Key goals of this proposed new effort include establishing closer cooperation between related research efforts using similar tools and developing algorithms and models for high priority soldier applications. A key product will be a live demonstration for the Committee of the Chiefs of Military Medical Services in NATO (COMEDS) on the utility of new soldier wearable biosensors.

The proposed activity has three related thrust areas:

1) **Development/refinement of sensors and wearable systems:** A commercial physiological monitoring system developed from U.S. Army research is currently being used by several nations in military performance research. The next generation system currently in development will be much smaller, with longer battery life, higher user acceptable for soldiers, easier to use, and carry a smaller electronic signature. The "generation beyond," currently in research, will use nanowatt components in a system on a chip design, enabling energy harvesting via body movement and/or heat. It is crucial for partner nations to drive the development of the right sensor sets and the militarily useable hardware, communications systems, and information displays with the soldier in mind since these needs are often orthogonal to commercial priorities. Cooperation between armies ensures interoperability and leverages limited resources through enhanced mutual reliance.

2) **Mathematical modelling of physiological data**: Raw heart rates are virtually useless to a soldier or commander, with elevated heart rate perhaps signalling a number of potential states including readiness

to fight, severe hemorrhage, extreme anxiety, or toxic chemical exposure. A major work effort is required to provide sensor data fusion and combine this with other contextual data such as personal history, archival normative data, ambient conditions, and mission requirements to produce simple useful actionable dashboard measures. The Heat Strain Index (HSI) is an example of a demonstrated application to monitor and protect encapsulated soldiers performing critical tasks, with visible and easily interpreted 10-point scale readouts. The HSI is derived from heart rate and core temperature. Recent efforts have refined this with a military algorithm that makes the predictions from time series heart rate alone. This new predictive capability needs further validation and may be improved by inclusion of skin temperature or other measures. Patterns of motion and body position (e.g., activity, distance travelled, ground contact time) have been used to successfully predict energy expenditure from a variety of simple wearable systems in military settings and are particularly useful in monitoring workload demands for physical training in association with injury reduction. This same data could provide behavioral status changes such as psychological stress and depression but requires sophisticated signal pattern analysis to improve predictive accuracy via other parameters such as vocal neuromuscular articulators and formant frequency, heart rate variability, real-time non-invasive cortisol levels, and single electrode EEG. Many other key predictions such as impending hypothermia based on peripheral temperature changes (e.g., toe and ankle temperatures), adjustment to altitude, and soldier physical and mental fatigue require purposeful development of psycho-physiological models and algorithms.

3) **Field studies and laboratory data collection:** Critical to physiological modelling is real soldier data, especially data sets collected in field during realistic soldier activities. This permits testing of multiple parameters which can then be modelled against outcomes of interest to reduce the inputs to the minimal sensor set required to produce valid and useful information. This thrust will help to coordinate national studies so that relevant measurements are made to help drive the device and algorithm development efforts. It also provides soldier feedback on the acceptability and usability of the systems in development.

Given the international nature of wearable monitoring and the international scope of the smart phone / personal technologies industry, NATO is strategically placed to leverage expertise and devise innovative strategies. The successful development of wearable biosensor technologies as described above will require advances in miniaturized sensors and bioelectronics, physiologic and emotive computing, human factors and a variety of other areas.

OBJECTIVE

The main objective is to explore the use of wearable biosensor systems and mathematical models to expand physiological monitoring applications for military training and operational use. Specific examples of potential priorities for the panel include:

- Protection of soldiers from overuse injuries in training produced by excessive workload and biomechanical (e.g., ground reaction forces) demands;
- Mission performance enhancement and injury prevention from real-time thermal-workload monitoring;
- Readiness status including sleep and wakefulness based on real-time sensor signals that go beyond activity measurements;
- Trigger alerts based on psychological stress and behavioral status monitoring to assess emotional activation and depression or other psychological disorders and trauma (e.g., PTSD, mTBI); and

- Provide tactically relevant feedback on route planning strategies based on metabolic costs and physical demands for increased effectiveness on target.

In addition to specific applications, the panel will:

- Identify performance metrics related to wearable monitoring systems;
- Determine philosophy of and appropriateness of wearable monitoring systems for training and operational use;
- Assess state-of-the-art and international scope of biosensor development;
- Explore civilian biosensor development efforts which can be leveraged for military applications;
- Identify technology gaps related to physiological monitoring effectiveness, such as in areas of physiological monitoring of cognitive and emotional status;
- Summarize human factors challenges and standards to support the effective design and objective evaluation of soldier wearable systems; and
- Identify technology gaps and areas for collaboration and additional investment and create a strategic roadmap for development within a mutual open system architecture.

DELIVERABLE AND/OR END PRODUCT

1) Devise a plan for an ongoing collaborative network and interest groups;
2) Outline specific interests and current research activities of participant nations;
3) Identify technology gaps and development strategy;
4) Promote technology demonstrations;
5) Publish peer-reviewed papers across a range of specialty journals and in special supplements;
6) Workshop resulting in a publication; and
7) Technical Report (final).

TECHNICAL TEAM LEADER AND LEAD NATION

- Primary: Reed W. Hoyt, PhD, USA
- Deputy/Alternate: Bertil Veenstra, PhD, NLD
- Lead Nation: USA
- Mentor: John Tangney, PhD, ONR
- Participating/Founding NATO Nations: FRA, NLD, NOR, USA

ANNEX B – AGENDA FOR THE 1ST INTERNATIONAL SYMPOSIUM ON HUMAN HYDRATION MONITORING TECHNOLOGIES

at the

14th International Conference on Wearable and Implantable Body Sensor Networks

BSN2017, Eindhoven, the Netherlands

Date and Venue

Friday, 12 May, 2017, 9:00 – 13:00

Auditorium Einstein, Conference Center, High Tech Campus, Eindhoven, the Netherlands

Organizers

Matthias Ring, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany

Karl E. Friedl, U.S. Army Research Institute of Environmental Medicine, Natick, MA, USA

Abstract

Humans are bags of mostly water. The amount of Total Body Water (TBW) constitutes about 55 – 60 % of an adult's body composition. The regulation of water balance is vital to health and performance, since moderate TBW reductions by 4 – 6 % already produce noticeable symptoms and severe TBW reductions by more than 10% become life-compromising. The detection of dehydration and management of TBW is particularly crucial for athletes in endurance sports, athletes that dehydrate to meet weight class limits, soldiers and workers with high sweat losses in hot environments, clinical patients with poorer body water regulation, and the elderly people. Technological approaches for dehydration detection have included, for example, bioelectrical impedance, changes in skin properties, and biochemical analyses of aqueous body fluids (urine, sweat, saliva, tears). However, there are still challenges in these technologies and so much the more in wearable technologies for continuous hydration monitoring. This workshop will therefore consider technological, physiological, and data analytics aspects that have been explored by researchers with first-hand experience in a range of applications from clinical patients to active athletes.

Speakers	
Salzitsa **Anastasova**, Ph.D.	The Hamlyn Centre, Imperial College London, United Kingdom
Clement Ogugua **Asogwa**, Ph.D.	College of Engineering and Science, Victoria University, Australia
Carlos **Castelar**, M.Sc.	Philips Chair for Medical Information Technology (MedIT), RWTH Aachen University, Germany
Karl E. **Friedl**, Ph.D.	U.S. Army Research Institute of Environmental Medicine, Natick, MA and University of California at San Francisco
Reed W. **Hoyt**, Ph.D.	Biophysics and Biomedical Modelling Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA, USA
Ahyeon **Koh,** Ph.D.	Department of Biomedical Engineering, Binghamton University-State University of New York (SUNY), USA
Matthias **Ring**, M.Sc.	Digital Sports Group, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany
Yutian **Shu**, Ph.D.	Biomindr Inc., Montreal, Canada and Bourque Lab, McGill University, Canada

Introduction	9:00 – 9:05

Matthias Ring, Karl Friedl

Machine Learning for Quantitative Water Loss Estimation During Physical Exercise	9:05 – 9:30

Matthias Ring

This talk considers the estimation of Total Body Water (TBW) loss during physical exercise. Marathon runners, for example, may lose up to 14% of their TBW during races in warm environments. This excess of TBW loss is considered close to life-threatening. But also less severe amounts of TBW loss can already impair aerobic endurance, muscular strength, and cognitive performance. In this light, three machine learning approaches are discussed to quantitatively estimate TBW loss based on bioimpedance measurements, sweat markers, and salivary markers, respectively. All three approaches were developed and evaluated using measurements from 10 male subjects who performed a 2-hour running workout without fluid intake. The experimental evaluation illustrated that the minimal TBW loss estimation error of 0.34 liter could be achieved based on the salivary markers. In the future, such TBW loss estimations might support accurate diagnoses of dehydration and corresponding recommendations on the amount of fluid to rehydrate properly.

A Soft, Wearable Epidermal Microfluidic Systems Capable of Sweat Monitoring	9:30 – 9:55

Ahyeon Koh, Daeshik Kang, John A. Rogers

The ability to monitor health and disease status transdermally via analysis of sweat obviating the need for a blood draw is a medical goal and unmet need. Present sweat monitoring technology remains limited as a largely experimental practice, relying on lab-based systems. Further, these approaches are unsuitable for actively monitoring sweats during dynamic human activities and thus impedes immediate treatments. Herein, I will present the study of epidermal, flexible, conformal microfluidic devices with integrated wireless communication electronics that allow collection and point-of-care analysis of sweat. Constructed devices offer advanced biomechanical capabilities affording strong skin adhesion, in situ sweat collection via perspiration, and thus the determination of local sweat rate and volume as well as biomarker content under dynamic conditions. The microfluidic designs satisfy sufficient stretchability, structure stability, and vapor permeability for epidermal sweat patch applications. The sweat patch enables multiple analysis of the concentration of representative biomarkers in sweat-glucose, lactate, chloride, and pH via quantitative colorimetric analysis and interrogates to smartphone utilizing near-field communication electronics. Two human studies demonstrate assessment of perspiration with the devices: temperature and humidity controlled mild indoor cycling, and real-world outdoor use during a long-distance cycling race. Indeed, the epidermal microfluidics for sweat analysis yield information of sweat loss and rate in situ and demonstrates reliable chemical assessment of perspiration compared to traditional lab-based analysis.

Wearable Sensors: Can We Get Enough Information from Sweat?	9:55 – 10:20

Salzitsa Anastasova, Benny Lo, Guang-Zhong Yang

Several different methods of non-invasive detection of analytes in body fluids are being evaluated and validated. Sweat is one candidate fluid that can be quite useful because it contains a many molecules ranging from simple electrically charged ions to more complex proteins that can provide insights to what is happening inside the human body. Sweat analytes may also provide insights to athletic performance. Our device used a microfluidic, lab-on-a-chip approach to sweat capture and analysis and electrochemical detection. In our study, we embedded chemical sensors into a soft, flexible silicone based microfluidic platform that can easily stick to skin. The flexible sweat sensor acts as a passive pump where the sweat passes constantly through the microfluidic channels and the sensors are able to detect the analytes. Different sections of the sensor react to different levels of certain chemicals found within sweat. The readings are transmitted wirelessly to a smart phone. In a trial involving six volunteers doing indoor cycling, measurements from the sweat sensor were comparable to lab-based standards. Measurements included sweat rate, pH (an indicator of hydration levels), and concentrations of lactate, glucose, potassium and sodium.

RF Technology for Non-Invasive and Real-Time Hydration Monitoring	10:20 – 10:45

Yutian Shu

In the medical field and hospital settings, there are many hydration assessment techniques such as isotope dilution, neutron activation analysis, blood plasma and urine osmolality analysis, urine specific gravity, urine conductivity, urine color, hematocrit, hemoglobin, rating of thirst, body mass change, bioelectrical impedance, etc. However, those techniques are often invasive, require cumbersome testing equipment, long testing hours, as well as expertise. The only method mentioned above that shows potential to be transformed into a wearable solution is bioelectrical impedance. Attempts have been made to develop wearable electronics for hydration detection based on bioelectrical impedance. However, the electric current passing through body parts require close and good electrical contact to human skin, which largely impairs its accuracy during scenarios like intense exercise and physical work. Also, the correlation between local skin hydration and global body hydration status can vary from person to person. Thus, alternative methods need to be explored for assessing hydration status conveniently. The interactions between electromagnetic (EM) waves and biological tissue have been investigated extensively since last century. The theoretical aspects of dielectric phenomena in biological materials across various ranges of electromagnetic waves have also been widely reviewed. When interacting with biological tissue, the mode of interaction between EM waves and water molecules is different from between EM and solute ions. At lower frequency (below 1 GHz), the electrical conduction is dependent on the quantity of water solute, and the ionic conduction results in energy absorption, which can lead to amplitude attenuation of EM waves. At higher frequency (above 3 GHz), the rotation of water molecules in response to alternating EM field starts to contribute to the energy absorption. Thus, based on the absorption of EM energy, the quantity of water can be determined in biological tissues. In this talk, the basic principle of RF and biological tissue interaction, and how it may help generate signals for characterizing body hydration, the nature of relevant signals, and what potential biological experiments could be designed to acquire trustworthy data, as well as the potential role of machine learning in assessing hydration level of human being will be discussed.

Break	10:45 – 11:00

A Galvanic Coupling Method for Assessing Human Body Hydration	11:00 – 11:25

Clement Ogugua Asogwa

Changes in human body hydration leading to excess fluid losses or overload affects the body fluid's ability to provide the necessary support for healthy living. We propose a time-dependent circuit for real-time monitoring of human body hydration using galvanic coupled intrabody communication technology. The circuit model predicts the attenuation of a propagating electrical signal. Current measurement techniques are mostly suitable for laboratory purposes due to complexity and technical requirements. Less technical methods are subjective and cannot be integrated into a wearable device. We model hydration rates by a time constant τ which characterizes the individual specific metabolic function of the body and a surrogate human body anthropometric parameter θ by the muscle-fat ratio. Our results show that hydration can be tracked non-intrusively with theoretical values varying from 1.73 dB/min, for high θ and low τ to 0.05 dB/min for low θ and high τ which is comparable to empirical measurements, which ranged from 0.6 dB/min for 22.7 kg/m^2 down to 0.04 dB/min for 41.2 kg/m^2. Our results show individuals with high BMI would have higher time-dependent biological characteristic, lower metabolic rate, and lower rate of hydration. And a galvanic coupled intrabody signal propagating through the body can provide qualitative hydration and dehydration rates in line with changes in an individual's urine specific gravity and body mass and can detect up to 1.30 dB reduction in attenuation when as little as 100 mL of water is consumed. The real-time changes in galvanic coupled intrabody signal attenuation can be integrated into devices to evaluate body fluid levels and can aid diagnosis and treatment of fluid disorders such as lymphoedema.

Principles and Pitfalls of Fluid Balance Monitoring for Hydration Management	11:25 – 11:50

Reed W. Hoyt

Hydration management is essential for individuals working in hot, cold, or mountainous environments, where under- or over-hydration can lead to decreased physical and cognitive performance, organ injury, and even death. Fluid balance depends on water influx: (a) ingestion of pre-formed dietary water from food or liquids, (b) metabolic water produced from fat, protein, and carbohydrate oxidation, (c) and water entering through the lungs or skin, and on water efflux: (i) respiratory water loss, (ii) cutaneous evaporative water loss, (iii) fecal water loss, and (iv) urine production. Typically, fecal water loss is negligible, and respiratory water loss is balanced by metabolic water production. Urine output, which is typically ~1 ml/min (~1.44 L/d), is a key indicator of intravascular volume status in normal individuals. A low urine output leads to a decreased circulating blood volume and decrements in strength and endurance if the fluid loss exceeds ~3% of body mass. Classic methods of logging water intake, urinary output, and changes in body mass, are not practical. Methods suited for use in the field include stable isotopic tracers that track water turnover, energy expenditure, and changes in extracellular space and total body water. However, a need exists for wearable sensor systems capable of monitoring urine output and fluid intake and providing real-time feedback. An ultrasound-based Bladder Volume Monitor (BVM) developed by Kristiansen et al. (2005) will be presented, along with Fluid Intake Monitor (FIM) capable of logging fluid consumed from a flexible canteen. BVM can be used to ensure normal hydration, even in the event of heavy fluid losses from sweating. The FIM can be used to teach good hydration practices and reduce the risk of over-hydration and hyponatremia.

Electrical Impedance Tomography for Bladder Volumetry	11:50 – 12:15

Carlos Castelar

Paraplegic patients, depending on the degree of neural damage, often suffer from an impaired bladder volume sensation, sometimes also associated with a complete lack of urinary function. A common treatment for these patients is the emptying of the bladder by self-catheterization, usually following a fixed self-catheterization schedule at regular time intervals. However, this procedure is not optimal. If the catheterization is performed too late, it may lead to general discomfort or even high blood pressure or kidney damage. If the bladder is emptied too early, it unnecessarily degrades the quality of life of the patient and increases the risk of urinary tract infection. A demand-driven emptying scheme would be preferred and could be made possible by a non-invasive and continuous bladder volume monitoring device. Our investigation deals with the evaluation of Electrical Impedance Tomography (EIT) as a potential solution. It includes FEM-simulation studies, in-vitro measurements and clinical trials. A good linearity between bladder volume and measured impedance has been shown. Recent work has focused on optimizing electrode positioning as well as current injection and voltage measurement patterns and the development of volume estimation algorithms. Furthermore, the influence of body position, movement artefacts and the a priori unknown urine conductivity have been analysed. EIT bladder volumetry already shows good promise and the potential to be improved with respect to measurement repeatability and artefact suppression.

Blue Skies Concepts and Technologies for Personal Hydration Monitoring Applications	12:15 – 12:40

Karl E. Friedl

Strategies to monitor human hydration status include assessment of hydration-dependent symptoms, compensatory physiological changes, or direct measures of fluid content or concentration. The best approach depends in part on the specific application. Implanted hydrogel sensors responding to extracellular fluid osmolality may signal the need to increase fluid intake in elderly patients at risk for dehydration or indicate fluid accumulation in a patient with congestive heart failure patient. Terahertz imaging may signal localized tissue hydration and viability in wound healing. Assessment of specialized fluid compartments such as intraocular fluid and localized changes in skin hydration may not provide a sensitive reflection of other fluid compartment changes. Surrogate markers such as nail bed capillary refilling, postural hypotension, and heart rate variability may be relatively insensitive or nonspecific indicators of water deficit especially without other contextual information. Direct spectroscopy-based measures of intravascular composition (i.e., plasma volume from hematocrit/hemoglobin) may prove to be quite sensitive to hydration changes. The practical continuous measurement of concentration of a variety of analytes in secreted body fluids (sweat, tears, saliva, urine) or in extracted fluid (e.g., laser poration, reverse iontophoresis) has been challenging but micro-scale technologies may provide new opportunities (e.g., unobtrusive mouth appliances for continuous salivary assessments).

Joint Discussion	12:40 – 13:00

ANNEX C – ABSTRACTS FROM RTG HFM-260 PARTICIPATION IN 4TH ICSPP

C.1 MILITARY APPLICATIONS OF WEARABLE PHYSIOLOGICAL MONITORING – FROM CONCEPT TO IMPLEMENTATION

B. Veenstra and K. Friedl (Session Co-Chairs)

Session Summary

The useful applications of soldier physiological sensing have been intensively explored by a NATO Research Technical Group (RTG HFM-260). There is a plethora of commercial wearable physiological devices available for general health and fitness applications but none that are suitable to military needs and that provide important actionable information to a soldier or commander. Important issues include identifying the relevant minimal sensor set and system on a chip integration; tactically secure communications systems; minimizing size, weight and power requirements; physiological algorithms validated for relevant use; and user need and acceptance. Field data collection with research grade wearable systems provides improved understanding of soldier health and performance limits outside of laboratory conditions. This iterative research and development with soldiers doing real soldier activities has led to discovery and refinement of the important problems that wearable systems may help to solve. Initial applications for routine military use involve training settings where it is important for individuals and teams to learn safe limits and optimize work load. Some of these monitoring technologies will also be important to performance and safety in operational settings, particularly where new and unanticipated threats may be encountered.

C.1.1 Speaker Abstract 1 – Ambulatory Energy Expenditure Estimation in Soldiers

Wyss, T.[1], Roos, L.[1], Beeler, N.[1], Veenstra, B.[2], Delves, S.[3], Buller, M.[4], Friedl, K.[4]

[1] Swiss Federal Institute of Sport Magglingen SFISM, Magglingen, Switzerland.

[2] Institute of Training Medicine & Training Physiology, MOD/TGTF, Utrecht, Utrecht, the Netherlands.

[3] Environmental Medicine & Science, Institute of Naval Medicine, Alverstoke, Hampshire, UK.

[4] United States Army Research Institute of Environmental Medicine, Natick, MA, USA.

[1] thomas.wyss@baspo.admin.ch

Purpose: The Swiss Armed Forces will implement a new formation concept during basic military training to reduce injury and dropout rates. Adaptations are based on scientific results from physical demands monitoring (Wyss et al. 2012). Since such data became very important in decision making processes, it is the aim of the present study, conducted within a NATO RTG HFM-260 international collaboration, to investigate wearing comfort, feasibility, and accuracy of different devices used in military organizations worldwide to assess heart rate and energy expenditure among soldiers.

Methods: The 32 volunteers from a Swiss Army Infantry Military Training school signed informed consent as approved by the local ethics committee. The investigated monitoring measurement systems were: ActiHeart (CamNTech, Cambridge, UK), Hidalgo EQ02 (Equivital, Cambridge, UK), TICKR X (Wahoo Fitness, Atlanta, USA), fēnix 3 (Garmin, Olathe, USA), GENEActive (Activinsights, Kimbolton, UK), Axiamote PADIS 2.0 (Axiamo, Biel/Bienne, Switzerland), VSM1/Everion (Biovotion, Zurich, Switzerland), and Blue Thunder

(IMeasureU, Auckland, New Zealand). Wearing comfort was investigated using a questionnaire (5-point Likert Scale) completed by volunteers, feasibility was calculated by a differentiated scoring system completed by scientists. Heart rate and energy expenditure were assessed during 10 different activities in a laboratory setting as well as during daily military routine and compared to data from MetaMax 3B (Cortex Medical, Leipzig, Germany).

Results: Sensors worn around the chest were rated to have greater negative impact on the body (4.3±1.0) than sensors worn around the wrist (4.8±0.4; p = .027) and other body parts (4.9±0.3; p = .002). A poor wearing comfort was the most frequently reported negative impact (21.0%), followed by interference with equipment (9.9%), and limited moving flexibility (7.4%). Sensors worn at locations other than the chest would be worn for five or more days by 85.2%, and sensors on/around the chest by 66.7% of volunteers. In the overall ranking VSM1/Everion, Axiamote and Blue Thunder were rated highest, followed by the devices worn at the wrist, then those worn on/around the chest.

Conclusion: The results of the present study have shown that with regard to wearing comfort, sensors placed on the upper arm, the hip, the shoe, or the wrist, should be preferred to sensors worn around the chest in a military setting. However, aspects on data accuracy and system feasibility are equally important. Those results will be presented in this talk as well.

Reference:

Wyss, T., Scheffler, J., and Mäder, U. (2012). Ambulatory physical activity in Swiss Army recruits. Int J Sports Med. 33(9).

C.1.2 Speaker Abstract 2 – Microsleep and Alertness Monitoring in French Air Force Long-Haul Pilots

Chennaoui, M.[1,2,4], Van Beers, P.[1,2], Caid, S.[3], Guillard, M.[1,2], Boissin, J.[3], Sauvet, F.[1,2]

[1] Fatigue and Vigilance Unit, French Armed Forces Biomedical Research Institute (IRBA), Brétigny-sur-Orge, France.

[2] VIFASOM team (EA 7330), Paris Descartes University, Hôtel Dieu, Paris, France.

[3] Air Warfare Center (AWC), French Air Force, Mont de Marsan, France.

[4] French member of NATO RTG HFM-260 group.

[1] mounirchennaoui@gmail.com

Purpose: Sleepiness and fatigue can reach particularly high levels during long-haul overnight flights. Under these conditions, voluntary or even involuntary sleep periods may occur, increasing the risk of accidents. In-flight fatigue occurs in about 20% of medium-haul flights and 40% of long-haul flights. Moreover, between 41% and 54% of the pilots reported that “fatigue severely impairs flight security, at least once” during their carrier. Actually, despite the efforts made for fatigue and alertness management programs, pilots still remain concerned by fatigue and sleepiness. Detecting pilots’ involuntary sleep periods has become a challenging objective to further improve flight safety. Microsleeps are temporary episode (1 to 30 sec) of sleep, associated with a brief lapse in consciousness, considered as an objective parameter of sleepiness. The aim of this study was to assess the risk factors of microsleeps during long all flight in military new tactical airlifter with strategic capabilities.

Methods: Eleven voluntary pilots were recording (18 flights, mean duration 6.4 h, ranged 2.5 – 9.6 h) representing a total of 130 flight hours. Sleep/wake activities were recorded 8 days before flights using an actimeter. Subjective Karolinska Sleepiness Scale (KSS) and sustained attentional Psychomotor Vigilance Test (PVT) were assessed every 2 hours during the flights. Two Electroencephalogram (EEG) and Electro-Occulogram (EOG) derivations were continuously recorded during the flights using a miniaturized recorder fixed on the pilots' skulls. Microsleep episodes were identified off-line by visual inspection.

Results: No subject was disturbed by the equipment during the flights. At least a microsleep occurred during each flight 6 ± 4 sec [ranged: 4 – 29 sec]). Pilots' habitual Total Sleep Time (TST) was 7.0 ± 1.3 h. TST during the night before the flight was 5.8 ± 1.6 h. Increased microsleeps occurrence and decreased attentional performances were associated with TST before the flight, cumulative sleep debt, time of the day and duty time. The main risk factor of microsleeps is a TST lower than 6 hours (OR = 2.6; 95% CI = 1.5 – 4.8, $p < 0.01$). We show correlations between microsleeps and the decrease of sustained attention performances ($p < 0.05$).

Conclusion: Preventing accidents in aviation caused by low vigilance states has become a major focus of safety. Our results demonstrated the interest of continuous EEG/EOG recording during real flight, in order to identify fatigue risk factors of low vigilance states, and open new perspective for online detection. The simplicity of the method proposed here suggest its potential application for online automatic detection of low vigilance states during real flights.

C.1.3 Speaker Abstract 3 – Physiological Monitoring During Multi-Day Norwegian Ski Patrols in the Arctic

Teien, H.K.[1], Castellani, J.W.[2], Martini, S.[3], Pasiakos, S.M.[4]

[1,3] Norwegian Defence Research Establishment (FFI), Kjeller, Norway.

[2,4] United States Army Research Institute of Environmental Medicine, Natick, MA, USA.

[1] hilde-kristin.teien@ffi.no

[2] john.w.castellani.civ@mail.mil

[3] svein.martini@ffi.no

[4] stefan.m.pasiakos.civ@mail.mil

Purpose: Hand and finger cooling can lead to loss of basic skills that are critical for soldiers in training and battle in Arctic environments. Furthermore, decreases in core body temperature will also impact performance and health. Physiological monitoring during metabolically demanding multi-day military operations in extreme cold weather environments can identify those individuals at greater risk of cold injury and provide insight into their performance capabilities. The purpose of this symposium presentation is to describe the use of physiological monitoring methods in Arctic environments and characterize the cardiovascular and thermal responses during a multi-day ski patrol using these methods.

Methods: Two studies were completed with Norwegian soldiers (n = 28) undergoing long duration ski patrols (~50 km over 3 – 4 days) in the Arctic (ambient temperature ranged from -18°C to -4°C). A physiological monitoring system (Equivital-1, Hidalgo Ltd. Cambridge, UK) was used to measure Heart Rate (HR), core (T_{core}), and chest skin temperature (T_{chest}). Ingested temperature pills (Jonah™ Core Temperature pill) were used to obtain T_{core}. Wired temperature thermistors were affixed to the nailbed region to obtain peripheral finger (T_{finger}, 4th finger) and toe (T_{toe}, large toe) temperatures (n = 10).

Results: Mean responses during exercise/skiing ranged from 120 – 140 bpm for HR, 37.5 – 38.0°C for T_{core}, 33 – 34°C for T_{chest}, 30 – 35°C for T_{finger} and 25 – 30°C for T_{toe}. At rest, HR ranged from 60 – 80 bpm, T_{core} was

36.0 – 36.3°C (lowest individual T_{core} was 35.6°C), T_{chest} was 35 – 36°C for, T_{finger} decreased to 15 – 20°C, although some individual temperatures fell to 6 – 10°C, and T_{toe} decreased to 15 – 20°C, with some individual temperatures decreasing as low as 9 – 10°C.

Conclusion: Physiological monitoring demonstrated that during these three- to four-day ski marches in the Arctic, exercise intensity was ~65% age-predicted maximal heart rate with mild elevations in T_{core}, suggesting little cardiovascular or thermoregulatory strain. Finger and toe temperatures were elevated during exercise, but at rest were at values associated with discomfort and possible decrements in manual dexterity. Development of new physiological monitoring concepts, perhaps instrumenting gloves and boots to provide peripheral T_{finger} and T_{toe} would provide additional real-time information and awareness to protect against cold injury. Due to the extreme Arctic environment, soldier monitoring requires very robust systems and long-life batteries.

C.1.4 Speaker Abstract 4 – Development of an Integrated Physiological Monitoring System for the Royal Netherlands Army

Veenstra, B.[1], Schwietert, H.R.[2], Goll, R.[2], Beijnum van, B.J.F.[3]

[1] Institute of Training Medicine & Training Physiology, MOD/TGTF, Utrecht, the Netherlands.

[2] Evalan, Amsterdam, the Netherlands.

[3] University of Twente, Biomedical Signals and Systems, Enschede, the Netherlands.

[1] bj.veenstra.01@mindef.nl

Purpose: The Royal Netherlands Army, in collaboration with partners, is developing an integrated multi-sensor system to measure physical workload, performance, and health status of soldiers. This so-called Ambulant Registration of Military Operational Readiness (ARMOR) system can be used to measure or estimate gait speed, distance, step frequency, activity class, heart rate, energy expenditure, sleep duration, and core temperature. An innovative feature of ARMOR is the automatic assessment of load carried by soldiers by means of an instrumented insole in the military boot. The aim of the present study is to develop algorithms to convert raw insole output to carried load and to establish the validity of the load measurement.

Methods: Twenty-six healthy subjects were equipped with the ARMOR system, with the instrumented insole in their left boot and a dummy insole in the right boot. Subjects completed a series of 20 trials, consisting of a 30 meter walk in a straight line on hard surface. The carried load (in hands and backpack) increased with 5 kg per trial, starting with 0 kg until the load of 45 kg was reached. Each load was carried during 2 trials at different gait speeds.

Results: A general multiple regression model was used to predict load without individual calibration, comprising five independent variables: total pressure of the insole, gait speed, swing time, body weight, and shoe size (R^2adj = 0.52; see = 9.6 kg). To improve the accuracy of the prediction, individual regression equations were constructed. These individual equations were based on the trials with 0 kg and 30 kg and consisted of two independent variables: total pressure of the insole and swing time. All other data points were calculated using these individual equations. The mean difference between the predicted load and the actual load was 0.02 kg (sd = 3.66kg). Bland Altman plots showed no systematic errors in predicting load.

Conclusion: The ARMOR system is capable of estimating carried load over the range 0 – 45 kg using the ARMOR insole. Individual calibration is needed to achieve an acceptable accuracy (95% confidence interval of ± 7.2 kg). For the individual calibration, soldiers need to walk four times 30 meters, with and without weight, prior to the actual measurement.

C.1.5 Speaker Abstract 5 – Mobility and Biomechanics Inserts for Load Evaluation (MoBILE): Measuring Load and Terrain Based Gait Changes

Lacirignola, J.[1], Davis, S.[2], Young, W.[2], Weston, C.[2], Collins, P.[2], Balcius, J.[3], Richter, M.[3], Palmer, J.[2]

[1,2] MIT Lincoln Laboratory, 244 Wood Street, Lexington, MA, USA.
[3] Marine Expeditionary Rifle Squad, Quantico, VA, USA.

[1] lacirignola@ll.mit.edu

Purpose: Dismounted Warfighters must carry equipment, ammunition and supplies, which can total 57 kg (125 lbs) or more, as part of training and to support their missions. Movement with this type of heavy load can inhibit range of motion, decrease agility and mobility and lead to an increased risk for musculoskeletal injuries. Measuring how different loads and load configurations affects movement, agility, mobility and endurance are critical to developing protocols and procedures to help maximize performance and minimize injury. It has been inherently difficult to acquire this type of data outside of the laboratory in a robust and repeatable way.

Methods: Previously we reported on the construction and calibration of a lower limb biomechanics measurement system in a shoe insert form factor. This system called the “Mobility and Biomechanics Inserts for Load Evaluation” (MoBILE) allows for the monitoring of complex biomechanical actions without compromising natural gait rhythms (Lacirignola 2017). Each insert combines three load measurements, an altimeter and a nine axis Inertial Measurement Unit (IMU) at the foot and a second IMU at the ankle to provide lab quality measurements. MoBILE inserts were used to collect outdoor data from participants to look for changes in gait patterns with and without loads. Analysis tools were developed to process data, determine features or combinations of features and show relationships between sensor types.

Results: The analysis of MoBILE data indicates that several features derived from the load sensors and IMUs can be used to gain insight into the effect of load and load distribution on performance and may help to identify injury. The features show detectable changes in gait arising from load and terrain conditions.

Conclusion: The MoBILE system is a tool for measuring outdoor lower leg biomechanics movements. The MoBILE measurements and resulting analysis provide a new method of monitoring potential changes to movement in relation to load and load configuration. This information can used to inform load carriage protocols and training procedures and potentially reduce the risk of musculoskeletal injury.

Reference:

Lacirignola, J, Weston, C., Byrd, K. et al. (2017) Instrumented footwear inserts: A new tool for measuring forces and biomechanical state changes during dynamic movements, presented at IEEE Body Sensor Network Conference, Eindhoven, the Netherlands.

C.1.6 Speaker Abstract 6 – Implementation of Physiological Status Monitoring in Weapons of Mass Destruction-Civil Support Teams (WMD-CSTs) to Enhance Performance and Ensure Safety of Soldiers

Tharion, W.[1], Buller, M.[2], Hoyt, R.[3]

[1,2,3] Biophysics and Biomedical Modelling Division, US Army Research Institute of Environmental Medicine, Natick, MA, USA.

[1] william.j.tharion.civ@mail.mil

[2] mark.j.buller.civ@mail.mil

[3] reed.w.hoyt.civ@mail.mil

Purpose: Typical safety of WMD-CST Chemical, Biological, Radiological, and Nuclear (CBRN) personnel within the contaminated "hot zone" uses a subjective "buddy" assessment system. Thermal-work limits have typically been set on the basis of group means and normal ranges. Individualised monitoring and predictions for mission management are now possible using real-time physiological monitoring.

Methods: The transition of "research for the soldier" solutions to actual soldier use requires the involvement of multiple organizations, product modifications, and navigating the government acquisition process. It is not a simple transition of the research solution to an end user solution. This implementation has been accomplished through continuous meetings with users, their leadership proponents, and commercial suppliers and involved detailed evaluation of user training and application needs.

Results: The US National Guard Bureau is the first organizational adopter of real-time physiological monitoring for operational safety and performance; with system roll out occurring in 2017 to its 57 teams across the US and its territories. This required a set of validation tests for the intended use, the development of training materials and a medical technical directive for suggested operating guidelines, and logistics integration.

Conclusion: The process will continue with a post-market surveillance research effort to ensure iterative adjustments and improvements are incorporated from the ultimate innovator, the end user.

C.2 NON-PHARMACOLOGICAL MILITARY PERFORMANCE ENHANCEMENT TECHNOLOGIES

Co-chairs: Karl Friedl (USA) and Mark Buller (USA)

Session Summary

Real-time physiological monitoring is beginning to produce unexpected benefits including the ability to produce performance that is "unnatural" because it would not likely occur without the technological advantage provided by real-time physiological feedback coupled with predictive models for non-intuitive performance advice. Well trained and experienced soldiers and athletes can achieve remarkable performances, in part, because of their learned performance strategies, yet even this group could benefit from advice against novel environmental and physiological challenges not previously experienced or trained for. Examples are provided for accelerated heat acclimation, thermal-workload management and planning, advance predictions during ascent to altitude, and novel monitoring and enhancement of restorative sleep.

C.2.1 Speaker Abstract 1 – A Novel Individual Heat Acclimatization Dosimeter Concept

Delves, S.[1], Buller, M.[2]

[1] Environmental Medicine and Science, Institute of Naval Medicine, Alverstoke, Hampshire, UK.

[2] Biophysics and Biomedical Modelling Division, United States Army Research Institute of Environmental Medicine, Natick, MA, USA.

[1] simon.delves216@mod.uk

[2] mark.j.buller.civ@mail.mil

Purpose: Acclimatization to hot environments will improve sporting and occupational performance. It is widely accepted that a constant strain, controlled hyperthermia model of acclimatization provides the most appropriate forcing function for core temperature that promotes acclimatization [1]. A prolonged elevation in core temperature in this manner stimulates the physiological responses leading to heat acclimatization. Previously, this could only be undertaken safely using direct measures of core temperature. The US Estimated Core Temperature (ECTemp™) [2] algorithm now allows for the estimation of core temperature, thus providing a safe, non-invasive approach that could be compared against an optimally modelled response by the combination of core temperature and heart rate in the calculation of the real-time Physiological Strain Index (PSI) [3].

Methods: Presenting the PSI in a personal display could provide a real-time feedback loop by which exercise/thermal strain could be controlled by the individual. This would allow the individual to maintain an appropriate core temperature, by modifying work rate, which would promote the most efficient acclimatization response in the time allocated. Attaining a PSI of 7.0 within the first 20 – 30 minutes and then maintaining for a 90 minute exercise period would follow the ideal modelled response.

Results: A calculation of the cumulative PSI acclimatization response for the duration of the acute exercise period would provide a daily dose of acclimatization that can be compared against the ideal modelled response. Further, when summed over a number of days a dose response can be calculated to define the percentage of acclimatization an individual has achieved in total.

Conclusion: For the first time this new, novel, dosimeter concept allows individuals to self-monitor thermal strain for the most efficient acclimatization exercise within the time available. This approach could be used with different exercise modalities such as running, cycling, rowing (ergometer), circuit training or stepping in hot environments.

References:

[1] Taylor, N.A.S. (2014) Human heat adaptation. Compr Physiol. 4:325-365.

[2] Buller, M.J. et al. (2013) Estimation of human core temperature from sequential heart rate observations. Physiological Measurement. 34 (7):781-798.

[3] Moran, Daniel S., Moran, D.S., Shitzer, A., and Pandolf, K.B. (1998) A physiological strain index to evaluate heat stress. American Journal of Physiology. 275 (1):R129-R134.

C.2.2 Speaker Abstract 2 – Physiologically Based Real-time Pacing Algorithms

Buller, M.[1], Welles, A.[2], Stevens, M.[3], Leger, J.[4], Gribok, A.[5], Looney, D.[6], Friedl, K.[7], Rumpler, W.[8], Hoyt, R.[9]

[1, 2, 6, 9] Biophysics and Biomedical Modelling Division, US Army Research Institute of Environmental Medicine, Natick MA, USA 01760.

[3, 4, 5, 8] Food Components and Health Laboratory, Beltsville Human Nutrition Research Center, United States Department of Agriculture, Beltsville, MD, USA 20705.

[1] mark.j.buller.civ@mail.mil

[2] alexander.p.welles.civ@mail.mil

[3] michelle.Stevens@ARS.USDA.GOV

[4] Jayme.Leger@ARS.USDA.GOV

[5] agribok@utk.edu

[6] david.p.looney4.ctr@mail.mil

[7] friedlke@gmail.com

[8] bill.rumpler@ars.usda.gov

[9] reed.w.hoyt.civ@mail.mil

Disclaimer: *The views expressed are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the US Government.*

Purpose: Pacing in competitive sports is an attempt to optimize an individual's energetic resources given the demands of the event and the environment. An athlete may approach an event with a pacing strategy based upon an understanding of the event demands and their own learned experience. Their predefined pacing strategy may be modified during the event based upon the environmental conditions, the athlete's volition and the onset of fatigue. Recent work indicates that the onset of fatigue is driven by a complex integration of the state of the peripheral muscles / peripheral sensory system and the central nervous system. Work rate is adapted in order to optimize performance and prevent potentially harmful changes to homeostasis (Sports. Med.2013:43:301-311). The purpose of this study was to examine whether control-theory based computational optimization techniques could be used to optimize the pace of humans over a novel task given physiological and task performance feedback.

Methods: Ten males and seven females (22.9±3.2yrs, 1.71±0.07 m, 67.1±8.5 kg) participated in two treadmill exercise sessions where they were expected to move 5 miles within an hour. Task optimality was defined as complete the task, maintain a safe level of physiological strain, and end as cool as possible. Participants paced themselves during the initial session (SELF) and were guided by an automated algorithm during the second (GUIDE). Ratings of thermal sensation were collected every 10 minutes. Heart Rate (HR), Core Body Temperature (CT) and Skin Temperature (ST) were recorded every minute. The algorithm used distance completed, Physiological Strain Index (PSI – a weighted combination of HR and CT) and time to suggest a pace.

Results: Nine volunteers completed the 5 miles in the GUIDE session while 8 were stopped by the algorithm as they would reach "unsafe" PSI limits (PSI > 7.5). Those stopped were less fit with longer 2 mile run times (15:34±0:29 min.) than those guided to completion (14:56±0:29 min.). Participants that completed the 5 miles in both sessions had significantly lower maximal CT (38.4 vs. 39.0°C), ST (35.0 vs. 35.7°C), HR (165 vs. 182 beats/min.), and thermal sensation ("Warm/Hot" vs. "Hot / Very Hot") during the GUIDE vs. the SELF session ($p<0.05$).

Conclusion: The pacing algorithm:

1) Minimized the physiological strain experienced when completing physically demanding tasks compared to self-pacing; and
2) Was able to quickly identify participants who were not fit enough to complete the task within the safety parameters.

C.2.3 Speaker Abstract 3 – Subject-Specific Prediction of Body Core Temperature Using Nonlinear Population Modelling

Seng, K.-Y.[1,2]*;* Fan, W.P.[1]; Lee, S.H.M.[1]; Ong, J.[1]; Tan, P.L.[1]; Law, Y.L.L.[1]; Lee, K.W.J.[1,2]

[1] Combat Protection and Performance, Defence Medical & Environmental Research Institute, DSO National Laboratories, Singapore.

[2] Yong Loo Lin School of Medicine, National University of Singapore, Singapore.

[1] skokyong@dso.org.sg

[2] fweiping@dso.org.sg

[3] lsihui@dso.org.sg

[4] ojunxian@dso.org.sg

[5] tpohling@dso.org.sg

[6] lydia.law@dso.org.sg

[7] lkaiwei@dso.org.sg

Purpose: Mathematical modelling to estimate individualised body core temperature (Tc) using data gathered from increasingly ubiquitous body worn sensors is a subject of active investigation. Many current modelling approaches, however, are adequate for assessing group mean Tc only. In this paper, we described estimation in the context of nonlinear mixed effects modelling where the full reference population's statistics (estimated fixed effects, variance-covariance of random effects, variance of noise) is used along with a new subject's non-invasive heat strain markers (heart rate and surface skin temperature) and surrogate Tc data as likelihood to predict individualised Tc over time.

Methods: Models were trained and internally validated using data from 72 volunteers who participated in a 16km route march with fixed work-rest cycles (air temperatures 23 – 32ºC; 65% – 97% relative humidity; Tc 36.4 – 40.1ºC). External model validation was conducted using data from 64 volunteers who participated in a timed route march (15 – 20 km) (air temperatures 25 – 30ºC; 67% – 95% relative humidity; Tc 35.9 – 40.5ºC). Under model validation, a new subject's Tc was estimated using three likelihood schemes: (L1) a singular Tc (at baseline; fixed at 37ºC); (L2) Tc measured at baseline and at the start of every work phase; and (L3) Tc estimated using a multiple linear regression model at baseline and at the start of every work phase. Model accuracy was assessed using the Bland Altman Limits of Agreement (LoA) and the proportion of errors within ±0.3ºC (PTA).

Results: Under internal validation, the L2 model achieved LoA of [-0.39, 0.42]ºC and 88% PTA compared to L1 ([-0.62, 0.59]ºC and 69%) and L3 ([-0.44, 0.51]ºC and 80%). Under external validation, the L2 model achieved LoA of [-0.38, 0.45]ºC and 84% PTA compared to L1 ([-0.69, 0.72]ºC and 62%) and L3 ([-0.43, 0.64]ºC and 74%).

Conclusion: While the L2 model was clearly superior, it required the usage of measured Tc of a new subject for estimation. In the absence of measured Tc, the L3 model provided a good compromise between estimation accuracy and practicality of implementation.

C.2.4 Speaker Abstract 4 – Predicting Individual Risk of Altitude Illness Using Real-Time Monitoring of Accumulated Hypoxic Debt

Beidleman, B., Welles, A., and Buller, M.

[1] Biophysics and Biomedical Modelling Division, US Army Research Institute of Environmental Medicine, Natick MA, USA 01760.

[1] beth.a.beidleman.civ@mail.mil

[2] alexander.p.welles.civ@mail.mil

[3] mark.j.buller.civ@mail.mil

Disclaimer: *The views expressed are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the US Government.*

Purpose: Dismounted Warfighters are the primary weapon platform in mountainous terrains and altitude illness can severely limit Warfighters' operational effectiveness in this environment. When altitude illness is severe, Warfighters may be completely incapacitated and unable to perform the physical work necessary to complete the mission. The purpose of this study was to develop a predictive algorithm based on individual real-time monitoring of accumulated hypoxic debt to predict the future occurrence of Acute Mountain Sickness (AMS) such that a timely warning can be given and corrective action can be taken before missions are compromised.

Methods: Sixteen healthy non-smoking unacclimatized lowlanders (M = 12, F = 4, age = 23 ± 2 yrs, wt = 75 ± 3kg; mean ± SD) ascended to the summit of Pikes Peak at 4300 m and wore a physiologic status monitor (Equivital™ EQ-02) that measured Heart Rate (HR) and pulse arterial oxygen saturation (SpO_2) every 15 s for the first 20 h of altitude exposure. The Environmental Symptoms Questionnaire was utilized to measure the prevalence and severity of AMS-C after 4, 8, 16 and 20 h of exposure. If AMS-C was ≥0.7, individuals were considered sick. Data was filtered such that all volunteers had the same number of physiologic measurements prior to each AMS measure. The mean HR and SpO_2 were calculated prior to each AMS measurement. Accumulated HD was calculated by multiplying the time period (15 s) by the difference between 90% and the actual SpO_2 for each of the 3738 collection points.

A general linear mixed model was developed to predict the severity of AMS using accumulated Hypoxic Debt (HD), mean HR, and mean SpO_2 as predictor variables.

Results: The mean HR ($P = 0.01$), mean SpO_2 ($P = 0.0001$), and accumulated HD ($P = 0.05$) were all significant predictors in the model. AMS severity increased ($P<0.05$) 58% for every 1000 m increase in accumulated HD. In addition, for every 1% decrease in mean SpO_2 and 10 beat per minute decrease in mean HR, the severity of AMS increased ($P<0.05$) by 26% and 16%. The model explained 65% of the variance in AMS-C severity scores.

Conclusion: Real-time individual physiologic monitoring of accumulated hypoxic debt, HR, and SpO_2 can be utilized to predict the severity of AMS. Individual monitoring of "hypoxic debt" during altitude exposure represents a promising approach for predicting altitude illness before its occurrence.

C.2.5 Speaker Abstract 5 – Auditory Closed-Loop Stimulation to Enhance Sleep Quality

Arnal, P.J.[1], Debellemaniere, E.[1], El-Kanbi, K.[1], Pinaud, C.[1], Thorey, V.[1], Chambon, S.[1], Galtier, M.[1], Léger, D.[2], Chennaoui, M.[2]

[1] Rythm, Paris, France.

[2] Alertness, Fatigue and Sleep Team (EA7330), Paris Descartes University, Paris, France.

[1] pierrick.arnal@gmail.com

Purpose: Recent researchers have tried to manipulate sleep to improve sleep quality and cognition. Auditory closed-loop stimulation has emerged as an efficient, easy and non-invasive way to boost slow oscillations during deep sleep. The present study aimed to assess the use and accuracy of a dry-EEG device (DREEM®) for auditory closed-loop stimulations in ecological setting.

Methods: Twenty young healthy subjects slept with both EEG device and a medical polysomnography. In parallel, an observational study on a cohort of 170 volunteers for a running total of 13,000 nights was realized at home to observe the impact of auditory stimulations.

Results: The sensitivity and specificity for deep sleep detection were of 0.73 and 0.90 respectively as compared to a medical polysomnography device. The performance of the SO up-phase stimulation targeting reached 315° on average and induce a significant increase in the amplitude of slow oscillations. The repeated applications of stimulations over time did not change the overall sleep architecture and the local stimulation impact as compared to stimulations applied on a single night.

Conclusion: DREEM® can be used as a tool to record sleep EEG and enable precise auditory closed-loop stimulation enabling to conduct broad, ecological sleep studies.

ANNEX D – AGENDA/PLANNING FOR COLLABORATION DEMONSTRATION OF TECHNOLOGY ON WEARABLE MONITORING MILITARY APPLICATIONS

NATO Panel HFM-260: Enhancing Warfighter Effectiveness with Wearable Biosensors and Physiological Models.

NATO CONCEPT DEMONSTRATION VISIT SCHEDULE AND INFORMATION

Background

1) NATO Panel HFM-260 was convened in 2015 where the main objective of the panel is to explore the use of wearable biosensor systems and mathematical models to expand physiological monitoring applications for military training and operational use. The UK has been influential in moving these areas forward and has benefited from the collaborations that have been formed, notably with the United States Army, Swiss Army and the Royal Netherlands Army.

2) The final meeting of this 3-year cycle will be hosted by the UK, and will incorporate a Concept Demonstration (CD) at Commando Training Centre Royal Marines (CTCRM), Lympstone, UK on 23 – 24 May 2018 to present the wearable technologies that have been developed by the member Nations.

Schedule

3) A series of presentations will precede the CD on the afternoon of 23 May 2018. These will present work from other NATO member Nations and collaborations that are ongoing. They will also present data that have been collected at CTCRM during the 9-Mile Speed March (9MSM) criterion test from Royal Marines (RM) recruit training.

4) The Concept Demonstration will comprise of a 4-Mile Speed March (4MSM) by eighteen RM from CTCRM, divided into three groups of six. The following wearable technologies will be demonstrated on all personnel, and with the sub groups.

5) Total Group: Personal, local and remote presentation of heat illness mitigation technology.

   Group-1: The Royal Netherlands Army Physical Demands ARMOR system.

   Group-2: The Swiss Army Aximote Training Load PADIS Sensor System.

   Group-3: Dead Reckoning System, University of Parma.

Timetable

Wednesday 23 May 2018

1300 CTCRM Commandant Welcome and Corp Background. Col. M. Tanner, CTCRM Commandant.

1310 Introduction to Presentations and Concept Demonstration. Dr. Simon Delves, Institute of Naval Medicine, UK.

1330 The Past, Present and Future of Wearable Technology. Dr. Karl Friedl, US Army Institute of Environmental Medicine, US.

1350 Monitoring of Physical Demands for Injury Prevention in the Swiss Army. Dr. Thomas Wyss, University of Magglingen, Switzerland.

1410 Data Management and Visualization System for Military Training and Operations. Dr. Craig Murdoch, US Air Force, US.

1430 Tea and Coffee.

1450 The Use of Monitoring Tools during Basic Military Training in the Netherlands. Mr. Bertil Veenstra, the Royal Netherlands Army, the Netherlands.

1510 CTCRM 9MSM Central Nervous System (CNS) Dysfunction and Gait Asymmetry Analysis. Dr. Jeff Palmer, Lincoln Laboratory, MIT.

1530 CTCRM 9MSM "ECTemp" Validation Data. Dr. Mark Buller, US Army Institute of Environmental Medicine, US.

1550 Plan for Concept Demonstration. Dr. Simon Delves, Institute of Naval Medicine, UK.

Thursday 24 May 2018

0800 Concept Demonstration Introduction, Dr. Simon Delves, Institute of Naval Medicine, UK.

0830 Concept Demonstration START. 4MSM into CTCRM.

0930 4MSM arrives at front gate.

0940 Rest and reorganisation. Tea and Coffee.

1030 Bottom field exercise.

1130 Wash-up Discussion.

1200 Finish.

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	STO-TR-HFM-260 AC/323(HFM-260)TP/927	ISBN 978-92-837-2252-6	PUBLIC RELEASE

5. Originator	
	Science and Technology Organization North Atlantic Treaty Organization BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title

Enhancing Warfighter Effectiveness with Wearable Biosensors and Physiological Models

7. Presented at/Sponsored by

Final Report of Task Group HFM-260.

8. Author(s)/Editor(s)	9. Date
Multiple	January 2020

10. Author's/Editor's Address	11. Pages
Multiple	74

12. Distribution Statement	
	There are no restrictions on the distribution of this document. Information about the availability of this and other STO unclassified publications is given on the back cover.

13. Keywords/Descriptors

Technologies, wearable	Neurophysiological	Initial entry
Physiological monitoring	Accelerometry	Inertial navigation
Mathematical modelling	Electrocardiography	Peripheral cold monitoring
Thermal injury	Boot inserts/instrumented insoles	Multinational research collaboration
Work load	Oximetry	Successful
Energy expenditure	Training	Military personnel
Sleep and alertness		

14. Abstract

Physiological monitoring has many potential applications for the military where real-time health and performance status of individual soldiers can provide actionable information to the individual, leaders, and medical personnel. This panel advanced the science of physiological monitoring technology applications for protection and enhancement of soldier performance. The results of four years of research discussion, coordination, and direct multinational collaborations were captured in three demonstrations and numerous peer-reviewed publications. Accomplishments of this panel included: information exchanges on technologies and use cases for wearable monitoring technologies; synchronized national wearable monitoring efforts on best practices and lessons learned; a common approach and basis for real-time thermal strain monitoring in the field, now proposed as a new RTG to develop a STANREC; shared mature national efforts on alertness monitoring and crew rest scheduling; explored sensor technologies to fill specific monitoring needs such as boot inserts for ground reaction forces, strategies for inertial navigation, and skin temperature monitoring in cold environments; dissemination of findings from national and multinational studies through relevant conferences, including annual IEEE Body Sensor Networks conferences; conduct of a multinational study led by Switzerland; development of a monitoring systems for applications in training safety for recruits, highlighted in one of the Cooperative Demonstrations of Technology (CDT).

NORTH ATLANTIC TREATY ORGANIZATION

NATO OTAN

BP 25

F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE

Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

SCIENCE AND TECHNOLOGY ORGANIZATION

DIFFUSION DES PUBLICATIONS
STO NON CLASSIFIEES

Les publications de l'AGARD, de la RTO et de la STO peuvent parfois être obtenues auprès des centres nationaux de distribution indiqués ci-dessous. Si vous souhaitez recevoir toutes les publications de la STO, ou simplement celles qui concernent certains Panels, vous pouvez demander d'être inclus soit à titre personnel, soit au nom de votre organisation, sur la liste d'envoi.

Les publications de la STO, de la RTO et de l'AGARD sont également en vente auprès des agences de vente indiquées ci-dessous.

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivi du numéro de série. Des informations analogues, telles que le titre est la date de publication sont souhaitables.

Si vous souhaitez recevoir une notification électronique de la disponibilité des rapports de la STO au fur et à mesure de leur publication, vous pouvez consulter notre site Web (http://www.sto.nato.int/) et vous abonner à ce service.

CENTRES DE DIFFUSION NATIONAUX

ALLEMAGNE
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7, D-53229 Bonn

BELGIQUE
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30, 1000 Bruxelles

BULGARIE
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

CANADA
DGSIST 2
Recherche et développement pour la défense Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

DANEMARK
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

ESPAGNE
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

ESTONIE
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

ETATS-UNIS
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

FRANCE
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc
BP 72
92322 Châtillon Cedex

GRECE (Correspondant)
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

HONGRIE
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

ITALIE
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

LUXEMBOURG
Voir Belgique

NORVEGE
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

PAYS-BAS
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

POLOGNE
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

PORTUGAL
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

REPUBLIQUE TCHEQUE
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

ROUMANIE
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

ROYAUME-UNI
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down
Salisbury SP4 0JQ

SLOVAQUIE
Akadémia ozbrojených síl gen. M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 01 Liptovský Mikuláš 1

SLOVENIE
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

TURQUIE
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

AGENCES DE VENTE

The British Library Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
ROYAUME-UNI

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivie du numéro de série (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Des références bibliographiques complètes ainsi que des résumés des publications STO, RTO et AGARD figurent dans le « NTIS Publications Database » (http://www.ntis.gov).

NORTH ATLANTIC TREATY ORGANIZATION

NATO
OTAN

BP 25
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE
Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

SCIENCE AND TECHNOLOGY ORGANIZATION

DISTRIBUTION OF UNCLASSIFIED STO PUBLICATIONS

AGARD, RTO & STO publications are sometimes available from the National Distribution Centres listed below. If you wish to receive all STO reports, or just those relating to one or more specific STO Panels, they may be willing to include you (or your Organisation) in their distribution.

STO, RTO and AGARD reports may also be purchased from the Sales Agencies listed below.

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number. Collateral information such as title and publication date is desirable.

If you wish to receive electronic notification of STO reports as they are published, please visit our website (http://www.sto.nato.int/) from where you can register for this service.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30
1000 Brussels

BULGARIA
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

CANADA
DSTKIM 2
Defence Research and Development Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

CZECH REPUBLIC
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

DENMARK
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

ESTONIA
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

FRANCE
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc – BP 72
92322 Châtillon Cedex

GERMANY
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7
D-53229 Bonn

GREECE (Point of Contact)
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

HUNGARY
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

ITALY
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

LUXEMBOURG
See Belgium

NETHERLANDS
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

NORWAY
Norwegian Defence Research Establishment, Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

POLAND
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

PORTUGAL
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

ROMANIA
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

SLOVAKIA
Akadémia ozbrojených síl gen M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 01 Liptovský Mikuláš 1

SLOVENIA
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

SPAIN
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

TURKEY
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

UNITED KINGDOM
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down, Salisbury SP4 0JQ

UNITED STATES
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

SALES AGENCIES

The British Library Document Supply Centre
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
UNITED KINGDOM

Canada Institute for Scientific and Technical Information (CISTI)
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Full bibliographical references and abstracts of STO, RTO and AGARD publications are given in "NTIS Publications Database" (http://www.ntis.gov).

ISBN 978-92-837-2252-6