Effects of smart garments on the well-being of athletes: a scoping review protocol

Abdullah Al Mahmud, Tharushi Indeewari Wickramarathne, Blair Kuys

ABSTRACT

Introduction With the advancements in wearable electronics, electronically integrated smart garments started to transpire in our daily lives. Smart garment technologies are incorporated into sportswear applications to enhance the well-being and performance of athletes. Smart garments applications in the sports sector are increasing, and the variety of smart garment applications available in the literature is overwhelming. Therefore, it is essential to compare the vast array of technologies incorporated in smart garments for athletes to understand the knowledge gaps for future studies. The protocol paper aims to examine the smart garments used in the sports domain to enhance the health and well-being of athletes.

Methods and analysis Relevant studies will be retrieved using predefined search terms from Scopus, Web of Science, Science Direct, PubMed and IEEE Xplore. The retrieved articles will be eliminated in two phases: title and abstract screening and full-text screening. The included articles will be primary studies published in the English language within the last 10 years. Subsequently, the included articles will be further studied to extract data using a data extraction form. The extracted data will undergo a thematic analysis. Also, quantitative analysis will be carried out using descriptive statistics.

Ethics and dissemination The results of this review will provide a comprehensive understanding of smart garment concepts used in the sports domain. The findings of this scoping review will be shared through a journal publication and a conference presentation. Ethical approval is not needed for this scoping review.

Protocol registration number DOI 10.17605/OSF.IO/34MF2 (https://osf.io/34mf2)

INTRODUCTION

Smart garments are clothing items that are made with intelligent materials or electronic technologies, which can sense, react or adapt behaviour to the circumstances. These smart garments are also known as a branch of wearable computers that evolved from the essential monitoring devices such as heart rate monitors, fitness monitors and smart wristwatches like Fitbit. Smart garments can be worn like regular clothing, and they can measure a broad spectrum of biomechanical and physiological metrics and provide advanced functions like posture controlling to support the health and well-being of the athletes.

The majority of smart garment applications integrate sensor technology that enables wireless health monitoring. One such example is Hexoskin, which is a clinically validated smart shirt that can measure biological/physical parameters like cardiac, respiratory, sleep and activity data. Temperature monitoring using wearable sensors and smart cooling are some other smart applications that can be integrated into clothing to enhance the comfort and wellness of an individual. Smart monitoring and other related functions offered by some of the existing smart garments are listed in table 1.

Sportswear started getting subjected to the unique demands of athletes, to protect the wearer from extreme environmental conditions. Also, researchers explored sensor technologies as a means of enhancing the health and well-being of athletes. Considering these, to address complex sportswear requirements and to improve the well-being of athletes, smart technologies with integrated sensors started to outspend into the sports market. Some of the existing studies explored the use of sensors to measure biological parameters (ie, heart rate, muscle
and oxygen saturation) and safety-related parameters (i.e., position, motion and impact) to enhance health, wellness and performance of athletes.\textsuperscript{11–13} Another study investigated the use of smart textiles in snowboarding activity where textile pressure sensors were utilised to recognise the activities performed by users.\textsuperscript{12} Also, researchers developed a smart shirt and leggings to measure heart and muscle activity, breathing rate and temperature.\textsuperscript{14} With these examples, it is evident that smart technology can be incorporated into sportswear applications to enhance the well-being and performance of athletes.

Sportswear manufacturers started stretching the boundaries of smart wearables by integrating technology into garments.\textsuperscript{4} As mentioned in market reports, smart garment applications in the sports sector are expected to exhibit high growth.\textsuperscript{15} However, most of the commercialised sport smart garments offer standard functions like smart monitoring, communication, compression and coughing. These garments consist of non-textile electrical/electronic devices/components to inbuild intelligent functions to the clothing inhibiting user experience. Researchers started exploring e-textiles and designed smart technologies into textiles.\textsuperscript{16 17} Also, some studies examined creative, smart applications to improve user experience. The smart garment that reacts to the wearer mood is one such example.\textsuperscript{18} These studies provide an opportunity for future smart sports garments that can improve the health and well-being of athletes. A technology mapping and review of existing smart garments designed for athletes will assist in understanding how these smart garments may inform the new product development and guide further research.

### Rationale

Several researchers have reviewed the applications of wearable technology and smart garment technology.\textsuperscript{10 13 19–22} However, most of these papers are focusing on medical or healthcare applications giving less priority to the wellness of athletes.\textsuperscript{21 23 24} Furthermore, the variety of smart garment applications available in the literature is overwhelming. Therefore, the proposed review is essential to compare the vast array of technologies incorporated into smart garments for athletes and also to understand the knowledge gaps for future research.\textsuperscript{25 26}

Some of the existing reviews discuss smart garment technologies that can be applied in the sportswear domain. Yet, they are either outdated\textsuperscript{11 12} or not comprehensive enough to provide an in-depth understanding of the current state of smart sportswear\textsuperscript{27} or focusing only on smart monitoring.\textsuperscript{13} Due to the fast-evolving nature of smart garment applications, researchers frequently introduce novel technologies and materials.\textsuperscript{28 29} One such novel application is recently introduced wearable textile electronics that can uplift the performance of future smart sports clothing.\textsuperscript{28} Metatextiles that offer adaptable thermal comfort and energy harvesting triboelectric materials that can be used to optimise power consumption of smart sports garments are few other new smart technology applications.\textsuperscript{28 29} These latest technologies can fulfil a wide variety of sportswear requirements shifting smart sports garments to a new dimension.

Considering the requirements described above, a comprehensive review, which follows a systematic approach and covers the latest smart sports garment applications is essential to ensure effective use of the latest technologies in future smart garment design projects. Therefore, this paper presents a protocol for conducting a scoping review that can provide a comprehensive evaluation and a technology mapping of the latest smart sports garment technologies to guide future research. The objectives of this review are to identify (A) the functions offered by the smart garments, (B) the types of technologies used in smart garments, (C) effects (beneficial and harmful) of those garments on the performance of athletes and their experience in using such garments.

### METHODS

We follow the scoping review methodology proposed by Arksey and O’Malley.\textsuperscript{30} This protocol consists of six phases namely; (1) identifying the research question, (2) identifying relevant literature, (3) study selection, (4) charting the data, (5) collating, summarising and reporting the articles and (6) consulting and translating knowledge (optional). Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews checklist (see online supplemental file 1) will be used throughout the proposed scoping review to ensure adherence.\textsuperscript{31} The study has been registered in the Open Science Framework (OSF) on 25 June 2020 (https://osf.io/3mf2).

#### Stage 1: identifying the research question

The objective of this study is to assess the existing studies to understand the current smart garment technologies, which are developed to enhance the health and well-being of athletes. Also, this review will generate input requirements for developing improved smart garment for athletes. To concretise the focus of this review, we will concentrate on smart garment studies related to professional athletes. The review is expected to address the below questions.

- What functions do smart garments offer for professional athletes?
What are the technologies incorporated into those smart garments?

How effective are those smart garments to enhance the health and well-being of athletes?

Stage 2: identifying relevant studies

The research team developed the search strategy after reviewing related literature, and an iterative approach was adhered to finalise the strategy (see online supplemental file 2). The search strings were generated by incorporating Boolean logic and operators. These strings consist of search terms, which were finalised after getting agreement from the research team. The search terms are “sensor garments”, “electronic garments”, “smart garments”, “smart apparel”, “sports”, and “athletes”.

The databases, which were selected to collect literature are Scopus, Web of Science, Science Direct, PubMed and IEEE Xplore, and these databases were chosen with the help of an expert university librarian. Due to the rapid technological changes, smart garment applications are quickly becoming outdated; hence only the studies published within the last ten years will be considered for the review. Furthermore, to ensure the credibility of the studies, we only considered peer-reviewed journal articles. Also, only the studies in the English language will be included for review. The research team will review the first 50 search results from each database before proceeding with the full search to ensure the accuracy of the search strategy. However, during the execution of search strategy, authors of primary studies or reviews will be contacted for further information, if required. The latest search was executed on 24 May 2020. The articles retrieved from the search will be imported into the Covidence software, which will remove duplicated items automatically.

Stage 3: study selection: inclusion and exclusion criteria

We will carry out study selection incorporating two-step method. Initially, titles and abstracts will be reviewed against the selection criteria and will be marked as ‘include’, ‘exclude’ or ‘uncertain’. Two reviewers will conduct this screening independently, and a discussion will be undertaken in the research team to resolve any discrepancy and to fine-tune selection criteria. This screening and discussion process will continue until we reach a consensus. Subsequently, for the included studies, the full-text review will be carried out against the selection criteria following the same screening procedure. Grey literature will not be considered for this review.

This two-stage study selection process will be conducted, incorporating a review form (see online supplemental file 3). Only the studies with electronic integrated smart sports garment, which focus on health and well-being of professional athletes will be included for the review. The review form will incorporate the following inclusion criteria to simplify the screening process.

- Is the article a peer-reviewed primary study?
- Is the article published within the last 10 years (2010–2019) in the English language?

- Does the article involve smart garments?
- Does the article focus on the health and well-being of professional athletes?

The citations of the included studies will be evaluated against selection criteria following the same two-stage study selection process to select the additional studies if required.

Stage 4: charting the data

All included studies will be reviewed and charted using a data extraction form (see online supplemental file 4). The details, which will be extracted from the studies are study citation, publication type, authors, study location, study year, target market, sample characteristics (number of participants and demographics), garment type, number of functions, function type (ie, biomonitoring, coaching, warning and posture control), technology characteristics (sensor type, method of power supply, communication/feedback mechanism and interconnection), evaluation protocol adhered, user acceptability of the concepts and outcome of the study (quantitative results, qualitative themes, recommendations, key learnings and limitations). The charting of the extracted information will be conducted by two reviewers.

Stage 5: collating, summarising and reporting the results

Initially, we will conduct a quantitative analysis for extracted data using descriptive statistics (eg, frequencies). This analysis will provide numerical summaries of (A) smart sports garment applications designed focusing on professional athletes, (B) the functions offered by those smart garments, (C) the types of technologies used in smart garments and (D) effects (beneficial and harmful) of those garments on the performance of athletes and their experience in using such garments. These details will be presented using tables, charts and graphs and will be followed by a brief summary. Afterwards, we will analyse all the extracted data thematically to identify emerging themes. Two reviewers will independently identify the emerging themes, and those themes will be reviewed later by both reviewers to determine the final themes.

Patient and public involvement

This scoping review protocol does not include patients or the public.

Ethics and dissemination

This protocol reports a comprehensive methodology derived from the standard and well-established best practices to guide a scoping review that will be conducted to understand the existing smart sports garments applications. The proposed study will provide a comprehensive review and a technology mapping of the latest smart sports garment technologies that were developed to enhance the well-being of athletes. The scoping review findings will offer foundational know-how on sports smart garment applications emphasising the technology and design gaps to assist new product development and to inform further research. In future work, we are planning...
to disseminate the results of this scoping review at relevant conferences and journals. Ethical approval is not needed for this scoping review, as we will not collect any primary data.

Contributors AAM and TIW contributed to plan the study and prepare the manuscript. All the authors (AAM, TIW and BK) read and approved the final manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data will be available on request.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID iDs Abdullah Al Mahmud http://orcid.org/0000-0002-2801-723X Tharushi Indewari Wickramarathne http://orcid.org/0000-0002-8040-4579 Blair Kuyk http://orcid.org/0000-0001-9857-0439

REFERENCES

1 Aryiatam B, Holland R, Harrison D, et al. The future design direction of smart clothing development. Journal of the Textile Institute 2005;96:199–210.

2 Nike granted patent for smart shoe with in-built fitness tracking. The Sunday Morning Herald. 2016

3 Draper S. Top 5 smart clothes for Workout Freaks in the market right now, 2018. Available: https://www.wearable-technologies.com/2018/08/top-5-smart-clothes-for-workout-freaks-in-the-market-right-now/

4 Sawh M. The best smart clothing, 2018. Available: https://www. wearable.com/smart-clothing/best-smart-clothing

5 Koh A, Kang D, Xue Y, et al. A soft, wearable microfluidic device for the capture, storage, and colorimetric sensing of sweat. Sci Transl Med 2016;8:366ra165–366.

6 HEXOSKIN HEXOSKIN SMART GARMENTS SPECIFICATIONS. n.d. Available: https://www.hexoskin.com/

7 Paul G, Gillett E, Westerfield D. Battery powered heating and cooling suit. In: IEEE Long Island Systems, Applications and Technology (LISAT) Conference 2014, 2014.

8 Suzuki Yet al. Wearable individual adapting cooling system using smartphone and heart beat sensor. In: 2016 55th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE), 2016.

9 Li H, Yang H, Li E, et al. Wearable sensors in intelligent clothing for measuring human body temperature based on optical fiber Bragg grating. Opt Express 2012;20:11740–52.

10 Cho J, Ghaffari R, Baker LB, et al. Skin-interfaced systems for sweat collection and analytics. Sci Adv 2018;4:eaaq9291.

11 Coyle Set al. Textile-Based Wearable Sensors for Assisting Sports Performance. In: 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks, 2009.

12 Holleczek Tet al. Textile pressure sensors for sports applications. In: SENSORS, 2010 IEEE. IEEE, 2010.

13 Seshadri DR, Li RT, Voos JE, et al. Wearable sensors for monitoring the internal and external workload of the athlete. NPJ Digit Med 2019;2:1–18.

14 Palva A, Ferreira F, Catania N, et al. Design of smart garments for sports and rehabilitation. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2018: 459, 012083.

15 Hanuska Aet al. Smart clothing market analysis. Technical Report, 2016.

16 IDTechEx. Introducing the latest in textiles: soft hardware, 2018. Available: https://www.IDTechEx.com/articles/15079/introducing-the-latest-in-textiles-soft-hardware

17 Lugoda P, Dias T, Morris R. Electronic temperature sensing yarn. Journal of Multidisciplinary Engineering Science Studies 2015;1.

18 eScent. PERSONALISED Scent Bubble. n.d. Available: https://www.escent.ai/smartcoatsandskins

19 Tang SL, Stylios G. An overview of smart technologies for clothing design and engineering. International Journal of Clothing Science Technology 2006.

20 Papi E, Koh WS, McGregor AH. Wearable technology for spine movement assessment: a systematic review. J Biomech 2017;64:186–97.

21 Patel S, Park H, Bonato P, et al. A review of wearable sensors and systems with application in rehabilitation. J Neuroeng Rehabil 2012;9:21.

22 Stoppa M, Chioriero A. Wearable electronics and smart textiles: a critical review. Sensors 2014;14:11957–92.

23 Moral-Munoz JA, Zhang W, Cobo MJ, et al. Smartphone-based systems for physical rehabilitation applications: a systematic review. Assist Technol 2019;31:1.

24 Kirk MA, Amin M, Pirbaglou M, et al. Wearable technology and physical activity behavior change in adults with chronic cardiometabolic disease: a systematic review and meta-analysis. Am J Health Promot 2019;33:778–91.

25 Fernández-Caramés T, Fragu-Lamas P. Towards the Internet-of-Smart-Clothing: a review on IoT Wearables and garments for creating intelligent connected E-Textiles. Electronics 2018;7:405.

26 Sayem ASM et al. Review on smart Electro-Clothing systems (SeCs), 2019.

27 Rejnoux M, Singh R. Study of smart textile in sports and designing a smart Jersey for athletes health issue. International Research Journal of Engineering and Technology 2017:4.

28 The Hong Kong Polytechnic University. Highly flexible high-energy textile lithium battery to cope with surging demand for wearable electronics, 2019. Available: https://www.sciencedaily.com/releases/2019/05/190524102744.htm

29 Kapfunde M. 5 innovations that could help smart clothing go mainstream, 2019. Available: https://www.wearable.com/smart-clothing/smart-clothing-technology-innovations-7284

30 Arkyse H, O’Malley L. Wearable studies: towards a methodological framework. Int J Soc Res Methodol 2005;8:19–32.

31 Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ 2015;349:g676.

32 Orwin R et al. The Handbook of research synthesis and critical review. IOP Publishing, 2019: 459. 012083.

33 Paiva Aet al. Design of a Smart Garment for Cycling. Cham: Springer International Publishing, 2019.

34 Durbhaka GK. Adaptive wearable smart fabric based on body posture and temperature. In: 2016 2nd International Conference on Advances in Computing, Communication, & Automation (ICACCA) (Fall), 2016.

35 Wang Q et al. Smart Rehabilitation Garment for posture monitoring. In: 2015 37th annual International Conference of the IEEE engineering in medicine and biology Society (EmBC), 2015.

36 Wang Q et al. Zishi: a smart garment for posture monitoring. In: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, 2016.

37 Linti Cet al. Sensory baby vest for the monitoring of infants. In: International Workshop on Wearable and Implantable Body Sensor Networks (BSN’06), IEEE, 2006.

38 Jahangir Met al. Design and Testing of Cooling Jacket using Peltier Plate. In: 2019 International Conference on Applied and Engineering Mathematics (ICAEM), IEEE, 2019.

39 Wickramarathne TI, Mahmud AA, Kuyk B. Exploring Smart Cooling Garments for Endurance Cycling Athletes. In: Proceedings of the 31st Australian Conference on Human-Computer Interaction, Fremantle, WA, Australia: Association for Computing Machinery, 2019: 563–7.

40 Belbasis A, Fuss FK. Muscle performance investigated with a novel smart compression garment based on pressure sensor force myography and its validation against EMG, 2018: 9(408).