BMJ Open

Effects of Smart Garments on the Wellbeing of Athletes: A Scoping Review Protocol

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-042127
Article Type:	Protocol
Date Submitted by the Author:	26-Jun-2020
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Keywords:	Health informatics < BIOTECHNOLOGY & BIOINFORMATICS, Information technology < BIOTECHNOLOGY & BIOINFORMATICS, Information management < BIOTECHNOLOGY & BIOINFORMATICS, World Wide Web technology < BIOTECHNOLOGY & BIOINFORMATICS

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Title: Effects of Smart Garments on the Wellbeing of Athletes: A Scoping Review Protocol

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ABSTRACT

Background: 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 wellbeing and performance of athletes. Smart garments applications in the sports sector are proliferating, and the variety of smart garment applications available in the literature is overwhelming. Therefore, it is essential to compare the wide variety of technologies incorporated in smart garments for athletes and also to understand the knowledge gaps for future studies. The protocol paper aims to examine the latest developments of smart garments used in the sports domain to enhance the health and wellbeing of athletes.

Methods and analysis: Relevant studies will be retrieved using pre-defined search terms, and the retrieved articles will be filtered, incorporating a two-stage screening process consisting of a title and abstract screening and full-text screening. The included articles will be primary studies published in the English language within the last ten 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, followed by a narrative review. Also, quantitative analysis will be carried out using descriptive statistics.

Discussion: The protocol was developed adhering to the preferred guidelines for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). Results of this scoping review will provide a comprehensive understanding of smart garment concepts used in the sports domain, which enhance the wellness and

health of athletes. The study findings will be disseminated through scientific publications.

Ethics and Dissemination: Ethical approval is not required for this study. The findings of this review will be disseminated through a peer-reviewed publication and a conference presentation.

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

Keywords: Smart garments, Athletes, Wellness, Sports, Health, Heat illnesses

Strengths and limitations of the study

- The proposed study uses existing scoping review methodology to identify the effects of smart garments on the wellbeing of athletes.
- The study will provide an in-depth understanding of the current state of smart sportswear for athletes.
- The review will investigate a large volume of literature from the last ten years.
- The scoping review will not consider the grey literature and studies published in English will be reviewed.

BACKGROUND

Smart garments are clothing items that have been integrated with technology such as sensors and may connect with an app or wearables such as Fitbit or smart watch.[1] These wearable computers evolved from basic monitoring devices such as heart rate monitor, fitness monitors and smart wristwatches to advance smart garments covering a wide variety of markets. Smart garments enabled the integration of smart materials into clothing for uplifting health, wellness and lifestyle of humans. Majority of smart garment applications integrate sensors in garments, which can track/monitor biological and environmental details. The 'smart shirt', which measure vital body parameters and communicate with remote units is an example of a smart garment

application in the healthcare sector. [2, 3] This development was conducted primarily to ensure occupational wellness focusing on occupations such as military, firefighters, healthcare professionals, and police officers.[2, 3] Innovative wound care biosensing is another smart clothing application.[4] These bio-monitoring sensors can monitor critical wounds to enable the development of advance wound care treatments. Temperature monitoring using wearable sensors for patients, aging population and for children is also an interesting, smart application, which can be integrated into garments.[5] Some studies elaborate on the smart cooling garment concepts, which can provide intelligent cooling to the public to enhance cooling comfort and wellness. [6, 7]

Sports wellness is another vital domain addressed by smart garments. Sportswear started getting subjected to unique demands of athletes, to protect the wearer from, rigorous physical activities as well as from extreme environmental conditions. Hence, to address complex sportswear requirements, smart garment concepts started to outspread into the sportswear market. Existing studies elaborate on the use of sensors in sportswear for applications such as body fluid measurement, physiological parameters monitoring, posture controlling. [8, 9] Furthermore, smart textiles are used in snowboarding activity where textile pressure sensors were used to recognise the activities performed by users.[9] Another study developed a smart shirt and leggings to measure heart and muscle activity, breathing rate and temperature. [10] With these examples, it is evident that the smart garment technology can be incorporated into sportswear applications to enhance the wellbeing and performance of sports consumers. As mentioned in market reports, smart garment applications in the sports sector are expected to exhibit high growth. [11]

Rationale

Several review papers have been published in the domain of wearable technology and smart garment technology. [12-15] However, most of these papers are focusing on medical or health care applications giving less priority to the wellness of athletes. [14, 16, 17] Furthermore, the variety of smart garment applications available in the literature is overwhelming. Therefore, the current review is essential to compare the wide variety of technologies incorporated in smart garments for athletes and also to understand the knowledge gaps for future studies. [18, 19]

Some of the existing reviews discuss smart garment technologies that can be applied in the sportswear domain, yet they are either outdated [8, 9] or not comprehensive enough to provide an in-depth understanding of the current state of smart sportswear. [20] Due to the fast-evolving nature of smart garment applications, researchers frequently introduce novel technologies and materials. [21, 22] One such novel application in smart garment domain is the introduction of highly flexible, high-energy textile lithium battery, which can offer a stable, durable and safe energy supply for wearable electronics. [21] Gas detecting textiles, metatextiles, which can offer adaptable thermal comfort and energy harvesting Triboelectrics materials and are few other new smart garment applications. [21, 22]. These latest technologies can fulfil a wide variety of sportswear requirements shifting smart sports garments to a new dimension.

Considering 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 latest technologies in future smart garment design projects and also to understand the gaps in the literature. Therefore, this study will provide a comprehensive review and a technology mapping of the latest smart sports garment technologies that can guide future research projects. 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, and we further refined it by the methodology developed by the Joanna Briggs Institute.[23, 24] 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). Also, this protocol follows the guidelines for the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) to optimise the quality of reporting (see additional file 1).[25] The study has been registered in the Open Science Framework (OSF) on June 25, 2020 (https://osf.io/34mf2).

Stage 1: identifying the research question

The objective of this scoping review is to assess the existing studies to understand the existing smart garment technologies, which are developed to enhance the health and wellbeing of athletes. Also, this review will generate input requirements for the research, which will carry out to develop a smart garment for endurance athletes. The review is expected to address the below question and sub-questions.

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

- How effective are those smart garments to enhance the health and wellbeing of athletes and experience of athletes in using them?

Stage 2: identifying relevant studies

The search strategy was developed by the research team after reviewing related literature, and an iterative approach was adhered to finalise the strategy (see additional 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, athletes.

The databases, which were selected to collect literature are Scopus, Web of Science, Science Direct, PubMed, and IEEE Xplore, and these databases were selected with the help of an expert university librarian. Due to rapid technological changes, smart garment applications are quickly becoming outdated; hence only the studies which were published within the last ten years were 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 in the analysis. 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 24/05/2020. The articles retrieved from the search will be imported into the Covidence software, which will remove duplicated articles automatically from the system.

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 conducted within 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. [26] 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 additional file 3). Only the studies with electronic integrated smart sports garment, which focus on health and wellbeing of athletes will be included for the review. To simplify the screening process review form incorporates a few questions to determine the inclusion decision;

- Does the article is a peer-reviewed primary study?
- Does the article is published within the last ten years (2010-2019) in the English language?
- Does the article involve smart garments
- Does the article focus on the health and wellbeing of 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 to be added.

Step 4: charting the data

All included studies will be reviewed and charted using a data extraction form (see additional 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, demographics), garment type, number of functions, function type (i.e., biomonitoring, coaching, warning, 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, limitations).

These details will be changed based on the studies included, and after a reviewer carries out the charting, another reviewer will independently validate the charted details.

Stage 5: collating, summarising and reporting the results

The filtered studies will be analysed regarding the location which the study was conducted, year of publication, market characteristics, garment type, technology components incorporated such as sensors, power supply, conductive materials, microprocessors and actuators, evaluation protocol adhered, user acceptability of the concepts and the outcome of the study. These details will be presented using tables, charts, and graphs and will be followed by a narrative review.

Also, to understand the key themes related to the technology components, to consider for the underlined research, a thematic analysis will be conducted for the review

results. The scoping review discussion will be designed, considering themes that will emerge. Furthermore, the research findings will be shared in relevant national and international conferences/peer-reviewed journals.

DISCUSSION

The primary objective of this scoping review is to obtain an understanding of smart garment applications in the sports domain, which were developed to enhance the wellbeing of athletes. The search terms and strings for the study were developed, and suitable databases were selected, referring to the related literature. The inclusion criteria for the review were determined based on the objectives of the study.

Even though the defined scoping review protocol is endorsed with preferred scoping review protocol guidelines, we want to admit some of the limitations in the study. Including the studies, which are published only in the English language, restrict the objectivity of the review. Also, the review will not include studies, which are review papers.

The proposed scoping review will provide a comprehensive understanding of the existing smart garment applications in the sports domain. Additionally, the results of this review will offer foundational know-how on sports smart garment applications that can inform new research.

Additional files

Additional file 01: PRISMA-ScR Checklist. doc

This document includes the PRISMA-ScR protocol checklist.

Additional file 02: Search Strategy. doc

This document includes the search strategy that will be incorporated to execute the search.

Additional file 03: Review Form.xls

This form includes the criteria for screening the sources for the scoping review.

Additional file 04: Data extraction Form.xls

This form includes the format that will facilitate the charting of scooping review data to enable analysis.

Declarations

Acknowledgments

Not applicable

Funding

Not applicable

Availability of data and materials

Not applicable

Author contribution

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.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Competing interest

The authors declare that they have no competing interests

Author details

Not applicable

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Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	5-6
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	5-6
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Click here to enter text.
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	7-9
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	7-8
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Appendix
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	8-9
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	9-10
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	9-10
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	NA
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	10

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	NA
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	NA
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	NA
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	NA
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	NA
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	NA
Limitations	20	Discuss the limitations of the scoping review process.	3
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	NA
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	11

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

Smart Garments to Enhance Health and Wellbeing of Athletes

database	Search string	Number of entries	date	Source type/s	Data	Time frame
Scopus	ALL (("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*) AND (health OR well-being OR wellness OR illnesses)) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010)) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))	50	05/06/2020	Journals	ALL*	2010-2019
IEEE	(("Full Text & Metadata":sensor garment OR sensor garments OR electronic garment OR electronic garments OR smart garment OR smart garments OR smart apparel) AND "Full Text & Metadata":sport% OR athlet%) **Filters Applied:** 2010 - 2019	84	05/06/2020	Journals	Full text + Meta data (*Abstract, title and indexing terms)*	2010-2019

Web of Science	TS=(("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*)) **Refined by**: DOCUMENT TYPES: (ARTICLE) **Timespan**: 2019-2010	1	05/06/2020	Article	TS=Topic Searches title, abstract, author keywords, and more	2010-2019
Science Direct	(sensor OR smart OR electronic) AND (garment OR garments) AND (sport OR sports OR athlete OR athletes) **Timespan**: 2019-2010	415	05/06/2020	Research articles	Full text	2010-2019
PubMed	("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*) Year-2010-2019	5	25/06/2020	Books and Documents Clinical trials Randomised control trial	Full text	2010-2019

**SCOPUS ALL: Entering ALL("heart attack") will return documents with "heart attack" in the article title, source title, language, author, editor, affiliation, abstract, keywords, references, DOI, ISBN, ISSN, CODEN, issue, volume, publication year, sequence bank, sequence bank number, article number, chemical name, CAS registry number, manufacturer, publisher, or conference fields*

Language Filter was not used for the pilot search strategy

SCOPUS

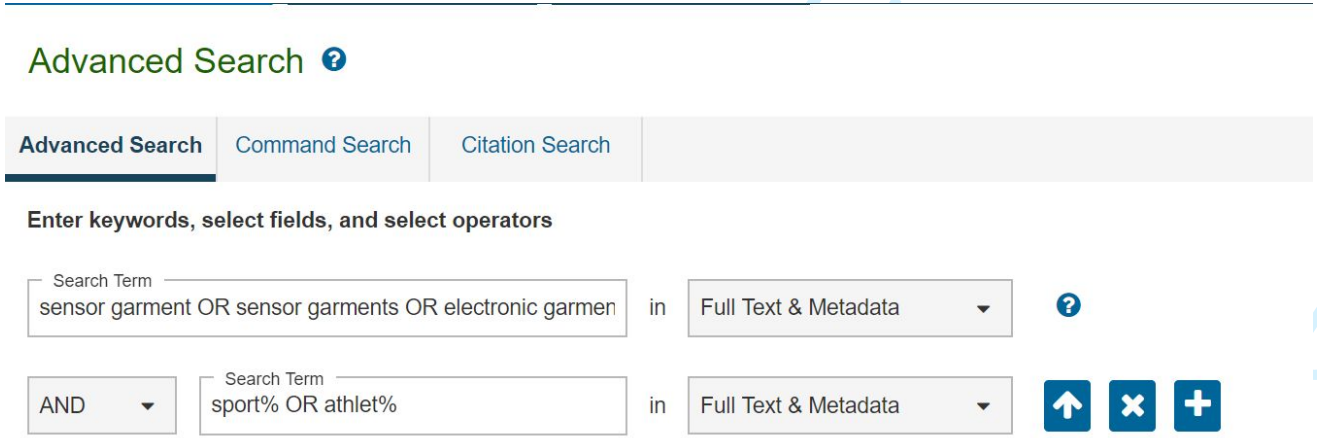
Advance search query:

ALL (("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*) AND (health OR well-being OR wellness OR illnesses))
) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND
LIMIT-TO (PUBYEAR,2018)
OR LIMIT-TO (PUBYEAR,2017)
OR LIMIT-TO (PUBYEAR,2016)
OR LIMIT-TO (PUBYEAR,2015)
OR LIMIT-TO (PUBYEAR,2019)

OR LIMIT-TO (PUBYEAR,2014)
OR LIMIT-TO (PUBYEAR,2013)
OR LIMIT-TO (PUBYEAR,2012)
OR LIMIT-TO (PUBYEAR,2011)
OR LIMIT-TO (PUBYEAR,2010)
)

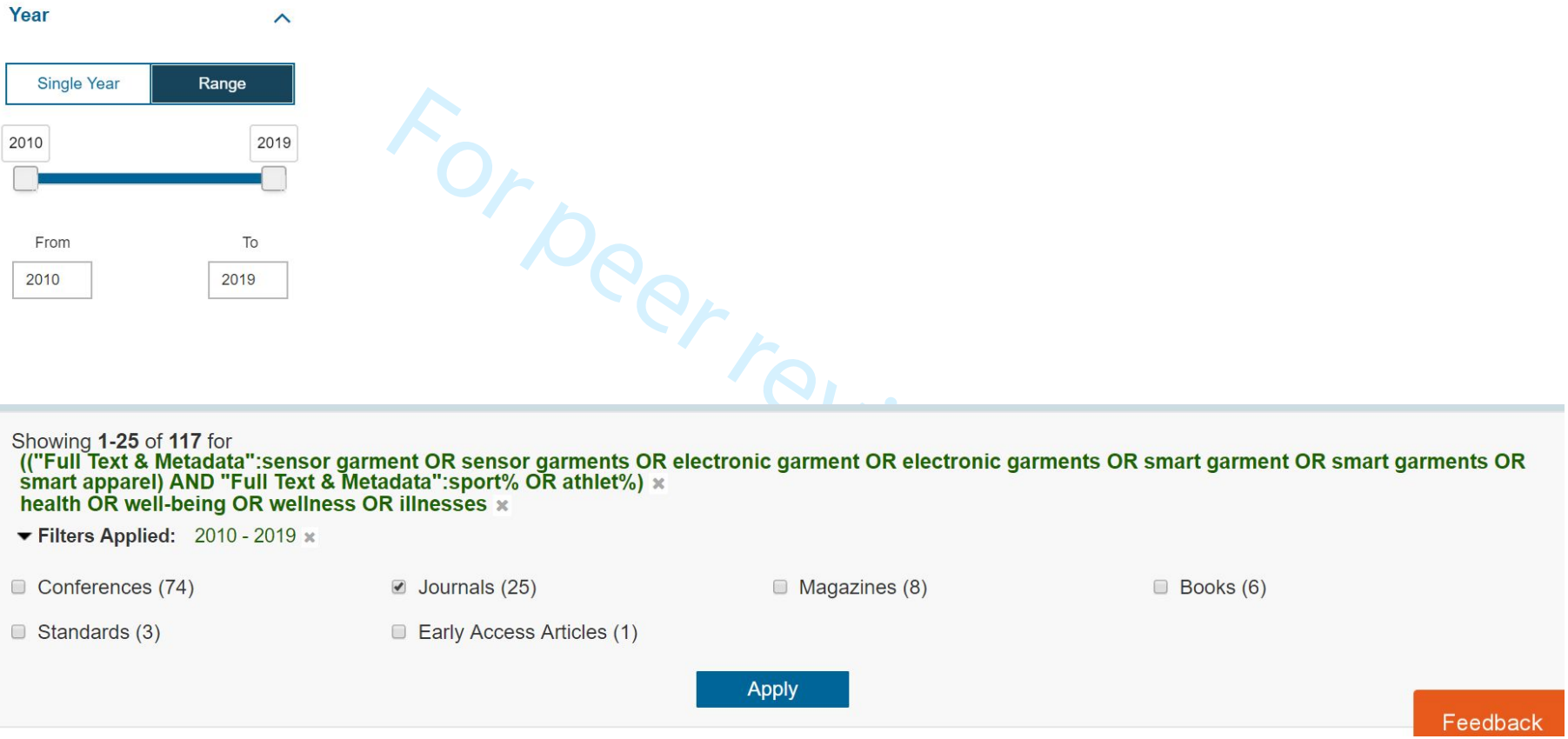
IEEE

Step 01



Step 02

Filtering year range & filtering the source types: Journals and conferences



Web of Science

Advance search query:

TS=(("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*))

Refined by: DOCUMENT TYPES: (ARTICLE)

Timespan: 2019-2010

Science Direct

Advance search query:

(sensor OR smart OR electronic) AND (garment OR garments) AND (sport OR sports OR athlete OR athletes)

Year: 2010-2019

Article Types: Research articles

PubMed

Advance search query:

("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*)

Year: 2010-2019

Article Types:

Books and Documents

Clinical trials

Randomised control trial

Paper ID	Title	Inclusion/exclusion criteria

Decision

#	Title	Publication type	Authors	Year	Country	Target market	Sample characteristics (number of participants, demographics)	Garment type	Number of functions	Function type (bio monitoring, couching, warning, posture control, etc...)	Technology characteristics	Outcome

BMJ Open

Effects of Smart Garments on the Wellbeing of Athletes: A Scoping Review Protocol

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-042127.R1
Article Type:	Protocol
Date Submitted by the Author:	26-Sep-2020
Complete List of Authors:	Al Mahmud, Abdullah ; Swinburne University of Technology, School of Design; Faculty of Health, Arts and Design Wickramarathne, Tharushi; Swinburne University of Technology, Centre for Design Innovation Kuys, Blair; Swinburne University of Technology, School of Design; Faculty of Health, Arts and Design
Primary Subject Heading:	Health informatics
Secondary Subject Heading:	Health informatics, Public health, Health services research, Health policy, Sports and exercise medicine
Keywords:	Health informatics < BIOTECHNOLOGY & BIOINFORMATICS, Information technology < BIOTECHNOLOGY & BIOINFORMATICS, Information management < BIOTECHNOLOGY & BIOINFORMATICS, World Wide Web technology < BIOTECHNOLOGY & BIOINFORMATICS

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Title: Effects of Smart Garments on the Wellbeing of Athletes: A Scoping Review Protocol

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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 wellbeing 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 wellbeing of athletes.

Methods and analysis Relevant studies will be retrieved using pre-defined 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 ten 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)

Keywords: Smart garments, Athletes, Wellness, Sports, Health, Heat illnesses

Strengths and limitations of the study

- The proposed study uses existing scoping review methodology to identify the effects of smart garments on the wellbeing of athletes.
- The study will give an in-depth understanding of the current state of smart sportswear for athletes.
- The review will investigate literature from the last ten years.
- The scoping review will consider studies published in the English language.
- To capture a broad spectrum of smart garment applications incorporated in professional sportswear, we will consider all the studies that reported the effects of smart garments designed for professional athletes.

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. [1] 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 wellbeing of the athlete.[2-4]

The majority of smart garment applications integrate sensor technology that enables wireless health monitoring.[5] 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. [6] 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. [7-9] Smart monitoring and other related functions offered by some of the existing smart garments are listed in Table 1.

Table 1: Some examples of smart garment applications

Smart Function	**Smart Garment Applications**
Smart monitoring	• Biomonitoring: Heart rate, body temperature, breathing [10-12] • Posture monitoring [12-14] • Micro-climate temperature and humidity monitoring [15, 16]
Other smart functions	• Smart cooling [12, 16, 17] • Smart compression [18]

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 wellbeing of athletes.[19] Considering these, to address complex sportswear requirements and to improve the wellbeing of athletes, smart technologies with integrated sensors started to outspread into the sports market. Some of the existing studies explored the use of sensors to measure biological parameters (i.e., heart rate, muscle and oxygen saturation) and safety-related parameters (i.e., position, motion and impact) to enhance health, wellness, and performance of athletes. [20-22] Another study investigated the use of smart textiles in snowboarding activity where textile pressure sensors were utilised to recognise the activities performed by users.[21] Also, researchers developed a smart shirt and leggings to measure heart and muscle activity, breathing rate, and temperature.

[11] With these examples, it is evident that smart technology can be incorporated into sportswear applications to enhance the wellbeing and performance of athletes.

Sportswear manufacturers started stretching the boundaries of smart wearables by integrating technology into garments. [4] As mentioned in market reports, smart garment applications in the sports sector are expected to exhibit high growth. [23] However, most of the commercialised sport smart garments offer standard functions like smart monitoring, communication, compression and couching. 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.[24, 25] Also, some studies examined creative, smart applications to improve user experience. The smart garment that reacts to the wearer mood is one such example. [26] These studies provide an opportunity for future smart sports garments that can improve the health and wellbeing 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. [19, 22, 27-30] However, most of these papers are focusing on medical or healthcare applications giving less priority to the wellness of athletes. [29, 31, 32] 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. [33, 34]

Some of the existing reviews discuss smart garment technologies that can be applied in the sportswear domain. Yet, they are either outdated [20, 21] or not comprehensive enough to provide an in-depth understanding of the current state of smart sportswear [35] or focusing only on smart monitoring. [22] Due to the fast-evolving nature of smart garment applications, researchers frequently introduce novel technologies and materials. [36, 37] One such novel application is recently introduced wearable textile electronics that can uplift the performance of future smart sports clothing. [36] Metatextiles that offer adaptable thermal comfort and energy harvesting Triboelectrics materials that can be used to optimise power consumption of smart sports garments are few other new smart technology applications. [36, 37]. 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. [38] 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). PRISMA-ScR checklist (see Additional file 1) will be used throughout the proposed scoping review to ensure adherence.[39] The study has been registered in the Open Science Framework (OSF) on June 25, 2020 (https://osf.io/34mf2).

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 wellbeing 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 wellbeing 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 Additional 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 24/05/2020. 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. [40] 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 Additional file 3). Only the studies with electronic integrated smart sports garment, which focus on health and wellbeing 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 ten years (2010-2019) in the English language?
- Does the article involve smart garments?
- Does the article focus on the health and wellbeing 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.

Step 4: charting the data

All included studies will be reviewed and charted using a data extraction form (see Additional 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 (i.e., 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 (e.g., 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/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 wellbeing 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.

Additional files

Additional file 01: PRISMA-ScR Checklist.pdf

This document includes the PRISMA-ScR protocol checklist.

Additional file 02: Search Strategy.pdf

This document includes the search strategy that will be incorporated to execute the search.

Additional file 03: Review Form.pdf

This form includes the criteria for screening the sources for the scoping review.

Additional file 04: Data extraction Form.pdf

This form includes the format that will facilitate the charting of scooping review data to enable analysis.

Declarations

Acknowledgments

Not applicable

Patient and Public Involvement

No patients and or public will be involved to conduct this study or to design the protocol.

Funding

Not applicable

Availability of data and materials

Not applicable

Author contribution

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.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Competing interest

The authors declare that they have no competing interests

Author details

Not applicable

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Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3-6
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	6
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	NA
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	7
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	7
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Appendix
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	7-8
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	9
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	9-10
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	NA

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	10
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	NA
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	NA
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	NA
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	NA
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	NA
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	NA
Limitations	20	Discuss the limitations of the scoping review process.	10
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	NA
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	NA

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

Smart Garments to Enhance Health and Wellbeing of Athletes

Database	Search string	Number of entries	date	Source type	Data	Time frame
Scopus	ALL (("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*) AND (health OR well-being OR wellness OR illnesses)) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010)) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))	50	05/06/2020	Journals	ALL*	2010-2019
IEEE	(("Full Text & Metadata":sensor garment OR sensor garments OR electronic garment OR electronic garments OR smart garment OR smart garments OR smart apparel) AND "Full Text & Metadata":sport% OR athlet%) **Filters Applied:** 2010 - 2019	84	05/06/2020	Journals	Full text + Meta data (*Abstract, title and indexing terms)*	2010-2019
Web of Science	TS=(("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*)) **Refined by**: DOCUMENT TYPES: (ARTICLE) **Timespan**: 2019-2010	1	05/06/2020	Article	TS=Topic Searches title, abstract, author keywords, and more	2010-2019

Science Direct	(sensor OR smart OR electronic) AND (garment OR garments) AND (sport OR sports OR athlete OR athletes) **Timespan**: 2019-2010 *Cannot use more than 8 Boolean operators and wildcards , hence the results are not filtered for below:* *(health OR well-being OR wellness OR illnesses)*	415	05/06/2020	Research articles	Full text	2010-2019
PubMed	("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*) Year-2010-2019	5	25/06/2020 Verified again-21/09/2021	All the studies except reviews	Full text	2010-2019

**SCOPUS ALL: Entering ALL("heart attack") will return documents with "heart attack" in the article title, source title, language, author, editor, affiliation, abstract, keywords, references, DOI, ISBN, ISSN, CODEN, issue, volume, publication year, sequence bank, sequence bank number, article number, chemical name, CAS registry number, manufacturer, publisher, or conference fields*

Language Filter was not used for the pilot search strategy

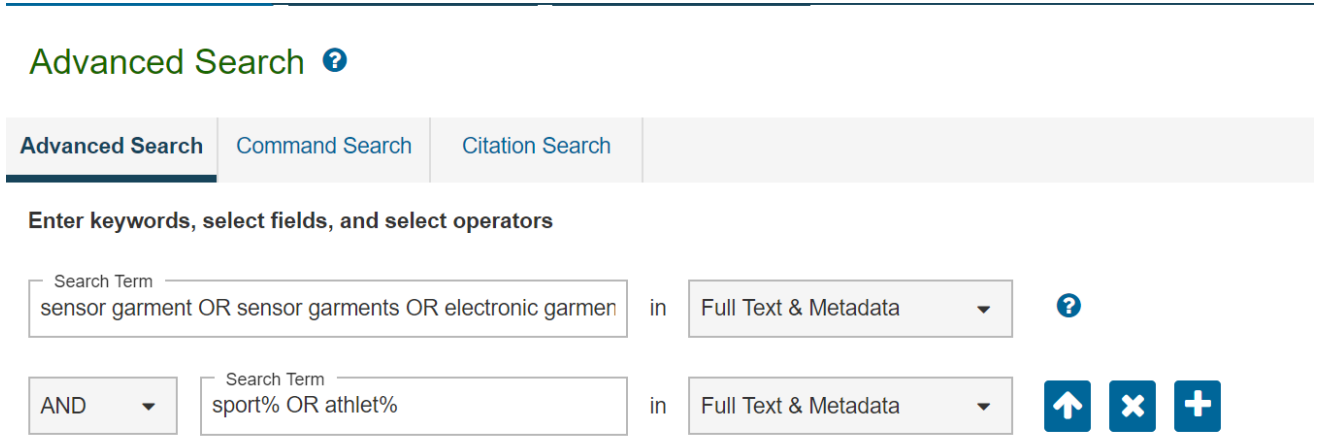
SCOPUS

Advance search query:

ALL (("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*) AND (health OR well-being OR wellness OR illnesses))
) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND
LIMIT-TO (PUBYEAR,2018)
OR LIMIT-TO (PUBYEAR,2017)
OR LIMIT-TO (PUBYEAR,2016)
OR LIMIT-TO (PUBYEAR,2015)
OR LIMIT-TO (PUBYEAR,2019)
OR LIMIT-TO (PUBYEAR,2014)
OR LIMIT-TO (PUBYEAR,2013)
OR LIMIT-TO (PUBYEAR,2012)
OR LIMIT-TO (PUBYEAR,2011)
OR LIMIT-TO (PUBYEAR,2010)
)

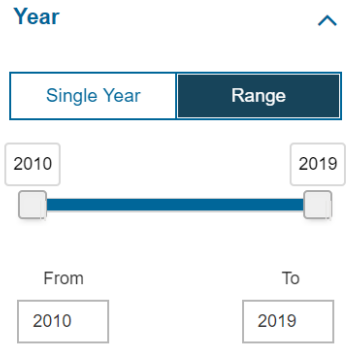
IEEE

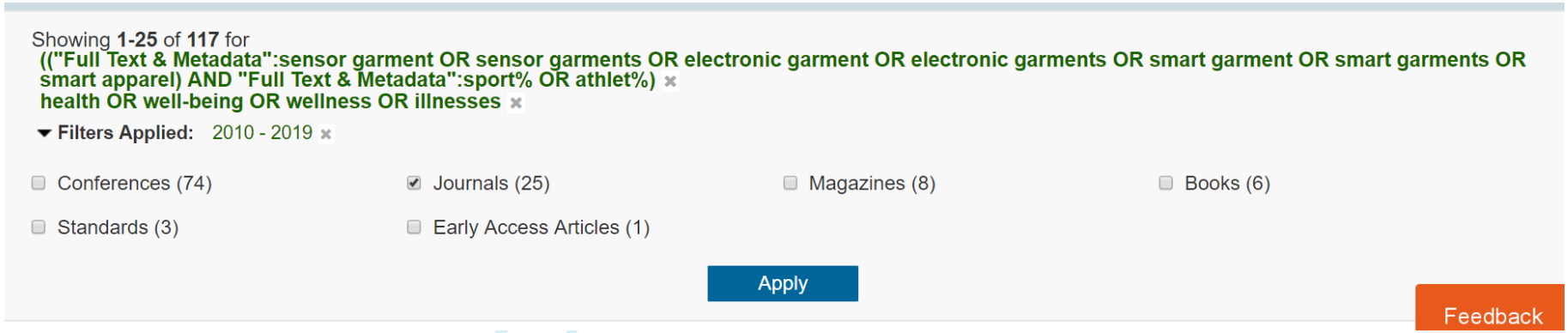
Step 01



Step 02

Filtering year range & filtering the source types: Journals and conferences





Web of Science

Advance search query:

TS=(("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*))

Refined by: DOCUMENT TYPES: (ARTICLE)

Timespan: 2019-2010

Science Direct

Advance search query:

(sensor OR smart OR electronic) AND (garment OR garments) AND (sport OR sports OR athlete OR athletes)

Year: 2010-2019

Article Types: Research articles

PubMed

Advance search query:

("sensor garment*" OR "electronic garment*" OR "smart garment*" OR "smart apparel") AND (sport* OR athlet*)

Year: 2010-2019

Article Types:

All the studies except reviews

Paper ID	Title	Inclusion/exclusion criteria	Decision
		• Is the article a peer-reviewed primary study? • Is the article published within the last ten years (2010-2019) in the English language? • Does the article involve smart garments? • Does the article focus on the health and wellbeing of professional athletes?	

#	Title	Publication type	Authors	Year	Country	Target market	Sample characteristics (number of participants, demographics)	Garment type	Number of functions	Function type (bio monitoring, couching, warning, posture control, etc...)	Technology characteristics	Evaluation protocol and User acceptance	Outcome