Grand Challenges in SportsHCI

Don Samitha Elvitigala
Monash University
Melbourne, Australia
don.elvitigala@monash.edu

Armağan Karahanoğlu
University of Twente
Enschede, Netherlands
a.karahanoglu@utwente.nl

Andrii Matviienko
KTH Royal Institute of Technology
Stockholm, Sweden
andriim@kth.se

Laia Turmo Vidal
KTH Royal Institute of Technology
Stockholm, Sweden
laiatv@kth.se

Dees Postma
University of Twente
Enschede, the Netherlands
d.b.w.postma@utwente.nl

Michael Jones
Brigham Young University
Utah, USA
jones@cs.byu.edu

Maria F. Montoya
Monash University
Melbourne, Australia
maria@exertiongameslab.org

Daniel Harrison
Northumbria University
Newcastle, UK
daniel.b.p.harrison@northumbria.ac.uk

Lars Elbæk
University of Southern Denmark
Odense, Denmark
lelbaek@health.sdu.dk

Florian Daiber
German Research Center for Artificial Intelligence (DFKI)
Saarbrücken, Germany
florian.daiber@dfki.de

Lisa Anneke Burr
University of Salzburg
Salzburg, Austria
lisaanneke.burr@plus.ac.at

Rakesh Patibanda
Monash University
Melbourne, Australia
rakesh.patibanda@monash.edu

Paolo Buono
University of Bari
Bari, Italy
paolo.buono@uniba.it

Perttu Hämäläinen
Aalto University
Espoo, Finland
perttu.hamalainen@aalto.fi

Robby van Delden
University of Twente
Enschede, the Netherlands
r.w.vandelden@utwente.nl

Regina Bernhaupt
Eindhoven University of Technology
Eindhoven, Netherlands
r.bernhaupt@tue.nl

Xipei Ren
Beijing Institute of Technology
Beijing, China
x.ren@bit.edu.cn

Vincent van Rheden
University of Salzburg
Salzburg, Austria
vincent.vanrheden@plus.ac.at

Fabio Zambetta
RMIT University
Melbourne, Australia
fabio.zambetta@rmit.edu.au

Elise van den Hoven
University of Technology Sydney, Australia and Eindhoven University of Technology, the Netherlands
elise.vandenhoven@uts.edu.au

Carine Lallemand
Eindhoven University of Technology and University of Luxembourg
Eindhoven, Netherlands
carine.lallemand@uni.lu

Dennis Reidsma
University of Twente
Enschede, the Netherlands
d.reidsma@utwente.nl

Florian 'Floyd' Mueller
Monash University
Melbourne, Australia
floyd@exertiongameslab.org

体育人机交互领域的重大挑战

唐·萨米莎·埃尔维蒂加拉
莫纳什大学
澳大利亚墨尔本
don.elvitigala@monash.edu

阿尔马甘·卡拉汉奥卢
特文特大学
荷兰恩斯赫德
a.karahanoglu@utwente.nl

安德烈·马特维延科
瑞典皇家理工学院
瑞典斯德哥尔摩
andriim@kth.se

莱娅·图尔莫·维达尔
瑞典皇家理工学院
瑞典斯德哥尔摩
laiatv@kth.se

迪斯·波斯特马
特文特大学
荷兰恩斯赫德
d.b.w.postma@utwente.nl

迈克尔·琼斯
杨百翰大学
美国犹他州
jones@cs.byu.edu

玛丽亚·F·蒙托亚
莫纳什大学
澳大利亚墨尔本
maria@exertiongameslab.org

丹尼尔·哈里森
诺森比亚大学
英国纽卡斯尔
daniel.b.p.harrison@northumbria.ac.uk

拉斯·埃尔贝克
南丹麦大学
丹麦欧登塞
lelbaek@health.sdu.dk

弗洛里安·戴伯
德国人工智能研究中心
人工智能（DFKI）
德国萨尔布吕肯
forian.daiber@dfki.de

丽莎·安妮克·伯尔
萨尔茨堡大学
奥地利萨尔茨堡
lisaanneke.burr@plus.ac.at

拉凯什·帕蒂班达
莫纳什大学
澳大利亚墨尔本
rakesh.patibanda@monash.edu

保罗·布诺
巴里大学
意大利巴里
paolo.buono@uniba.it

佩尔图·哈马莱宁
阿尔托大学
芬兰埃斯波
perttu.hamalainen@aalto.f

罗比·范·德尔登
特文特大学
荷兰恩斯赫德
r.w.vandelden@utwente.nl

雷吉娜·伯恩豪普特
埃因霍温理工大学
荷兰埃因霍温
r.bernhaupt@tue.nl

任希佩
北京理工大学
中国北京
x.ren@bit.edu.cn

文森特·范·雷登
萨尔茨堡大学
奥地利萨尔茨堡
vincent.vanrheden@plus.ac.at

法比奥·赞贝塔
皇家墨尔本理工大学
澳大利亚墨尔本
fabio.zambetta@rmit.edu.au

艾莉丝·范登霍芬
悉尼科技大学，
澳大利亚和埃因霍温理工大学
技术学院，荷兰
elise.vandenhoven@uts.edu.au

卡琳·拉勒芒
埃因霍温理工大学
和卢森堡大学
荷兰埃因霍温
carine.lallemand@uni.lu

丹尼斯·雷德斯马
特文特大学
荷兰恩斯赫德
d.reidsma@utwente.nl

弗洛里安·‘弗洛伊德’·穆勒
莫纳什大学
澳大利亚墨尔本
foyd@exertiongameslab.org

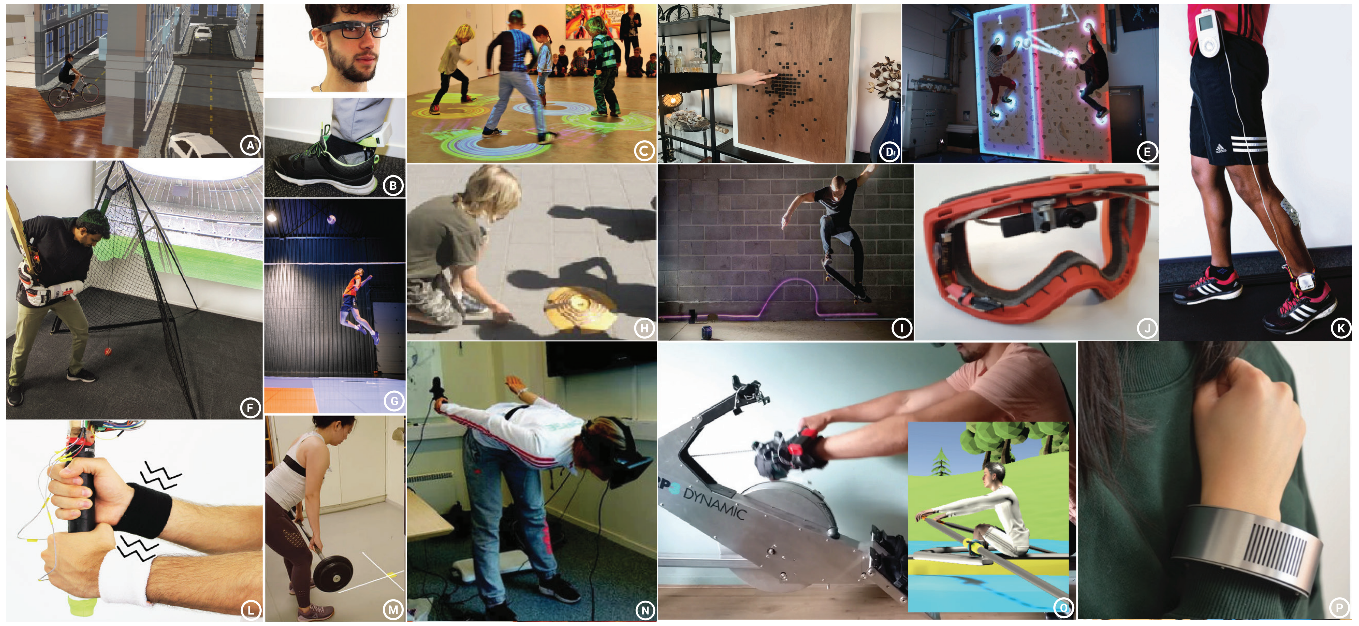

Figure 1: The image shows examples of SportsHCI systems a). BikeAR, AR bike training system to enhance safety [90] b). GymSoles, feedback system to improve posture in full-body exercises [37] c). Interactive tag playground, steering behaviour in terms of proxemics and movement [170] d). Laina, physicalizes running routes to motivate runners. [104] e). An interactive wall to gamify climbing. [66] f). SMA based feedback system to train cricket strikes [117] g). Interactive LED floor for volleyball training h). Marbowl, an intelligently moving bowl for target training [41] i). Haptic, visual and auditory feedback for skateboarding tricks [128] j). Eye-tracker integrated in ski goggles to capture snow experiences [86, 112] k). Footstrike [28] provide EMS feedback about heel strike during running l). CricketCoach, interactive bat and gloves to improve awareness of gripping forces [118] m). BodyLights, an open-ended visual feedback wearable to support personalized performance training [162] n). Virtual ski-jump training to learn skills in a safer environment. [148] o). Feedback system on rowing technique in VR [169] p). Grace: physicalisation of social support for exercising motivation [101].

ABSTRACT

The field of Sports Human-Computer Interaction (SportsHCI) investigates interaction design to support a physically active human being. Despite growing interest and dissemination of SportsHCI literature over the past years, many publications still focus on solving specific problems in a given sport. We believe in the benefit of generating fundamental knowledge for SportsHCI more broadly to advance the field as a whole. To achieve this, we aim to identify the grand challenges in SportsHCI, which can help researchers and practitioners in developing a future research agenda. Hence, this paper presents a set of grand challenges identified in a five-day workshop with 22 experts who have previously researched, designed, and deployed SportsHCI systems. Addressing these challenges will drive transformative advancements in SportsHCI, fostering better athlete performance, athlete-coach relationships, spectator engagement, but also immersive experiences for recreational sports or exercise motivation, and ultimately, improve human well-being.

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CCS CONCEPTS

• **Human-centered computing** → **Interaction paradigms**.

KEYWORDS

Sports technology, Physical Activity, grand challenges

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1 INTRODUCTION

Sports Human-Computer Interaction (SportsHCI) is a dynamic, multi-disciplinary field that merges interactive technologies and

图1：该图像展示了体育人机交互系统的示例 a). 自行车增强现实（BikeAR），增强现实自行车训练系统以提高安全性 [90] b).
智能鞋垫（GymSoles），用于改善全身锻炼姿势的反馈系统 [37] c). 互动标签游乐场，通过近体学和运动引导行为
[170] d). 莱娜（Laina），将跑步路线实体化以激励跑者 [104] e). 一面用于攀岩游戏化的
互动墙 [66] f). 基于形状记忆合金的反馈系统用于训练板球击打 [117] g). 用于排球训练的互动LED地板
h). 智能滚球（Marbowl），一个智能移动的滚球用于目标训练 [41] i). 为滑板技巧提供的触觉、视觉和听觉反馈
[128] j). 集成在滑雪护目镜中的眼动追踪器以捕捉雪地体验 [86, 112] k). 足部着地 [28]
提供跑步时足跟触地的电肌肉刺激反馈（l）。板球教练，互动球棒与手套提升感知能力
握力可视化 [118] m）。身体灯光：开放式视觉反馈可穿戴设备，支持个性化表现
训练 [162] n）。虚拟跳台滑雪训练：在更安全环境中学习技巧 [148] o）。虚拟现实中的划船技术
反馈系统 [169] p）。格蕾丝：社会支持实体化以提升锻炼动机 [101]。

摘要

体育人机交互 (SportsHCI) 领域致力于研究交互设计以支持身体活跃的人类。尽管过去几年体育人机交互文献的关注度和传播度不断提升，许多出版物仍聚焦于解决特定体育运动中的具体问题。我们相信，更广泛地为体育人机交互领域生成基础性知识将推动整个领域的进步。为此，我们旨在识别体育人机交互领域的重大挑战，以帮助研究人员和实践者制定未来研究议程。本文通过为期五天的工作坊，汇集了22位曾研究、设计并部署过体育人机交互系统的专家，提出了一系列重大挑战。应对这些挑战将推动体育人机交互领域的变革性进步，从而更好地服务于运动员
运动员表现、运动员-教练关系、观众参与度
同时也为休闲运动或锻炼提供沉浸式体验
动机，并最终提升人类福祉。

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CCS概念

• **以人为中心的计算** → **交互范式**。

关键词

体育技术，体育活动，重大挑战

ACM参考格式：
唐·萨米莎·埃尔维蒂加拉、阿尔马甘·卡拉汉奥卢、安德烈·马特维延科、莱娅·图尔莫·维达尔、迪斯·波斯特马、迈克尔·琼斯、玛丽亚·F·蒙托亚、丹尼尔·哈里森、拉斯·埃尔贝克、弗洛里安·戴伯、丽莎·安妮克·伯尔、拉凯什·帕蒂班达、保罗·布诺、佩尔图·哈马莱宁、罗比·范·德尔登、雷吉娜·伯恩豪普特、任希佩、文森特·范·雷登、法比奥·赞贝塔、艾莉丝·范登霍芬、卡琳·拉勒芒、丹尼斯·雷德斯马与弗洛里安·'弗洛伊德'·穆勒。2024年。体育人机交互领域的重大挑战。收录于《计算机系统中人为因素会议论文集》（CHI 2024年会议），2024年5月11日至16日，美国夏威夷州檀香山。美国计算机协会，

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1 引言

体育人机交互 (SportsHCI) 是一个动态的领域，
一个融合交互技术与多学科领域

human-centric design principles to optimise and enhance the sports experience of athletes at all levels, from amateurs to elite athletes, including recreational sportspeople. As sports have evolved into highly competitive and technologically driven domains, the demand for innovative solutions that empower athletes, coaches, and spectators has become increasingly evident. Furthermore, the last few years have seen tremendous growth in the use of technology in the sports industry, often building on human-computer interaction (HCI) research. However, we note that there seem to be many similar projects and products emerging (mainly in the form of smartphone apps that allow for athletic performance comparison), suggesting that innovation in SportsHCI might have come to a point where it has stagnated. We believe this stagnation might be occurring because SportsHCI lacks a structured and coherent research agenda, as is often the case in emerging research fields [21]. And we might, in turn, lack a structured and coherent research agenda because there has not yet been a systematic articulation of the field's grand challenges [131].

In addition, articulating grand challenges for SportsHCI will broadly impact the rapidly growing technology-driven sports industry, with the sports technology market projected to reach significant turnover in the coming years [136]. SportsHCI designs interactive technology that enhances users' experiences, performance, and data-driven decision-making, contributing to this market growth. In this context, identifying grand challenges and articulating a research agenda will ensure the responsible and sustainable development of SportsHCI in the activity-based sports industry. And, in this regard, the sustainable development of next-generation interactive technologies supports humans' physically activity, which has broader positive impacts on our mental and physical well-being and, consequently, our overall quality of life [87].

In this paper, we articulate 16 challenges, categorised into five themes: 1) Athletic performance optimisation analysis; 2) The athlete as a multifaceted individual; 3) Human-centered design and sports engagement; 4) Technological considerations in the real world; and 5) Strategic vision on what to strive for through SportsHCI. By addressing these grand challenges, we aspire to nurture the future of sports, employing technology to augment athletic prowess and enrich the holistic sports experience for all. We formulated our grand challenges using a community-centric methodology, comprising a structured five-day workshop involving 22 renowned SportsHCI researchers and practitioners, during which we drew upon the insights arising from their broad spectrum of disciplines and areas of expertise. We drew inspiration from prior works that articulated grand challenges in diverse fields, such as shape-changing interfaces [2], immersive analytics [40], and human-computer integration [114]. Like these works, we also believe that by articulating grand challenges, we might be able to help develop the field further, in particular:help contribute towards a structured research agenda for the growing SportsHCI community; offer guidance to newcomers to SportsHCI; present a consolidated perspective to external stakeholders; foster potential collaboration avenues with industry partners and funding bodies; and elevate the world of sports through human-computer interaction. The contributions of this work are:

- A set of grand challenges that researchers and practitioners in SportsHCI can use to position their future research which might pave the way toward a structured and coherent research agenda for the growing SportsHCI community. Furthermore, we provide an overview and the interconnections of these challenges using figures.
- An overview of state-of-the-art related to grand challenges, allowing researchers to understand how prior work can be grouped to identify future collaborators.

2 RELATED WORK

This section briefly presents what we learned from previous workshops and review papers that aimed to advance the SportsHCI field. We also highlight how these prior works inspired the seminar. Prior work related to each grand challenge is described later in the paper.

Over recent years, the prospect of designing interactive systems to support sports and exercise activities has engaged the HCI community.This engagement has occurred in workshops on "HCI and Sports" by Mueller et al. [109] and Nylander et al. [122, 176], and in the Sport-HCI SIG meetings presented at CHI conferences [115]. There has also been a surge in research on embodied interaction for sports [23, 106, 142]. In this regard, Mencarini et al. [94, 96] identified emerging trends in SportsHCI, highlighting the sports experience's digital evolution over the past 15 years, and Postma et al. [131] developed a taxonomy for SportsHCI systems based on related work in HCI and sports science. While these works inspired us to delve deeper, they also identified that future work is needed [94, 96, 131] because the participants in this field do not yet appear to have systematically articulated its challenges. Consequently, our work begins to respond to this imperative.

Several studies, including Jensen et al. [62, 63] and Tholander et al. [157], have tackled challenges tied to specific sports and the role of technology in amplifying the sports experience. However, although they have brought the field forward, due to their case-study nature, they fall short of comprehensively advancing the field as a whole (evident by, for example, missing key facets of sports such as audience interaction, long-term practices, and non-competitive physical activities). We also learned from sports science which, as a discipline, has investigated the incorporation of wearable and interactive devices [123], instrumentation concerns [44], gear optimisation [34, 93, 153], and injury prevention technologies [10]. Furthermore, prior literature has reviewed particular SportsHCI technologies, such as sports wearables [163]. However, these prior works do not tell us what HCI researchers should do next.

As such, we believe it is worthwhile for the community to articulate the grand challenges in SportsHCI. Therefore, this paper aims to fill the identified gap by providing a set of grand challenges formulated systematically and collaboratively.

3 METHOD

We elicited grand challenges in SportsHCI during a 5-days collaborative seminar in July 2023, uniting 22 international experts on the topic, representing various perspectives and disciplinary backgrounds. Our approach is motivated by previous efforts in HCI to pinpoint key challenges through extensive multi-day workshops

以人为本的设计原则以优化和提升体育运动
从业余运动员到精英运动员等各个级别运动员的体验，
包括休闲运动爱好者。随着体育运动已发展成为
高度竞争且技术驱动的领域，对赋能运动员、教练及

观众的创新解决方案的需求日益显著。此外，过去
近年来，技术在体育运动产业中的应用呈现爆发式增长
这些应用往往建立在人机交互（HCI）研究的基础上。然而我们注意到

市场上涌现了大量同质化的项目和产品（主要体现为
支持运动表现对比的智能手机应用），这表明体育人机交互领域的创新可能已

陷入停滞状态。我们认为这种停滞现象
或许源于体育人机交互缺乏系统化、连贯性的
研究议程，正如新兴领域常见的情况
[21]。反过来，我们可能缺乏一个结构化和连贯的研究

议程，因为尚未对该领域的重大挑战进行系统阐述
[131]。

此外，阐明体育人机交互的重大挑战将对快速发展的技术驱动型体育产业产生广泛影响，预计体育技术市场在未来几年将达到可观的营业额[136]。体育人机交互设计的交互技术提升了用户体验、表现和数据驱动决策，推动了这一市场的增长。

在此背景下，明确重大挑战并制定研究议程将确保体育人机交互在活动型体育产业中负责任且可持续地发展。并且，

在这方面，下一代交互技术的可持续发展支持人类的体育活动，这对我们的身心健康乃至整体生活质量 [87]产生更广泛的积极影响。

本文阐述了16项重大挑战，分为五大主题：1) 运动表现优化分析；2) 运动员作为多面性个体；3) 以人为本的设计与体育参与；4) 现实世界中的技术考量；5) 体育人机交互的战略愿景。

通过应对这些重大挑战，我们期望培育体育运动的未来，运用技术提升运动表现并丰富所有人的整体体育体验。我们采用以社区为中心的方法论制定了这些重大挑战，包括一个为期五天的结构化研讨会，邀请了22位知名的体育人机交互研究人员和从业者参与，期间我们汲取了他们广泛学科领域和专业知识的见解。我们从先前工作中汲取灵感，这些工作阐述了不同领域的重大挑战，如形状变化界面[2],、沉浸式分析[40], 以及人机交互[114]。与这些工作类似，我们也相信通过阐明重大挑战，可能有助于进一步推动该领域发展，具体而言：为日益壮大的体育人机交互社区贡献一个结构化的研究议程；为体育人机交互的新人提供指导；向外部利益相关者呈现统一的视角；促进与产业界合作伙伴和资助机构的潜在协作途径；并通过人机交互提升体育界水平。本工作的贡献包括：

- 一系列重大挑战，供体育人机交互领域的研究人员和从业者用以定位其未来研究，这可能为日益壮大的体育人机交互社区铺就一条结构化且连贯的研究议程之路。此外，我们通过图表概述了这些挑战及其相互关联。
- 关于重大挑战的最新研究综述，帮助研究人员理解如何将先前工作归类以识别未来合作者。

2 相关工作

本节简要介绍了我们从先前旨在推动体育人机交互领域发展的研讨会和综述论文中所学到的内容。

我们还强调了这些先前工作如何启发了本次研讨会。与每个重大挑战相关的先前工作将在论文后续部分详细描述。

近年来，设计交互系统以支持体育运动和锻炼活动的前景吸引了人机交互社区的关注。这种关注体现在穆勒等人[109] 和尼兰德等人[122, 176], 关于“人机交互与体育运动”的研讨会中，以及在CHI会议 [115]上展示的体育人机交互特别兴趣小组会议上。

关于体育运动具身交互的研究也出现了激增[23, 106, 142]。在这方面，门卡里尼等人 [94, 96] 识别了体育人机交互的新兴趋势，强调了体育运动体验在过去15年中的数字化演变，而波斯特马等人[131] 基于人机交互和运动科学的相关工作，开发了一套体育人机交互系统的分类法。尽管这些工作激励我们深入探索，但它们也指出未来仍需更多工作[94, 96, 131]，因为该领域的参与者尚未系统性地阐明其挑战。因此，我们的工作开始响应这一迫切需求。

多项研究，包括延森等人 [62, 63] 和托兰德等人[157],，已着手解决与特定体育运动相关的挑战，以及技术在提升运动体验中的作用。然而，尽管这些研究推动了该领域的发展，但由于其案例研究的性质，它们未能全面推动整个领域（例如，明显缺失了体育运动的关键方面，如观众互动、长期实践和非竞技性体育活动）。我们还从运动科学中了解到，

作为一门学科，运动科学已研究了可穿戴和交互设备[123], 的整合、仪器设备问题[44],、装备优化[34, 93, 153], 以及伤害预防技术[10]。

此外，先前的文献已回顾了特定的体育人机交互技术，如运动可穿戴设备 [163]。然而，这些先前的工作并未告诉我们人机交互研究人员下一步应该做什么。

因此，我们认为社区有必要阐明体育人机交互领域的重大挑战。为此，本文旨在通过系统地、协作地提出一系列重大挑战，填补已识别的空白。

3 方法

我们于2023年7月举办了一场为期5天的协作研讨会，汇集了22位来自不同视角与学科背景的国际专家，共同探讨体育人机交互领域的重大挑战。这一方法灵感源自人机交互领域先前通过多日研讨会确定关键挑战的努力。

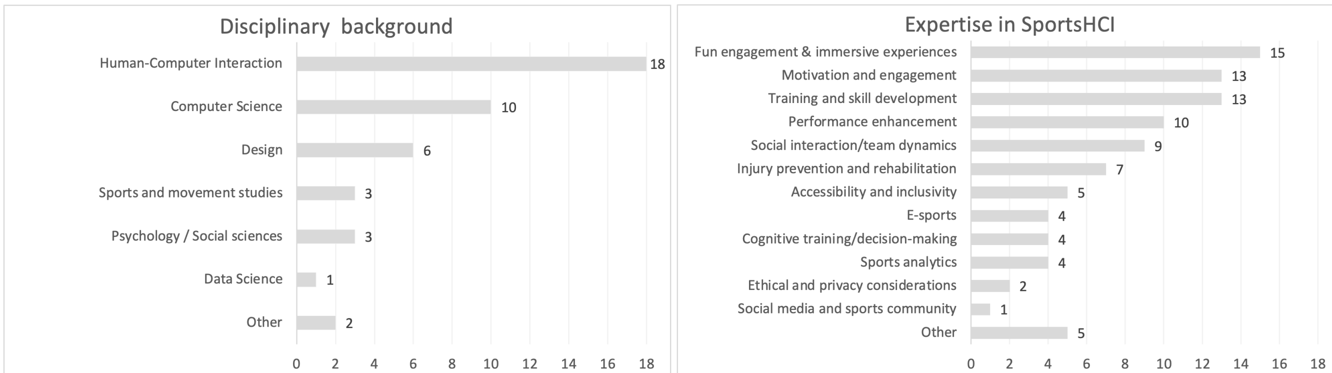

Figure 2: Disciplinary backgrounds of the workshop participants and their specific expertise in the SportsHCI domain.

and discussion sessions. Examples include immersive analytics [40] and topics on food and sustainability [120], as well as broader HCI challenges [151].

3.1 Participants

The recruitment process began by inviting experts in several rounds, with a concern for (a) international and institutional diversity, (b) a balance between experts on the different facets of the research topic, and (c) a mix of senior and junior researchers. Based on these criteria, we approached 55 people other than the organisers. Twenty-six responded positively, four dropping out due to personal reasons. Thus, the seminar involved 22 international experts (15 men, seven women, no non-binary or self-described, aged 28 to 62 years old), including four co-organisers. All participants signed an informed consent form. Our pool included 3 PhD candidates, three postdoctoral researchers and lecturers, 11 assistant and associate professors, and five full professors. Participants had 13.7 years of experience in HCI on average (Min= 3, Max = 25) and 7.3 years of experience in SportsHCI (Min = 1, Max = 25) on average. Participants represented the following disciplinary backgrounds (some having more than one): HCI (n=18), computer science (n=10), design (n=6), sports and movement studies (n=3), psychology/social sciences (n=3).

Our participants' expertise in SportsHCI spans multiple areas (Figure 2), primarily fun, engagement and immersive experiences, training and skill development, motivation and engagement, and performance enhancement. Similarly, our experts represent a mix of methodological expertise (qualitative methods, quantitative methods, design research, experimental research, lab studies, field studies, first-person perspective, and embodied methods) and technological expertise (e.g., XR, tangible UIs, wearables, sensors/actuators). Their research work focuses on a diversity of users: recreational sportspeople (n=20), sports experts (n=10), individuals with disabilities (n=7), teenagers (n=6), older adults (n=5), children/parents (n=7), professional athletes (n=4) and others (sedentary workers, larger populations).

Most of the experts in the seminar are practising sports at different levels, from amateur to semi-professional, and more than half are actively involved in sports communities or organisations beyond their research activities.

3.2 Procedure

The seminar organisers began the first day with a short introduction to the grand challenges activity, including examples from past grand challenges papers in other areas of HCI. The organisers presented the number and type of grand challenges in these papers, emphasising that one could find patterns in the main overarching categories under which these prior publications clustered the grand challenges: users, technology, design, and society.

Identification of grand challenges by each presenter. Each seminar participant gave a presentation introducing their research. Each presentation also articulated the challenges facing their investigations, which each participant had individually prepared before the seminar. We added these challenges to four flip-over sheets during each presentation, initially clustering them under the four overarching categories (as a starting point).

Collective listing of challenges with all participants. The organisers encouraged participants to go to the flip-over sheets at any point during the sessions and add challenges and opportunities for designing SportsHCI systems. Through the presentations, we collated a comprehensive list of challenges, consisting of challenges identified by the authors in their preparation for the seminar and challenges identified by participants while listening to other presentations. These outputs provided a foundation for steering discussions during later activities.

Initial clustering. Based on the challenges gathered by the participants, one of the authors completed an initial clustering (Figure 3). Extending on the four clusters derived from previous exemplary grand challenges papers, the author grouped the challenges across "users", "technology", "design", "society", "research/transversal", and "policy, politics and industry". They added these extra clusters because research issues and the topics of policy, politics, and industry seemed to resonate with people during the previous step. All participants discussed this clustering at the start of the next day to reach a consensus before deriving grand challenges from the resulting collection of materials.

Definition of a grand challenge. After the initial clustering, we discussed the following inclusion criteria to omit common challenges not specific to SportsHCI.

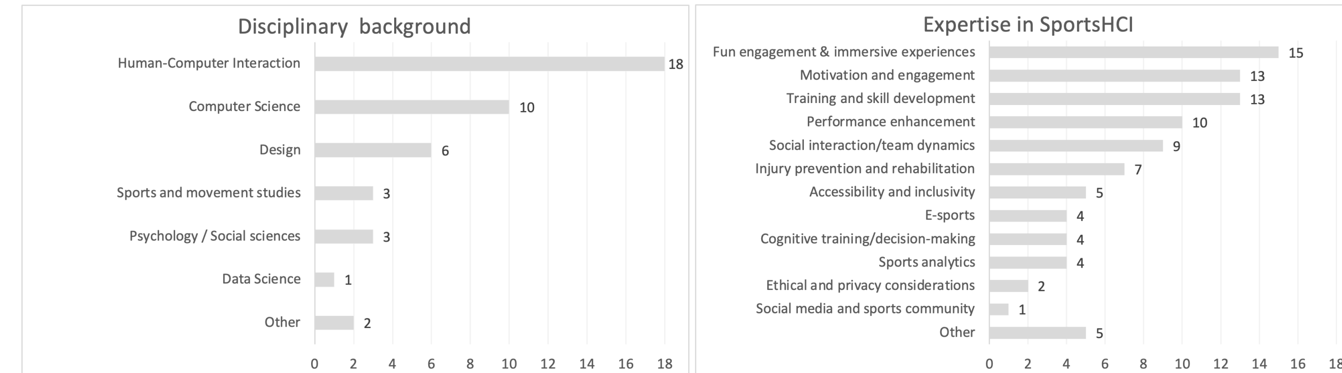

图2：研讨会参与者的学科背景及其在体育人机交互领域的具体专长。

以及讨论环节。实例包括沉浸式分析 [40]
以及食品与可持续性[120], 主题和更广泛的人机交互
挑战[151]。

3.1 参与者

招募流程始于分多轮邀请专家，
重点关注：(a) 国际与机构多样性，(b) 研究主题不同方面的专家之间保持平衡，

以及 (c) 资深与初级研究人员的混合。基于这些标准，我们联系了除组织者外的55人。其中26人积极响应，4人因个人原因退出。

因此，研讨会汇集了22位国际专家（15名男性，7名女性，无非二元性别或自我描述者，年龄28至62岁），

包括4位联合组织者。所有参与者均签署了知情同意书。我们的专家库包含3名博士候选人、3名博士后研究人员与讲师、11名助理教授与副教授，

以及5名正教授。参与者平均拥有人机交互领域13.7年经验（最小值= 3，最大值= 25），体育人机交互领域平均7.3年经验（最小值 = 1，最大值= 25）。参与者的学科背景如下（部分人具备多重背景）：人机交互（n=18）、计算机科学（n=10）、设计（n=6）、体育与运动研究（n=3）、心理学/社会科学（n=3）。

我们的参与者在体育人机交互领域的专长涵盖多个方面（图2），主要包括乐趣、参与感和沉浸式体验，

训练与技能发展、动机与参与以及性能提升。同样，我们的专家代表了方法学专长的混合（定性方法、定量方法、设计研究、实验研究、实验室研究、实地研究，

第一人称视角和体现方法）以及技术专长（例如扩展现实、有形用户界面、可穿戴设备、传感器/执行器）。

他们的研究工作聚焦于多样化的用户群体：休闲运动爱好者（n=20）、体育专家（n=10）、残障人士（n=7）、青少年（n=6）、老年人（n=5）、儿童/父母（n=7）、职业运动员（n=4）以及其他群体（久坐工作者，

更大群体）。

研讨会中的大多数专家都在从事不同水平的体育运动，从业余到半职业，且超过

半数积极参与体育社区或组织
除了他们的研究活动之外。

3.2 流程

研讨会组织者在第一天开始时简要介绍了重大挑战活动，包括过去人机交互其他领域的重大挑战论文中的例子。组织者展示了这些论文中重大挑战的数量和类型，

强调人们可以从这些先前出版物归类重大挑战的主要总体类别中发现模式：用户、技术、设计和社会。

每位演示者识别重大挑战。每次研讨会
参与者都进行了演示介绍他们的研究。每位
演示还阐明了他们调查所面临的挑战，这些挑战是每位参与者事先独立准备的

该研讨会。我们将这些挑战添加到四个翻转板上
在每场演示期间，最初将它们归类于四大
总体类别之下（作为起点）。

参与者集体列出的挑战清单。组织者鼓励参与者在会议期间随时前往翻转板，添加设计体育人机交互系统时面临的挑战与机遇。通过演示环节，我们整理出一份综合挑战列表，包含作者们在研讨会准备阶段提出的挑战，以及参与者聆听其他演示时识别出的挑战。

这些成果为后续活动中的讨论引导奠定了基础。

初始聚类。根据参与者收集的挑战，其中一位作者完成了初步聚类（图3）。

基于先前典范性重大挑战论文中得出的四个集群，作者将挑战分为"用户"、"技术"、"设计"、"社会"、"研究/横向"、

以及"政策、政治与产业"几大类。新增这些集群是因为研究问题及政策、政治与产业主题似乎在上一步骤中引发了参与者的共鸣。所有参与者在次日开始时讨论了这一集群划分，以达成共识，进而从最终的材料集合中提炼出重大挑战。

重大挑战的定义。在完成初始聚类后，我们讨论了以下纳入标准，以排除那些并非体育运动人机交互特有的常见挑战。

Figure 3: Digital whiteboard used by participants for the initial clustering of the Grand Challenges.

(1) Is the challenge specific to SportsHCI, or at least more salient? If not, does it at least play out differently in SportsHCI than in other fields?
(2) Is the challenge important for the field and not easily solved?
(3) Is the challenge not addressed yet in the current work?
(4) Is the challenge feasible, i.e., solvable in, say, the next ten years?

Group discussion on each grand challenge. Based on the challenges collectively gathered, participants discussed a list of potential grand challenges according to the defined criteria. This list included reconciling performance and experience, the feeling of data (objective vs. subjective data), the temporal aspect in SportsHCI, sports data in a wider context (home, nature, city, work) from both a technology and an activity perspective, designing for political futures, athletic performance from the experiential perspective, the role of the audience, promoting physical literacy, addressing inequality by reaching people at a disadvantage, developing a strategic vision for the field, and engineering challenges for SportsHCI. Those topics were all identified in the group discussion as potentially being “grand” challenges.

The participants split themselves into four breakout groups. We tasked each group with discussing and elaborating on one of the proposed grand challenges. We then conducted a second round, for which the groups were ‘shuffled’ to work a different challenge. After each round, the researchers conducted a plenary presentation of highlights (a brief description of each possibly revised challenge and its list of sub-facets).

Final grouping and selection of grand challenges and sub-challenges. We took the various sub-facets of the proposed Grand Challenges already discussed and the detailed and extended list of underlying challenges identified in earlier steps and incrementally iterated it into a final grouping. We conducted this stage of analysis in an AI-assisted manner, using ChatGPT[1] to obtain the following outcomes: (a) additional suggestions for challenges that we might have missed in the initial discussions; (b) additional input regarding the possible interrelated structure between ideas that we already had; and (c) align our work with the kind of grouping that existing grand challenges papers typically use, so we could follow a common best practice for narrative structures of grand challenges. As input, we used the challenges identified in the first steps, examples of the earlier grand challenges papers mentioned in the introduction [2, 40, 114], and specific instructions for what we wanted to achieve at the end of this step, such as “what additional challenges are missing?”. By iterating over the ChatGPT output, we gathered about 20 additional fragments and ideas, which we manually verified to represent the underlying data more accurately. Subsequently, within a breakout group, we discussed and fit them with the existing ideas and groupings. This re-fitting continued asynchronously after the seminar and as part of writing this paper. Finally, the authors wrote this paper without using ChatGPT to generate any text or undertake any copy-editing.

Selecting related work to elaborate on the grand challenges. Figure 3 shows some intermediate results, including a fragment of the Miro board used for the initial clustering. This way, we arrived at the broader grand challenges that can inform priorities for the field’s research over the next ten years. After identifying grand challenges, we reviewed the literature to identify the state-of-the-art related to each grand challenge.

4 GRAND CHALLENGES

Table 1 presents the final 16 grand challenges. By organising the grand challenges into five main categories, researchers and practitioners can better focus their efforts in each respective area, fostering advancements that collectively contribute to the broader goal of elevating the world of sports through human-computer interaction.

In the following sections, we (1) explain the challenges around performance optimisation in Sports HCI that current research efforts can and should tackle and provide the big picture of the challenge space; (2) delve into the human-centred challenges of Sports HCI from the perspective of the three main stakeholders (i.e., athletes, coaches and spectators); (3) zoom into the athlete-centred challenges and articulate the complexity of designing for multifaceted athlete needs; (4) and explicate the challenge of designing for the real world. Finally, we will explain the challenges relating to (5) the strategic research vision in Sports HCI.

[1]https://chat.openai.com

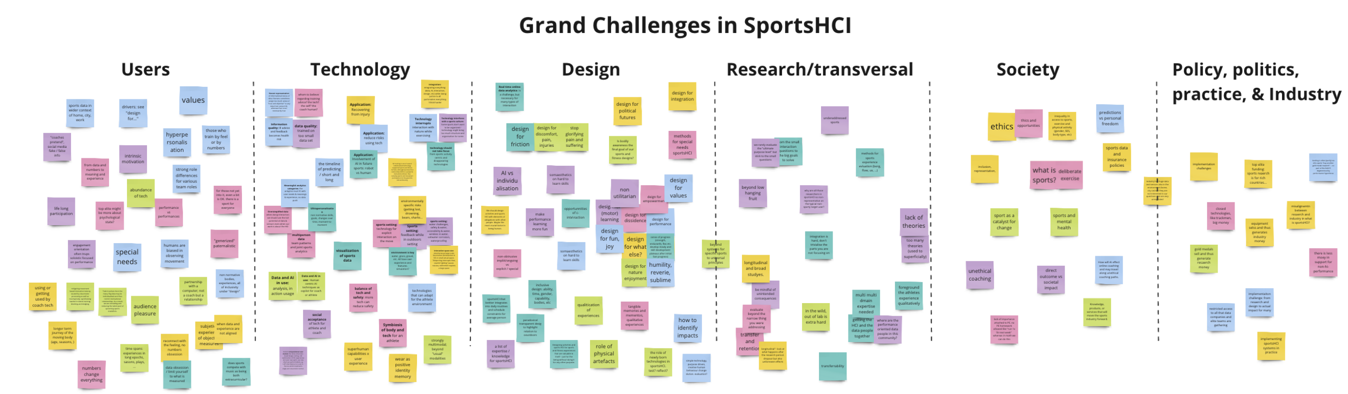

图3：参与者用于重大挑战初始聚类的数字白板。

(1) 这一挑战是否专属于体育运动人机交互领域，或至少在该领域中更为突出？
如果没有，它在体育人机交互领域是否至少与其他领域表现不同？
(2) 该挑战对该领域是否重要且不易解决?
(3) 当前工作中是否尚未解决该挑战?
(4) 该挑战是否可行，即在未来十年内可解决?
多少年?

针对每项重大挑战进行分组讨论。基于共同汇总的挑战，参与者根据既定标准讨论了一系列潜在的体育人机交互重大挑战。该清单包括：协调表现与体验、数据感知（客观数据与主观数据）、体育人机交互中的时间因素、更广泛背景下的体育数据（家庭、自然、城市、工作）（从技术和活动双重视角）、为政治未来设计、

从体验角度看待运动表现、观众的角色、提升体育素养、通过接触弱势群体解决不平等问题、制定该领域的战略愿景，以及体育人机交互的工程挑战。这些主题在分组讨论中均被认定为潜在的“重大”挑战。

参与者自行分为四个分组讨论小组。我们要求每组讨论并详细阐述其中一项挑战。提出的重大挑战。随后我们进行了第二轮，各组被‘打乱’以应对不同的挑战。每轮结束后，研究人员会进行全体会议展示重点内容（简要说明每个可能修订后的挑战及其子方面列表）。

重大挑战及子挑战的最终分组与选定。我们采纳了所提议重大挑战的各个子方面已讨论过的内容以及详细扩展的底层挑战清单，这些挑战在前期步骤中已被识别并通过迭代逐步完善最终形成分组。我们以人工智能辅助的方式开展这一阶段分析，使用ChatGPT1获取以下成果：(a) 针对我们可能面临的挑战提出的补充建议在最初的讨论中可能遗漏的内容；(b) 关于已提出观点之间可能存在的相互关联结构的补充意见拥有；以及 (c) 使我们的工作与现有重大挑战论文通常采用的分组方式保持一致，以便我们能遵循一个共同重大挑战叙述结构的最佳实践。作为输入材料，我们采用了初步阶段识别出的挑战、以及引言{v1}中提及的早期重大挑战论文案例 40, 114], 以及我们想要实现的具体目标说明在此步骤结束时，例如“还有哪些额外的挑战未被提及？”。通过迭代ChatGPT的输出，我们收集了约20个额外的片段和想法，并进行了人工验证以更准确地反映基础数据。随后，在一个分组讨论中，我们进行了讨论并将其与现有内容整合想法与分组。这种重构在研讨会后异步持续进行，并作为撰写本文的一部分。最终，作者们在未使用ChatGPT生成任何文本或进行任何文字编辑的情况下完成了本文。

选择相关工作以阐述重大挑战。图*3*展示了一些中间成果，包括Miro平台的部分片段。用于初始聚类的白板。通过这种方式，我们得出了更广泛的重大挑战，这些挑战可为该领域未来十年的研究提供优先级参考。在确定重大挑战后，我们查阅了文献，以了解与每个重大挑战相关的最新技术。

4 项重大挑战

表1展示了最终的16项重大挑战。通过将这些重大挑战划分为五大主要类别，研究人员和从业者能够更有针对性地在各自领域集中精力，推动技术进步，共同为实现通过人机交互提升体育界的更宏伟目标贡献力量。

在接下来的章节中，我们将：(1) 阐述当前体育人机交互研究中关于性能优化的挑战，这些挑战是现有研究能够且应当攻克的，并提供挑战空间的全景概览；(2) 从三大核心利益相关者（即运动员、教练和观众）的视角，深入探讨体育人机交互中以人为中心的挑战；(3) 聚焦以运动员为中心的挑战，剖析为满足运动员多元化需求而设计的复杂性；(4) 阐明为现实世界设计所面临的挑战。最后，我们将解释与(5)体育人机交互战略研究愿景相关的挑战。

1https://chat.openai.com

4.1 Challenge 1: Lack of knowledge of how interactive technology can support performance optimization

Imagine that a national governing body for track and field asks us to enhance the performance of a 100m runner. However, we do not yet know how interactive technology can support performance optimisation.

Most contemporary SportsHCI systems are concerned with performance analysis and optimisation [131]. Sensor technologies such as motion capture systems and wearable devices are used to measure athletes' performance. Various real-time and non-real-time performance analysis techniques are used to model and interpret this data. The data science life cycle runs from gathering and analysing to communicating and using insights [183]. There are two main ways in which SportsHCI builds upon this life cycle: first, dashboard and retrieval systems communicate the insights directly to athletes and coaches; and, second, interactive training systems where a digital-physical training exercise can be adapted to the athlete's specific performance. For both of these applications, the challenges are closely tied to the nature of the data and data processing of underlying performance analysis and optimisation.

4.1.1 Lack of knowledge of how to design real-time bodily performance analysis systems. The insights and advice regarding performance optimization need to be communicated to athletes and coaches using technology. Dashboard and retrieval-like approaches allow coaches and athletes to gain more insight into performance and thus make better decisions about modifying their strategies and exercise regimes. Such SportsHCI systems may involve, for example, augmented retrieval and browsing of video recordings [77], or specialised overviews and visualisations that provide concise insights to support the athlete's and coach's sensemaking of the data [25, 126, 129, 144]. Interactions with such systems often occur after training and during post-game analysis [82, 167, 168]. During a real-time training activity, an athlete can use real-time performance visualisation to steer their execution of an exercise. Real-time visualisation represents the summarised measurements directly and in comparison with ideal schedules or past self or peer performance [155, 171]. This situation raises the question of how exactly to provide performance-related feedback to athletes and coaches. For example, the right time to provide feedback may vary from case to case. Sometimes, the right time may be immediately during competition or training. In other cases, the right time may be after several repetitions of a skill in practice or after the conclusion of a competition. Immediate feedback may allow adaptive tuning, while delayed feedback may allow reflection. For example, figure 1K shows prior work that delivered prompt feedback during sports activities. In this system, Hassan et al. used an EMS system to provide feedback about footstrike in running [54]. The system gives feedback mid-stride while the foot is in the air by directly actuating calf muscles to drop the forefoot and avoid heel strikes. Many researchers have instead used vibrotactile or auditory modalities to provide feedback to enhance a specific skill in a sports activity [141, 175]. In all such cases, researchers must undertake more work to identify effective content, the best modality to provide feedback, and when to deliver the feedback. While sports science knowledge might help with this work [131, 145], it is primarily focused on individual feedback on a particular aspect as captured by a coach that is then delivered verbally, thereby missing the opportunities that interactive technology can provide, such as capturing more fine-grained data at a faster pace and then delivering feedback across multiple modalities in quick successive repetition.

Suppose we wish to address the challenge of providing the right feedback based on real-time performance analysis. In that case, it is not enough to address specific feedback for specific measurements. We must take into account the complex interconnectivity between many facets, including the athlete's physiological data, body characteristics, and biomechanical data; training routines and the mechanisms underlying injury risk and prevention; and a deep understanding of athletes' sensemaking of their performance and the corresponding data (analysis), and how feedback leads to changes in an athlete's behaviour and thus their performance and development. We cannot disentangle and address these individually. Instead, we need a holistic understanding of performance optimisation that can underlie our designs that use data effectively and beneficially for the athlete's performance.

4.1.2 Lack of knowledge in designing interactive technologies for the longitudinal nature of athletic performance. Sports performance has many longitudinal characteristics. Acquisition of skills takes a long time. Lasting behaviour change regarding sports and physical activity is a long-term endeavour. Our bodies change over longer timeframes (sometimes months and years), not hours or days.

Longitudinal performance tracking has been primarily investigated through data-driven approaches, including machine learning algorithms, to identify trends and patterns in an athlete's progress. These patterns are used for sports analytics, recruitment and management of teams, betting, and gathering long-term statistics to better understand the nature of sports performance. However, in SportsHCI, we seldom focus on the longitudinal aspects of sports. We must address longitudinal issues because understanding SportsHCI in a longitudinal setting is essential to generalising the impact of interactive technologies in athlete performance optimisation in the long run and understanding the life cycle of performance optimisation.

However, carrying out long-term studies in SportsHCI has various challenges. Technologically, designing longitudinal studies with interactive technologies requires prototypes to be robust enough to withstand complex, repetitive biomechanical activities over long periods. If a technology uses novel sensing and feedback, confirming that the sensing and actuation response remains the same over time is important. Finally, for long-term data, the technology may get outdated more quickly than the temporal scope of the effects we are interested in. Regarding the role of participants in long-term studies, it is a challenge to develop suitable injury mitigation protocols and monitoring mechanisms for the athlete. Furthermore, having regular SportsHCI interactions with a participant over a long period poses unique challenges to keeping participants engaged and on board. Regarding the organisation of longitudinal studies, the complex logistics, higher dropout rates, and more complex research ethics challenges make such studies harder to organise and carry out than one-shot studies.

4.1 挑战1：缺乏关于如何利用交互技术支持性能优化的知识

假设某国家田径管理机构要求我们提升一名*100*米跑运动员的表现。然而，我们尚不清楚交互技术如何支持性能优化。

大多数当代体育人机交互系统专注于表现分析与优化[131]。传感器技术（如动作捕捉系统和可穿戴设备）被用于测量运动员的表现。各种实时与非实时性能分析技术被用来建模和解读这些数据。

数据科学生命周期涵盖从数据收集、分析到洞察传递与应用的全过程[183]。体育人机交互在此基础上主要通过两种方式延伸：首先，仪表板和检索系统直接将洞察结果传递给运动员和教练；其次，交互式训练系统可根据运动员的具体表现调整数字-物理训练练习。这两类应用的挑战均与底层性能分析及优化的数据特性及数据处理密切相关。

4.1.1 缺乏关于如何设计实时身体表现分析系统的知识。需要通过技术将表现优化的见解和建议传达给运动员和教练。仪表板和类似检索的方法使教练和运动员能够更深入地了解表现，从而更好地决定修改他们的策略和锻炼方案。此类体育人机交互系统可能涉及，例如，增强的视频记录检索和浏览[77]，

或专门的概览和可视化，提供简洁的见解以支持运动员和教练对数据的意义建构[25, 126, 129, 144]。与此类系统的交互通常发生在训练后和赛后分析期间[82, 167, 168]。

在实时训练活动中，运动员可以使用实时性能可视化来引导他们的锻炼执行。

实时可视化直接并以与理想时间表或过去自身或同伴表现相比较的方式呈现汇总的测量结果[155, 171]。这种情况引发了一个问题，即如何准确地向运动员和教练提供与性能相关的反馈。例如，提供反馈的正确时机可能因情况而异。有时，正确的时机可能是在比赛或训练期间立即进行。在其他情况下，正确的时机可能是在多次练习技能后或比赛结束后。即时反馈可能允许自适应调整，而延迟反馈可能允许反思。例如，图1K展示了在体育活动中提供即时反馈的先前工作。在该系统中，Hassan等人使用了电肌肉刺激系统来提供关于跑步中足部着地的反馈[54]。

该系统在步幅中期、脚部悬空时通过直接驱动小腿肌肉使前脚掌下压以避免脚跟着地来提供反馈。许多研究人员转而采用振动触觉或听觉模态提供反馈，以增强体育运动活动中某项特定技能[141, 175]。在所有此类情况下，研究人员必须投入更多工作来确定有效的内容、提供反馈的最佳模态以及反馈时机。尽管运动科学知识可能对此项工作有所帮助[131, 145]，它主要侧重于教练捕捉到的特定方面的个体反馈，并以口头形式传达，从而错失了交互技术所能提供的机会，

例如以更快的速度捕捉更精细的数据，并通过多种模态快速连续重复地提供反馈。

假设我们希望应对基于实时表现分析提供正确反馈的挑战，那么仅针对特定测量提供特定反馈是不够的。我们必须考虑包括运动员生理数据在内的多个方面之间复杂的相互联系，

身体特征和生物力学数据；训练常规以及受伤风险与预防的机制；以及对运动员表现及其相应数据（分析）意义建构的深刻理解，以及反馈如何导致运动员行为变化，进而影响其表现和发展。我们无法将它们分开单独处理。

相反，我们需要一种对表现优化的整体理解，以此为基础设计出有效且有益地利用数据来提升运动员表现的系统。

4.1.2 缺乏针对运动表现纵向特性的交互技术设计知识。体育运动表现具有诸多纵向特性。技能的习得需要漫长的时间。在体育运动和体育活动方面实现持久的行为改变是一项长期任务。我们的身体变化发生在更长的时间跨度内（有时是数月乃至数年），而非几小时或几天。

纵向表现追踪主要通过数据驱动的方法进行研究，包括运用机器学习算法来识别运动员进步中的趋势与模式。这些模式被用于运动分析、团队招募与管理、博彩业以及收集长期统计数据，以更深入地理解体育运动表现的本质。然而，在体育人机交互领域，我们很少关注体育运动的纵向维度。我们必须解决纵向问题，因为理解体育人机交互

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从纵向研究的角度出发，对于长期推广交互技术在运动员表现优化中的影响以及理解表现优化的生命周期至关重要。

然而，在体育人机交互领域开展长期研究面临诸多挑战。从技术角度看，设计采用交互技术的纵向研究需要原型具备足够鲁棒性，以承受长期复杂、重复的生物力学活动。若某项技术采用新型传感与反馈，确保传感与驱动响应随时间推移保持稳定至关重要。最后，对于长期数据而言，技术过时的速度可能快于我们关注效应的时间跨度。就参与者在长期研究中的角色而言，为运动员制定合适的伤害缓解协议和监测机制是一大挑战。此外，与参与者保持长期的体育人机交互关系，在维持参与者持续投入方面也面临独特挑战。从纵向研究的组织层面看，复杂的后勤协调、较高的退出率以及更复杂的研究伦理挑战，使得此类研究比一次性研究更难组织实施。

On top of that, there is a major challenge related to the fact that longitudinal studies in HCI are not a commonly established tradition compared to fields such as health and medicine. Long-term studies are complex and require substantial time to plan and execute [59, 69]. They commonly have a larger scope than PhD projects, typically requiring a large, sustainable, collaborative research infrastructure to maintain a study over a longer time. In contrast, in the field of HCI, the tradition is more for a PhD thesis to explore multiple variations of a system or intervention, possibly even in multiple related usage domains. While one paper about a long-term study of a single usage domain and population would require more work, it might not yield as much acknowledged scientific output. Consequently, planning and carrying out long-term studies may constitute a risky career move, placing yet more obstacles in the way of successful long-term SportsHCI explorations of interaction technology. However, with the field of SportsHCI maturing, we should gain the necessary confidence in our systems, interventions, and hypotheses to design and execute longitudinal studies.

4.1.3 Lack of knowledge on how to integrate biomechanics into sportsHCI. Integration of biomechanics principles in interactive technologies is vital for performance optimisation. Biomechanics principles suggest what to measure and what feedback to give. Developing ways of integrating complex biomechanics into SportsHCI is still a challenge. This integration includes measuring biomechanical systems in the body, such as muscles or bones. For example, certain tasks (including localising the activity of a particular muscle group or tracking the interconnectivity of muscle groups and skeletons) require highly responsive sensing technologies with capabilities beyond those available in a wearable IMU (Inertial Measurement Unit) and EMG (Electromyography), which are commonly used to measure muscle reactions in response to a nerve's stimulation of a muscle.

Integrating biomechanics into interactive technology will require extensive collaboration between the biomechanics and HCI research communities. However, creating these collaborations is challenging because biomechanics reduces the body to a mechanical system without considering lived experience. In contrast, HCI focuses on creating an experience without understanding the body's biomechanics. The two fields use data differently and place different demands on accuracy and precision. The two fields might even see the importance of one type of measurement or classification error over another differently. When using measurement systems as inputs into interactive systems, the nature and purpose of that interactive system may substantially determine which types of errors, level of noise, or accuracy the system requires to function well for a specific user in a specific setting. These requirements may differ from what is needed to draw significant generalised conclusions from the data regarding biomechanics and human performance [8].

4.1.4 Lack of knowledge on how to utilise real-time sensemaking of bodily performance analysis in novel digital-physical exercises. Dashboards and retrieval systems offer the athlete or coach quick access to sports data and, through the data, often also to salient recordings of past training situations— to base training programs, match strategies, and other decisions, often to optimise the athlete's performance. Stein et al. [150], who published extensively on visual sports data analytics, discussed how this step is about making sense of the data, from analysing the data to re-representing it and disclosing it in a way that contributes real insight. Importantly, this approach focuses not only on finding out what situations and events have occurred but also on gaining insights into when and why they occurred [150].

However, SportsHCI systems can also be used in real-time during training to adapt the training session, that is, to modify the training or steer the player's behaviour to enhance the training experience. These interactive systems use specialised hardware [113] whereby the moving body and the data derived from it form the interface through which athletes interact with digital-physical exercise systems by providing the input triggers to which the system should respond in interaction. This approach provides rich learning environments for better motor learning in controlled circumstances. Athletes and coaches can use the data-based insights regarding performance optimisation and analysis generated by these systems to customise training experiences to specific goals.

We see several challenges associated with the relationship between performance optimisation and these types of interactive digital-physical SportsHCI systems. First, we consider that where the data science technology used in performance optimisation and analysis is quite advanced, SportsHCI systems typically do not remotely leverage the full power of advanced data processing. Usually, these systems focus on innovative interaction technology but use only quite basic forms of sensor measurements and data processing compared to the state of the art. Thus, the challenge lies in developing SportsHCI systems that effectively utilise state-of-the-art data science approaches and results.

Furthermore, various detection and modelling solutions employ different approaches, which may vary due to the facts, such as online or offline, real-time or requiring more computational power. In the specific parametrisations of a method, it may be possible to impact the typical mistakes that an algorithm makes, for example, favouring false negatives over false positives, accepting single errors as long as the cumulative statistics of certain events in the data remain correct, putting more focus on discriminating between certain subsets of categories than on others, etc. As mentioned earlier, the choices to be made in that respect heavily depend on the application of the algorithms [8].

Finally, while substantial knowledge exists regarding performance optimisation and analysis for athletes in their sports, we have much less understanding of how to integrate an athlete's physiology and biomechanics in a technology-enhanced novel training setting. Furthermore, the methods and feedback modalities of skill training in a technological setting differ from those in the real world. Consequently, we still need a deeper understanding of the dynamics of different methods and modalities that will work in technology-enhanced settings. Moreover, our understanding of transfer and retention from (not fully representative) technological exercise settings to the real world remains underdeveloped. Therefore, it is imperative not only to create SportsHCI systems that align with contemporary data science but also to potentially customise the data science techniques to suit the specific demands of the SportsHCI applications. This imperative arises where the nature of the SportsHCI interactive application closely interacts with the characteristics of the technology behind the performance analysis.

更重要的是，人机交互领域的纵向研究尚未形成如健康医疗等领域那样普遍确立的传统，这构成了主要挑战。长期研究复杂度高，需要大量时间规划执行[59, 69]，其范围通常超越博士项目的范畴。

通常需要一个庞大、可持续、协作的研究基础设施来维持长期研究。相比之下，在人机交互领域，传统做法更倾向于让博士论文探索系统或干预措施的多种变体，甚至可能在多个相关使用领域中进行。虽然一篇关于单一使用领域和人群的长期研究论文需要更多工作，但它可能不会产生那么多公认的科学成果。

因此，规划和执行长期研究可能构成一种冒险的职业举动，为成功的体育人机交互技术长期探索设置了更多障碍。然而，随着体育人机交互领域的成熟，我们应该对我们的系统、干预措施、

以及假设有足够的信心来设计和执行纵向研究。

4.1.3 缺乏如何将生物力学整合到体育人机交互中的知识。将生物力学原理整合到交互技术中对性能优化至关重要。生物力学原理提示了需要测量什么以及提供何种反馈。开发将复杂生物力学整合到体育人机交互中的方法仍然是一个挑战。这种整合包括测量体内的生物力学系统，如肌肉或骨骼。例如，

某些任务（包括定位特定肌肉群的活动或追踪肌肉群与骨骼的互连性）需要具备超越可穿戴惯性测量单元（IMU）和肌电图（EMG）现有能力的灵敏传感技术，这两种技术通常用于测量肌肉对神经刺激的反应。

将生物力学融入交互技术需要生物力学与人机交互（HCI）研究领域之间的广泛合作。然而，建立此类合作具有挑战性，因为生物力学将人体简化为机械系统而未考虑生活体验，而人机交互则专注于创造体验却缺乏对人体生物力学的理解。这两个领域对数据的使用方式不同，对准确性和精度的要求也存在差异，甚至可能对某类测量或分类错误的重要性持有不同看法。当将测量系统作为交互系统的输入时，该交互系统的性质与目的可能从根本上决定哪些类型的错误更具影响。

系统在特定用户和特定环境中良好运行所需的噪声水平或精确度。这些要求可能与从数据中得出关于生物力学和人类表现的重要普遍性结论所需的条件有所不同[8]。

4.1.4 缺乏关于如何在新型数字-物理练习中利用身体表现分析的实时意义建构的知识。

仪表盘和检索系统为运动员或教练提供了快速访问体育数据的途径，并且通过这些数据，通常还能获取过去训练场景中的关键记录——以此为基础制定训练计划。

比赛策略及其他决策，通常旨在优化运动员的表现。Stein等人[150]，曾广泛发表关于视觉运动数据分析的著作，讨论了这一步骤如何从理解数据开始，包括分析数据到重新呈现数据，并以一种能带来真正洞见的方式披露它。重要的是，这种方法不仅着重于发现何种情境与事件已经发生，同时也在于深入了解何时以及它们为何发生[150]。

然而，体育人机交互系统也可在训练过程中实时使用，以调整训练课程，即修改训练内容或引导运动员行为，从而提升训练体验。

这些交互系统采用专用硬件[113]，通过运动身体及其衍生的数据构成交互界面，运动员借此与数字-物理锻炼系统互动，提供系统应响应的输入触发。这种方法为受控环境下更好的运动学习提供了丰富的学习环境。

运动员和教练可利用这些系统生成的、基于数据的表现优化与分析洞察，根据特定目标定制训练体验。

我们发现表现优化与这类数字-物理体育人机交互系统之间存在若干挑战。首先，我们认为虽然用于表现优化与分析的数据科学技术已相当先进，但体育人机交互系统通常远未充分利用高级数据处理的全部潜力。通常，

这些系统专注于创新的交互技术，但与最先进技术相比，仅采用相当基础的传感器测量和数据处理形式。因此，挑战在于开发能有效利用最新技术数据科学方法与结果的体育人机交互系统。

此外，各种检测和建模解决方案采用不同的方法，这些方法可能因以下事实而有所差异，例如在线或离线、实时或需要更多计算能力 .
在方法的特定参数化过程中，有可能影响算法犯下的典型错误，例如偏向假阴性而非假阳性，接受单一

只要特定事件的累积统计在数据中保持正确，就会更侧重于区分某些类别子集而非其他类别等。如前所述，这方面的选择很大程度上取决于算法[8]的应用。

最后，尽管关于运动员在其体育运动中的表现优化与分析已有大量知识，但我们对于如何将运动员的生理学与生物力学整合到技术增强的新型训练环境中仍知之甚少。此外，技术环境下技能训练的方法与反馈模式与现实世界中的有所不同。因此，我们仍需更深入地理解适用于技术增强环境的不同方法与模式的动态特性。更重要的是，我们对于从（不完全具代表性的）技术化锻炼环境到现实世界的转移和保留机制的理解仍不成熟。

因此，不仅需要创建与现代数据科学相契合的体育人机交互系统，还可能需要定制数据科学技术以满足体育人机交互应用的特定需求。这一必要性源于体育人机交互应用的本质与支撑性能分析的技术特性之间的紧密互动。

Figure 4 summarises Challenge 1 and its sub-challenges. Next, we turn to challenges related to various parties involved in sports engagement.

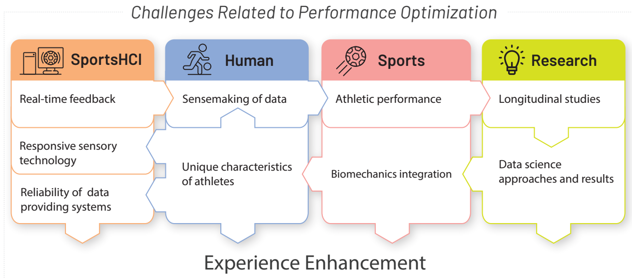

Figure 4: summarises how performance optimisation and analysis challenges arise from the interplay between SportsHCI and the human athlete doing their sports activities.

4.2 Challenge 2: Lack of understanding of how to design interactive technologies for various parties involved in Sports Engagement

Suppose we were asked to design a system to manage a beginner athlete's engagements with a new coach. We do not yet know how to design an interactive system to support the various parties involved in sports engagement.

Various approaches in SportsHCI foster sports engagement through interactive technologies, such as augmented reality (e.g., [140]), virtual reality (e.g., [48]), and gamification techniques (e.g., [75]). Recently, a different human-centred approach emerged, which brings forward "movement" as a core creative resource. As a result, a growing body of literature describes these creative methods and the facilitation of movement-based design sessions [88, 108, 135, 177]. Human-centred design has been a prominent starting point for these endeavours, with studies emphasising the importance of involving three main stakeholders (i.e., athletes, coaches, and spectators) in the design process to create intuitive and user-friendly interfaces. For example, context-aware coaching research has investigated adaptive coaching feedback based on the specific context and situation during training and competitions [186, 187]. Gamification and motivation techniques have been examined to encourage athletes to adhere to training regimes and continuously improve their performance [75, 166]. Still, many human-centred challenges remain unaddressed. We discuss them with specific reference to the three stakeholders' needs, goals, and experiences.

4.2.1 Lack of understanding of how to support the coach-athlete relationship using interactive technology: Coaches also face the challenge of tailoring coaching methods to each athlete's unique attributes [14, 32]. Balancing personalized guidance with broader training strategies is a hurdle they navigate [58, 181]. Coaches, similar to athletes, need to balance data-driven performance enhancement with nurturing athletes' holistic experiences. They play a crucial role in recognising and addressing athlete motivation and their emotional and psychological aspects [64, 85].

Furthermore, coaches are central to translating objective and subjective data into actionable insights. They use their expertise to contribute to the interpretation of quantitative metrics and an athlete's subjective experiences [119]. On the other hand, poor coaching can result in an athlete doubting their own skills and performance [45]. The challenge is aligning coaching methods with an athlete's aspirations and goals, which involves finding a balance between personalised guidance and broader training strategies. This challenge also extends to merging data-driven performance enhancement with improving athletes' overall sporting experiences [14]. Collaborating with coaches to integrate their expertise into SportsHCI design is crucial for creating solutions that combine performance objectives and athletes' well-being (e.g., [14]. This integration can be challenging because coaching usually focuses on performance while SportsHCI focuses on experience and performance. However, involving coaches in technology development ensures that the insights provided are relevant, practical, and aligned with coaches' philosophies.

4.2.2 Lack of understanding of how to support the intricate relationship between athletes and spectators using interactive technology: Spectatorship in sports entails an active process whereby spectators engage with athletes, teams, and other participants [11]. SportsHCI research on spectatorship has predominantly revolved around the dynamics among the spectators themselves [11]. This work includes designs to allow the creation, sharing, and crowdsourcing among spectators of multimedia content related to sporting events [42, 61, 72]. Other studies have delved into the intricate relationship between athletes and spectators [47]. Within this subset of works, some have primarily focused on one-way interactions from the athlete directed toward the spectator. For instance, TickTockRun facilitates sharing runners' performances and daily training updates with interested spectators in their homes [74]. Other solutions have aspired to establish synchronous and bidirectional interactions between athletes and spectators. For example, the HeartLink platform shares long-distance runners' heart rate information with spectators, and the spectators can reciprocate by sending supportive cheering vibrations back to the runners [26].

Furthermore, SportsHCI projects have started to create closer relationships between spectators and athletes by allowing distance tracking of individuals and direct contact with athletes [26, 27]. Applications to encourage and keep tracking friends during a race [27] and social media channels to connect with famous athletes have gained use [22, 154]. Few studies have addressed the direct loss of analogue social relations using computer-supported interaction during sports, although direct relationship building during sports for various athletes is highly valued [36]. Additionally, only a few studies have investigated the spectator-athlete dynamics from the experiential aspects [84].

While several isolated attempts have been made to support spectator-athlete engagement, the intricate relationship between athletes and spectators still needs to be better understood. This understanding will help to find answers for pre- and post-game spectator engagement and real-time interactions to enhance the

图4总结了挑战1及其子挑战。接下来，
我们将探讨与参与体育互动的各方相关的挑战
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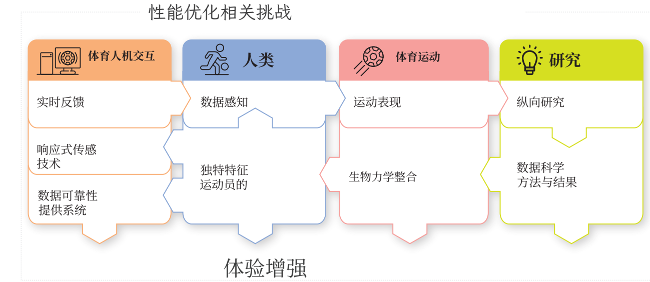

图4：总结了体育人机交互与人类运动员进行体育活动时相互作用所产生的性能优化与分析挑战。

4.2 挑战二：缺乏对如何为参与体育互动的各方设计交互技术的理解

假设我们被要求设计一个系统来管理新手运动员与新教练的互动。我们尚不清楚如何设计一个交互系统来支持参与体育互动的各方。

体育人机交互领域的多种方法通过
交互技术促进体育参与，例如增强现实（如[140]）、虚拟现实（如[48]）和游戏化技术（如[75]）。最近，一种不同的以人为本的方法兴起，将"运动"作为核心创意资源。因此，越来越多的文献描述了这些创意方法以及基于运动的设计会议
[88, 108, 135, 177]的促进。以人为本的设计一直是这些努力的重要起点，研究强调在设计过程中涉及三个主要利益相关者（即运动员、教练和观众）以创建直观且用户友好的界面的重要性。例如，情境感知教练研究调查了基于训练和比赛中的特定背景和情境的适应性教练反馈[186, 187]。游戏化和激励技术已被研究用于鼓励运动员遵守训练制度并持续提升表现[75, 166]。然而，许多以人为中心的挑战仍未得到解决。我们将结合三位利益相关者的需求、目标和经验具体讨论这些问题。

4.2.1 缺乏对如何利用交互技术支持教练-运动员关系的理解：教练们还面临着根据每位运动员独特属性[14, 32]定制训练方法的挑战。在个性化指导与更广泛的训练策略之间取得平衡是他们需要克服的障碍[58, 181]。教练们，
与运动员类似，需要平衡数据驱动的表现提升与培养运动员的整体体验。他们扮演着
关键角色，即识别并应对运动员的动机及其情感和心理方面 [64, 85]。

此外，教练在将客观和主观数据转化为可操作的见解方面起着核心作用。他们运用专业知识帮助解读定量指标和运动员的主观体验[119]。另一方面，不当的指导可能导致运动员对自己的技能和表现产生怀疑[45]。
挑战在于使教练方法与运动员的志向和目标保持一致，这需要在个性化指导与更广泛的训练策略之间找到平衡。这一挑战还延伸到将数据驱动的性能提升与改善运动员整体运动体验[14]相结合。与教练合作将其专业知识融入体育人机交互设计，对于创建兼顾性能目标和运动员幸福感（例如[14]）的解决方案至关重要。这种整合可能具有挑战性，因为教练通常关注表现，而体育人机交互则关注体验与表现。然而，

让教练参与技术开发可确保所提供的见解具有相关性、实用性，并与教练的

理念保持一致。

4.2.2 缺乏对如何利用交互技术支持运动员与观众之间复杂关系的理解：体育赛事中的观赛行为是一个观众与运动员、团队及其他参与者[11]互动的动态过程。
体育人机交互研究中关于观赛行为的部分主要围绕观众之间的动态关系展开[11]。相关设计包括允许观众创建、分享及众包与体育赛事相关的多媒体内容[42, 61, 72]。另有研究深入探讨了运动员与观众[47]之间的复杂关系。在这类研究中，部分成果着重于运动员指向观众的单向互动。例如，

TickTockRun实现了跑步者向家中关注他们的观众分享训练表现及日常训练更新的功能[74]。
其他解决方案致力于建立运动员与观众之间同步且双向的交互。例如，

HeartLink平台将长跑运动员的心率信息分享给观众，观众则可以通过向运动员发送支持的加油振动作为回应[26]。

此外，体育人机交互项目已开始建立更为紧密的
通过保持距离来调节观众与运动员之间的关系
追踪个人及与运动员的直接联系[26, 27]。应用于鼓励并在比赛期间持续追踪朋友[27]

以及通过社交媒体渠道与著名运动员建立联系的途径
获得了使用[22, 154]。很少有研究探讨直接损失
模拟社交关系通过计算机支持的互动
在体育运动中的情况，尽管体育运动中的直接关系建立
对于各类运动员而言备受重视[36]。此外，仅有少数
研究从体验层面调查了观众与运动员互动关系
[84]。
尽管已有若干孤立尝试旨在支持
观众与运动员互动参与，但两者之间错综复杂的关联仍需
更深入的理解。这种
理解将有助于为赛前赛后问题寻找答案
观众参与和实时互动以增强

spectatorship experience. For instance, in sports where the spectators do not see the athletes for a relatively long time (e.g., long-distance running or cycling), the interaction between the athlete and the spectator is yet to be explored [11].

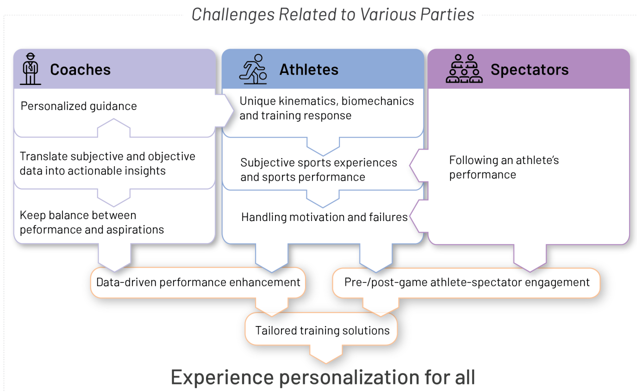

Figure 5: summarises the challenges related to the three main stakeholders and their interactions with SportsHCI, with each challenge having its own focus but cannot be seen fully independently from each other.

4.2.3 Lack of understanding of how to design for the athlete-oriented challenges. Despite the progress made in SportsHCI, creating personalised solutions for individual athletes remains a significant challenge due to the many intricate factors that impact an athlete's performance [179]. Elements such as kinematics, biomechanics, and training responses are unique, making it hard to develop solutions that individually fit different athletes [149]. SportsHCI can take on this challenge via personalised and gamified technology development. However, it takes time and effort to find the right balance between offering Personalised sports experiences and scaling the approach [113] because creating tailored solutions for each athlete can be resource-heavy and technically complex [30]. The challenge is encouraging athletes to actively contribute to the technology development studies that suit their diverse needs and create a collaborative atmosphere. Technology enhances their performance in such contexts without disregarding their distinct physical and cognitive attributes.

While SportsHCI has already benefited from human-centred design methods involving athletes [83, 116, 177], an important challenge remains: addressing athlete's subjective sports experiences along with their performance-related ambitions and aspirations. We need to grasp how athletes feel and translate that understanding into helpful advice that complements performance values instead of solely quantifying and summarising the sports experiences. This endeavour requires a thoughtful understanding of how athletes' sports (dis)engagement can impact athletes mentally (for an overview, see [156]). While we aim for athletes to perform well, we also want them to enjoy the experience. Sports HCI should strike the right balance between experience and performance.

Designing for sports motivation is another athlete-oriented challenge because failures, injuries, and physical and mental fatigue can impact an athlete's motivation [67, 100, 137]. These factors can result in maladaptive behaviours or irrational beliefs [165], including disbelief in self and "awfulising" (i.e., it will be awful if I do not succeed). SportsHCI work could contribute to healthy motivation by carefully designing technologies to handle failures, investigating technology and methods of post-injury management, and identifying the means of physical and mental pain. However, designing for motivation is not trivial, as it needs collaborations with experts in sports psychology, coaches, trainers, and athletes.

Last, motivation, experience, and performance relate not only to the athlete's sports practice but also to other aspects of their lives. Thus, the challenge for a proper athlete-centric design approach to SportsHCI is to also consider non-sports factors, like the development of personal values, life goals, and other facets beyond the sports itself.

Figure 5 summarises Challenge 2 and its sub-challenges. In the next challenge, we will zoom in to Athlete and discuss the challenges we face when designing interactive technologies for individual athletes, who are multifaceted.

4.3 Challenge 3: Lack of knowledge of how to design interactive technologies for the athlete being a multifaceted individual

Imagine the National Cricket Board asking us to design a system to manage the injury recovery of a cricket player. At the moment, we do not have an understanding of how we can provide a solution through interaction technologies for the athlete, who is a multifaceted individual.

Prior research in sports science and psychology has emphasised the importance of supporting athletes in transitions, such as injury recovery and maintaining their health and well-being [33]. Researchers have also emphasised the importance of technology and the collaborative synthesis of knowledge with the domains of sports science, psychology, and data science to support the athlete's health and well-being during these transitions [31]. The health and well-being of an athlete's body, including resilience, also have extensive mental facets, both cognitive and emotional in addition to bodily facets. Furthermore, these bodily and mental facets vary from individual to individual, presenting challenges for modeling an athlete, determining what kind of support to offer them, and deciding how to tailor SportsHCI to them.

4.3.1 Lack of knowledge of how to model the athlete to design interactive technologies. Understanding an athlete's physical, emotional and cognitive states is essential to supporting them during transition periods, such as during injury recovery, a competitive game, or a tournament. Developing an interactive system that can take into account the athlete in all their complexity is a challenging task as the athlete's behaviour depends on multiple internal factors, such as the athlete's level of experience, physical and emotional state, and mental resilience, as well as external factors, such as training and family environment, food intake, etc. Hence, it is important to take a multimodal approach that covers internal and external factors to understand an athlete's physical and mental state.

Previous research has emphasised the importance of analysing athlete behaviour on and off the field to support their well-being [33].

观赛体验。例如，在那些观众较长时间无法看到运动员的体育运动（如长跑或自行车）中，运动员与观众之间的交互仍有待探索[11]。

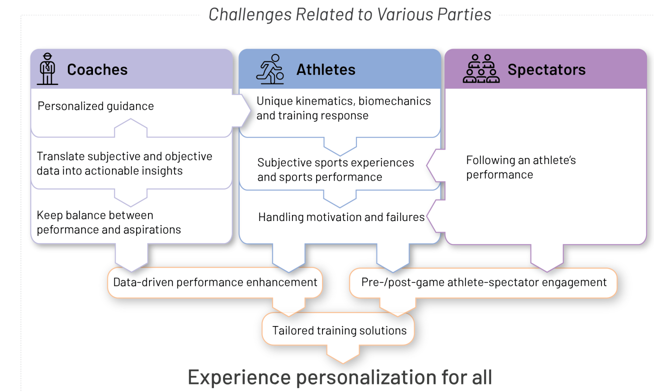

图5：总结了与三大利益相关者相关的挑战及其与体育人机交互的关联，每个挑战虽各有侧重，但无法完全独立看待，彼此之间相互影响。彼此独立。

4.2.3 缺乏对如何为面向运动员的挑战进行设计的理解。尽管体育人机交互领域取得了进展，但由于影响运动员表现的诸多复杂因素[179]，为个体运动员创建个性化解决方案仍是一项重大挑战。运动学、生物力学和训练反应等元素具有独特性，使得开发适合不同运动员的个体化解决方案[149]变得困难。体育人机交互可通过个性化和游戏化的技术开发应对这一挑战。然而，在提供个性化体育运动体验与规模化推广该方法[113] 之间找到恰当平衡需要时间和精力，因为为每位运动员量身定制解决方案可能耗费大量资源且技术复杂[30]。当前的挑战在于激励运动员积极参与符合其多样化需求的技术开发研究，并营造协作氛围，使技术能在不忽视其独特生理与认知属性的前提下提升其表现。

虽然体育人机交互已从涉及运动员的以人为本的设计方法中获益[83, 116, 177]，，但一个重要挑战依然存在：在关注运动员表现相关目标与抱负的同时，如何兼顾其主观体育运动体验。

我们需要把握运动员的感受，并将这种理解转化为有益的建议，以补充表现价值，而非仅仅量化和总结体育运动经历。

这一努力需要对运动员在体育运动中的（脱离）参与如何影响其心理状态有深思熟虑的理解（概述请见[156]）。我们既希望运动员表现出色，也期望他们享受这一过程。体育人机交互应在体验与表现之间找到恰当的平衡点。

为体育运动动机进行设计是另一项以运动员为导向的挑战，因为失败、伤病以及身心疲劳会影响运动员的动机[67, 100, 137]。这些因素可能导致适应不良行为或非理性信念[165]，

包括自我怀疑和"灾难化"（即如果我不成功将会非常糟糕）。体育人机交互工作可通过精心设计处理失败的技术，为健康动机做出贡献，

研究伤后管理的技术与方法，
并识别身心疼痛的应对手段。然而，
为动机进行设计并非易事，因为它需要与运动心理学专家、教练、训练师及运动员展开协作。

最后，动机、经验与表现不仅关联着运动员的体育训练，还涉及其生活的其他方面。

因此，体育人机交互领域采用真正以运动员为中心的设计方法所面临的挑战在于：还需考量非体育因素，例如个人价值观的塑造、人生目标的确立，以及体育运动之外的其他多维特质。

图5总结了挑战2及其子挑战。在接下来的挑战3中，我们将聚焦运动员个体，探讨为具有多面性的运动员设计交互技术时面临的难题。

4.3 挑战3：缺乏关于如何为作为多面性个体的运动员设计交互技术的知识

假设国家板球委员会委托我们设计一套板球运动员伤病恢复管理系统。当前，

我们尚未理解如何通过交互技术为运动员这一多面性个体提供解决方案。

先前运动科学与心理学的研究强调，在运动员面临转型（如伤病恢复及维持健康与福祉[33]）时提供支持的重要性。

研究人员还强调了技术的重要性，以及与运动科学、心理学和数据科学领域知识协同整合的必要性，以支持运动员在这些转型期的健康与福祉[31]。运动员身体的健康与福祉（包括韧性）不仅涉及身体层面，还包含广泛的心理层面——认知与情感维度。此外，这些身心层面的特征因人而异，这为运动员建模、确定应提供何种支持以及如何为其定制体育人机交互技术带来了挑战。

4.3.1 缺乏关于如何通过运动员建模来设计交互技术的知识。理解运动员的生理、情绪和认知状态对于支持其度过转型期（如伤病恢复、竞技比赛或锦标赛期间）至关重要。开发一个能全面考量运动员复杂性的交互系统具有挑战性，因为运动员的行为取决于多种内部因素，例如其经验水平、生理和情绪状态，

以及心理韧性和外部因素，如训练和家庭环境、食物摄入等。因此，采取一种涵盖内外因素的多模态方法来理解运动员的身体和心理状态至关重要。

先前的研究强调了分析运动员在领域内外的行为以支持其幸福感[33]的重要性。

Developing interactive technologies to track this data across all facets is challenging, as some of these modalities can contain very private information. Furthermore, identifying the interconnectivity of those elements of an athlete's state is even harder since such interconnected models require much data. And yet, when one needs to model specific athletes in their individual characteristics, by definition, less data is available. Finally, this latter problem may be exacerbated when looking at amateur and recreational athletes, rather than elite athletes who may habitually track large amounts of varied data about their performance. In such cases, the challenge relates to the system's ability to model the athlete as an individual, including their mental and emotional states, using only limited amounts of individualised data. In this instance, most of the available reference data is drawn from a more generalised population.

4.3.2 Lack of knowledge about developing interaction technologies to support the athlete beyond bodily performance advice. The next challenging task is to develop technologies to support athletes emotionally, and not just with their physical performance. While prior work [38, 91] explored self-emotional awareness systems to build intervention mechanisms that support stress management techniques, these intervention mechanisms have not been tested with athletes, whose emotional dynamics can differ from non-athletes. Moreover, the dynamics of emotional support for athletes are likely to be different for athletes who are children or adolescents and often have different emotional needs to adults. Also, long-term evaluations should be conducted in collaboration with coaches, trainers, and sports psychologists to better understand feedback methods for emotional support from an athlete's point of view. Interactive technologies in understanding behaviour and technologies to provide support should be developed together. Hence, any interactive technology developed to provide emotional support should also use the best modalities to understand behaviour.

4.3.3 Lack of knowledge of how to consider individual non-athletic performance facets when designing SportsHCI technologies. Even more than when providing support for physical athletic performance, support for the mental and emotional side of the athlete must take into account the individual nature of each athlete, requiring personalisation of the support provided. Certainly, technologies for sports have provided athletes and coaches with tools to improve their outcomes and achieve personalised performance goals [68]. For example, mobile apps to guide personalised nutrition [143], personalised monitoring from coaches [19], guidance from digital coaches [71] and virtual training [160], tangible feedback in the environment [173, 174], and personalised wearable feedback [138, 161]. Although these initiatives try to tackle the individual and contextual requirements of athletes by adopting a personalised approach to technology development, the recognition of individual human factors, such as individual sensations of the living body [134, 138], personal enjoyment of the physical activity [121, 158], sports goals and life goals balance [92, 133], and coaches growth and aligning athletes interests [185], need to be considered explicitly in this personalisation.

Figure 6 summarises Challenge 3 and its sub-challenges. Given that the interactions between SportsHCI and its users do not happen in isolation, the next challenge we discuss looks at the long-term, real-life perspective, considering a wider view of how SportsHCI is practiced in a wider context.

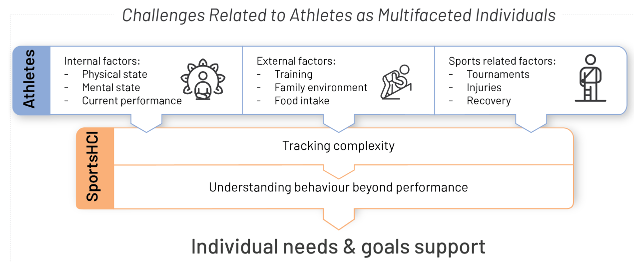

Figure 6: summarises the challenges related to athletes as multifaceted individuals. Individualised support needs to consider this wider perspective on athletes; modelling approaches must explicitly address the relationship between limited individual data and larger-scale generalised data on larger populations.

4.4 Challenge 4: Lack of knowledge of how to take SportsHCI research and design into the real sporting world

Imagine we have an interactive technology that works in the lab to track the heart rate of a rugby player, and we have been asked if it can be used in a match. We do not yet know how to take interactive technology from the research lab into the sporting arena.

Here, we discuss challenges related to this move from research to practice, including real-world validation, the experience of sports and technology as part of daily life, data integration and interoperability, and social impact.

4.4.1 Lack of knowledge of how to validate SportsHCI technology in complex and dynamic real-world sports environments. SportsHCI technologies are often evaluated in controlled settings or short-term experiments [95, 163]. An opportunity in SportsHCI for researchers conducting field studies and experiments is to deploy their technologies in actual sports environments to validate the effectiveness of their solutions in the real world. This opportunity brings its own challenges because sports are complex, dynamic, and evolving practices, and sports technology needs to be robust, dependable, and accurate. Furthermore, there is a need for longitudinal studies to tell us how a deployed technology changes a sporting practice, as technology is never neutral and will shape actions, perceptions, emotions, and behaviour [178]. Video assistant referee technology (VAR) for professional soccer provides a real-world example of a system that has fundamentally altered how soccer is played [1].

4.4.2 Lack of understanding of how to design interactive technology to support the experiential side of sports in a real-world environment. In addition to the athlete's experiential perspectives on sports, there is also the experience of the technology as a potential intrusion into daily life. For many athletes, the experience of being in nature, "away from it all", is a crucial part of the experience in real-world environments. Mueller and Young [111] describe the many virtues people may ascribe to sports; not all of these virtues are equally

开发交互技术来追踪所有方面的数据具有挑战性，因为其中某些模式可能包含非常隐私的信息。此外，识别运动员状态各要素间的互联性更为困难，因为此类互联模型需要大量数据。而当需要针对特定运动员的个体特征建模时，根据定义，可用数据会更少。最后，这一问题在考察业余和休闲运动员时可能进一步加剧。

而非可能习惯性追踪大量多样化表现数据的精英运动员。在此类情况下，挑战在于系统能否基于有限的个性化数据对运动员进行个体化建模，

包括其心理和情绪状态。这种情况下，大多数可用参考数据来源于更泛化的人群。

4.3.2 缺乏开发交互技术以超越身体表现建议支持运动员的知识。下一个挑战性任务是开发技术以在情感层面支持运动员，而不仅限于其身体表现。虽然先前工作[38, 91] 探索了自我情绪感知系统来构建支持压力管理技巧的干预机制，但这些干预机制尚未在运动员群体中测试——他们的情绪动态可能与非运动员存在差异。

此外，针对儿童或青少年运动员的情绪支持动态很可能与成人不同，他们通常具有不同的情感需求。同时，应与教练、训练师合作开展长期评估，

以及运动心理学家，以便从运动员的角度更好地理解情绪支持的反馈方法。理解行为的交互技术与提供支持的技术应共同开发。因此，任何旨在提供情绪支持的交互技术也应采用最佳模式来理解行为。

4.3.3 在设计体育人机交互技术时，缺乏如何考虑个体非运动表现方面的知识。与为身体运动表现提供支持相比，对运动员心理和情绪方面的支持更需要考虑每个运动员的个体差异，这要求所提供的支持具有个性化。当然，体育运动技术已为运动员和教练提供了改善成绩和实现个性化表现目标的工具[68]。

例如，指导个性化营养的移动应用[143],
来自教练的个性化监测[19], 数字教练的指导[71] 虚拟训练[160], 环境中的有形反馈[173, 174], 以及个性化可穿戴反馈[138, 161]。

尽管这些举措试图通过采用个性化的技术开发方法来应对运动员个体及情境需求，但对个体人为因素（如活体[134, 138],的个体感知）的认知仍需加强。

体育活动[121, 158], 的个人享受、运动目标与人生目标
[92, 133], 的平衡，以及教练成长与运动员兴趣[185], 的协调，都需要在这种个性化过程中得到明确考量。

图6总结了挑战3及其子挑战。鉴于体育人机交互与其用户之间的交互并非孤立发生，我们接下来讨论的挑战将从长期、现实生活视角出发，更全面地考量体育人机交互的应用场景。置于更广泛的背景中实践。

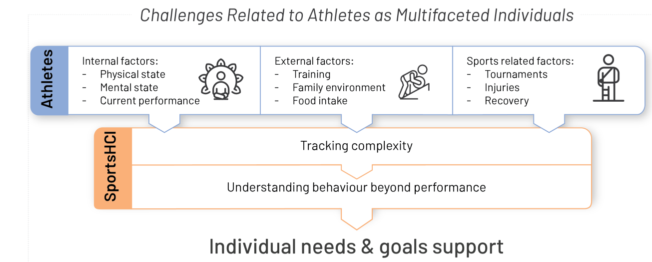

图6：总结了运动员作为多面性个体所面临的挑战
个性化支持需要
考量运动员这一更宏观的视角；建模方法必须明确处理其间的关联

有限的个体数据与大规模通用数据
更大群体

4.4 挑战4：缺乏将体育人机交互研究与设计引入

真实体育世界

假设我们开发了一项在实验室中可用的交互技术，用于追踪橄榄球运动员的心率，现在有人询问该技术能否应用于比赛。我们尚不清楚如何将交互技术从研究实验室引入体育竞技场。

在此，我们探讨从研究到实践过程中相关的挑战，包括现实世界验证、体育运动与技术作为日常生活组成部分的体验、数据整合与互操作性，以及社会影响。

4.4.1 缺乏如何在复杂且动态的现实世界体育环境中验证体育人机交互技术的知识。体育人机交互技术通常在受控环境或短期实验[95, 163]中进行评估。对于进行实地研究和实验的研究人员而言，体育人机交互领域的一个机遇是将他们的技术部署到实际的体育环境中，以验证其解决方案在现实世界中的有效性。这一机遇也带来了自身的挑战，因为体育运动是复杂、动态且不断演进的实践，而体育技术需要具备鲁棒性、可靠性、

和准确性。此外，需要进行纵向研究以揭示部署的技术如何改变体育实践，

因为技术从来都不是中立的，它将塑造行动、认知、
情感和行为[178]。职业足球中的视频助理裁判技术（VAR）提供了一个现实世界的例子，该系统从根本上改变了足球的比赛方式[1]。

4.4.2 缺乏对如何设计交互技术以支持现实世界环境中体育的体验层面的理解。

除了运动员的体验视角对体育运动的看法外，技术作为对日常生活的潜在侵入也带来了另一种体验。对许多运动员而言，身处大自然的体验，

“远离尘嚣”，是现实环境中体验的关键部分。Mueller和Young[111]
描述了人们可能赋予体育运动的诸多美德；并非所有这些美德都同等重要。

easy to align with interactions with a piece of technology. Thus, we raise the challenges of making SportsHCI unobtrusive with added urgency. We need a deeper understanding of the interrelation between the sense of wilderness and the interaction with ubiquitous SportsHCI systems [12].

Furthermore, the two (experience of sports and experience of technology) are not unrelated. The measures, metrics, and feedback that SportsHCI offers regarding performance will change how people train for the sport and what they value and pay attention to. For example, many current SportsHCI systems, especially smartphone apps, appear to invest heavily in sharing numerical performance metrics, which may lead to athletes developing an unhealthy obsession with athletic performance and "being emotionally invested" in achieving specific numbers [105]. Alternative approaches emerged in recent years ([104, 137], see [80] for many examples in SportsHCI), arguing that "much of our experience is qualitative rather than quantitative".

A move into the real world might bring the fundamental purpose of SportsHCI into question. Sports technologies are part of the innovative wave in sports [159]. Various exertion artefacts [108] build on the preconception that movement games support people's change from a sedentary lifestyle to an active one. However, Cooper [24] and Kent [70] point out that the Nintendo Wii, of which the exertion interface character was one of the main innovative characteristics, stopped sale[2]. In this context, what else do we require to make lab-proven concepts work in the market, and what are they really good for? A dilemma arises regarding whether movement values in sports technology are individualised and thus aesthetic, as computer use often is. Contrary values in game and play may have a more self-contained character as one element and, on the other side, have an ethical dimension of interpersonal obligation and helpfulness [16]. In sports, these values and virtues may be described as lenses or logics of sport, play, and movement [39, 107, 184]. Brinkmann's [15] interpretation of

[2]https://www.statista.com/statistics/349078/nintendo-wii-and-wii-u-console-sales/

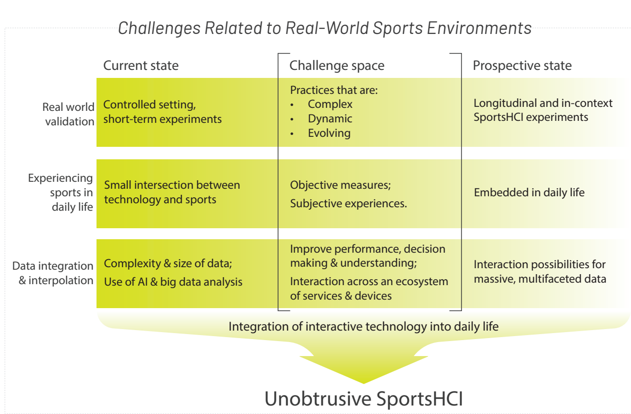

Figure 7: summarises the current and prospective states of three challenges relating to the lack of knowledge of how to take SportsHCI research and design into the real sporting world.

Kierkegaard (1813-1855) states that these stances occur in a continuum between ethical and aesthetic values. Brinkmann et al. [15] claim that contemporary people mainly strive for the aesthetic – enjoyment, feel-good, and beautiful experiences – and perhaps too little as being an ethical dimension of life. The challenging dilemma may arise from too often arguing for SportsHCI design based on instrumentalised purposes and too little on self-contained and ethical values, striving for sustainable values. SportsHCI scientists should not be an extension of societal health preachers for a better health economy. They should also focus on building human inter-related existence and sports as its own end.

4.4.3 There is a lack of understanding of how to design interactions to deal with enormous volumes of multifaceted sports data. Data provides the basis for understanding and improving performance and making strategic decisions [89]. Data visualisation allows coaches, athletes, and analysts to develop data models, identify patterns, and make more informed decisions [127]. The complexity and size of data have favoured the use of artificial intelligence (AI) and big data analytics, enabling the automatic analysis of large amounts of complex information [79]. Integrating data management and analysis with visualisation techniques and HCI aspects may improve performance, decision-making, and understanding in sports. Even if there are many approaches to data analysis and management, it is still challenging to present the data because data and text must be transformed into forms of presentation (such as stories) that are suitable for the intended users.

Moreover, integrating athlete's data to create a generalised understanding of a particular factor will be challenging, as it needs a deeper level of data integration using AI and machine learning while considering human factors. Also, different sports technologies have already been developed in the sporting arenas (e.g., camera-based player trackers, ball tracking in cricket and baseball, heat signature tracking in cricket, speed analysis, and projections). Hence, integrating data collected from many interactive technologies through standard technologies is important to create holistic understandings. This integration is challenging because it requires further development of standardisations with relevant parties such as sports technology companies and sports managers. Furthermore, this introduces interaction challenges with SportsHCI: how does a user interact with large longitudinal data? How do they interact in an integrated manner with data that comes from multiple devices across disparate activities and parts of life? How does a user manage interaction across the ecosystem of services and devices cohesively and consistently when some interactions are frequent, others very infrequent, some momentary, others episodic, some only salient in limited periods in life, and others salient across years or even decades? We lack understanding of the interaction possibilities for massive, multifaceted, disparate data across the past, present, and future, and we do not know well enough how users experience and understand such vast data.

Figure 7 summarises Challenge 4 and its sub-challenges. In the next section, we step away from the challenges *within* SportsHCI to consider what challenges can or should be addressed *through* SportsHCI, leading to a more strategic perspective on the field.

易于与一项技术的交互保持一致。因此，
我们提出了实现无干扰体育人机交互的挑战
紧迫性增加。我们需要更深入地理解相互关系
在荒野感与无处不在的体育人机交互系统之间的交互
体育人机交互系统 [12]。

此外，两者（体育运动的体验与技术的体验）并非无关。体育人机交互提供的关于表现的措施、指标和反馈将改变人们训练体育的方式以及他们所重视和关注的方面。例如，许多当前的体育人机交互系统，尤其是智能手机应用，似乎大量投入于分享数值性能指标，这可能导致运动员对运动表现产生不健康的痴迷，并"情感投入"于实现特定数字 [105]。近年来出现了替代方法（[104, 137], 参见[80] 体育人机交互中的许多例子），认为"我们的体验大多是定性的而非定量的"。

进入现实世界可能会引发对体育人机交互根本目的的质疑。体育技术是体育运动创新浪潮的一部分 [159]。各种运动设备 [108] 基于运动游戏支持人们从久坐生活方式转变为积极的生活方式这一预设。然而，

Cooper [24] 和Kent [70] 指出，以运动界面特性为主要创新特点之一的任天堂Wii已停止销售2。在此背景下，我们还需要什么才能使实验室验证的概念在市场中发挥作用，

它们真正的作用又是什么？关于体育技术中的运动价值是否如计算机使用般个性化且具有美学属性的困境由此产生。游戏与玩耍中的对立价值可能一方面具有自足特性作为要素，另一方面又蕴含人际义务与乐于助人[16]的伦理维度。在体育运动中，这些价值与美德可被描述为体育运动、游戏的视角或逻辑，

与运动[39, 107, 184]。布林克曼[15] 对

2https://www.statista.com/statistics/349078/nintendo-wii-and-wii-u-console-sales/

图7：总结了当前及预期状态下
关于如何将体育人机交互研究与设计
应用于真实体育场景的三大挑战
world.

克尔凯郭尔（1813-1855）认为这些立场存在于伦理与美学价值之间的连续统中。布林克曼等人[15]
认为当代人主要追求的是美学层面的——
享受、愉悦感和美好体验——而可能过于忽视了
生活伦理维度的重要性。这一具有挑战性的困境
可能源于体育人机交互设计过于频繁地基于工具化目的进行论证，而太少关注自足性与伦理
价值，未能充分追求可持续价值。体育人机交互科学家应当
不应成为社会健康倡导者追求更佳健康经济的延伸
他们还应专注于构建人类相互关联的
存在以及将体育运动作为其自身目的

4.4.3 目前缺乏对如何设计交互
以处理海量多维度体育数据的理解。数据为理解和提升表现及

制定战略决策[89]提供了基础。数据可视化使教练们能够
运动员与分析师共同开发数据模型、识别规律，并
做出更明智的决策[127]。数据的复杂性与规模促使
人们采用人工智能（AI）与大数据
分析技术，实现对海量
复杂信息的自动解析[79]。将数据管理与分析同可视化技术及人机交互（HCI）相结合，可提升
体育运动中的表现、决策效率与理解深度。甚至
尽管存在多种数据分析和管理的途径，
展示数据仍具挑战性，因为数据和文本必须
转化为适合目标用户的呈现形式（如故事）。
适合目标用户。

此外，整合运动员数据以形成对特定因素的普适性理解将面临挑战，因为这需要结合人工智能和机器学习进行更深层次的数据整合，同时考量人为因素。目前，体育场馆中已开发出多种运动技术（例如，

基于摄像头的球员追踪器、板球与棒球中的球追踪技术）。
板球中的热特征追踪、速度分析和预测）。
因此，通过标准技术整合从多种交互技术收集的数据对于形成整体理解至关重要。这种整合具有挑战性，因为它需要与体育技术公司和体育经理等相关方进一步推进标准化工作。此外，

这带来了体育人机交互领域的挑战：用户如何与大量纵向数据交互？如何以综合方式处理来自不同生活领域多个设备的数据？当某些交互频繁发生、另一些极少出现，有些转瞬即逝、有些呈阶段性，有些仅在人生特定时期凸显、而另一些可能跨越数年甚至数十年时，用户如何连贯一致地管理整个服务和设备生态系统中的交互？我们对于跨越过去、现在和未来的大量、多面、不同数据的交互可能性缺乏理解，也不够了解用户体验和理解此类海量数据的方式。

图7总结了挑战4及其子挑战。在
下一节中，我们将暂时离开体育人机交互中的挑战
转而思考哪些挑战能够或应该通过
体育人机交互，引领对该领域更具战略性的视角。

4.5 Challenge 5: Lack of a long-term vision on the design of SportsHCI for social impact

Let's assume that we need to convince policymakers to provide more grant opportunities for SportsHCI work; at the moment, we do not have a long-term vision of how SportsHCI should be designed for social impact.

SportHCI has been designed to support autonomous learning in sports [78, 139, 152], to enable geographically distributed athletes to play sports together [107, 110], to enhance performance [20] or prevent injuries [137, 138], and to balance gameplay [3, 46, 49]. This is just a small selection of the research ambitions that the field of SportsHCI has pursued so far [43, 55, 56, 65, 162, 164]. These works show that HCI can make a meaningful contribution to sports. The next step is to widen the scope of research beyond the boundaries of singular sporting disciplines. Given the quality and the quantity of recent SportsHCI work, we argue that the field has matured to the point that it can take on more complex societal issues, such as physical inactivity, physical illiteracy, and inclusivity in sports. We need a collective and focused effort to address these and other problems. Researchers and designers in the field of SportsHCI should be working more programmatically to address these societal challenges on a larger scale – this requires close collaborations with the fields of sports science, human movement science, life science, etc. In broad strokes, this section paints an initial research agenda addressing the major contemporary societal issues in sports and movement.

4.5.1 Lack of understanding of how to address the pandemic of physical inactivity through SportsHCI. Physical activity has been defined as "any bodily movements produced by skeletal muscles that result in energy expenditure" [18]. Sports, household, and occupational activities all contribute to an active lifestyle. The benefits of physical activity are widely established. Physical activity is a known protective factor against non-communicable chronic diseases, such as cardiovascular disease, diabetes, cancer, and depression [76, 180]. Additionally, it has been shown that physical activity is beneficial for mental health, the maintenance of a healthy weight, and the development of cognitive functioning and prosocial behaviour in children and adolescents [17, 51, 52]. Despite its benefits, physical inactivity is reported as being the fourth leading cause of death worldwide [51, 76]. Worldwide, 27.5% of the population is insufficiently active [17, 51]; among adolescents, this number is as high as 81.0% [52]. Globally, women are more than 8% less physically active than men [52], and specific challenges have been described for this population [97, 101, 102]. Furthermore, it was found that the prevalence of physical inactivity increased by 5.9% in high-income countries between 2001 and 2016 [51]. *"Given the prevalence, global reach, and health effect of physical inactivity, the issue should be appropriately described as a pandemic, with far-reaching health, economic, environmental, and social consequences."* [76].

The pandemic of physical inactivity is not easily remedied. The issue is truly complex as the correlates and determinants of physical activity are multi-dimensional. Individual determinants (psychological and biological), interpersonal determinants, environmental determinants (social, built, natural), and regional and global determinants all relate to physical activity [7]. The World Health Organisation's Global action plan on physical activity sets out a framework for action to reduce the global prevalence of physical inactivity in 2030 by 15% [124]. We argue that researchers in the field of SportsHCI can contribute towards making that happen, and indeed, there is already a lot of work in SportsHCI that pursues improved physical activity. However, much of the work remains limited in scope. First, many works in SportsHCI aim to improve physical activity and sports participation by focusing on the separable outcomes of sports and physical activity, such as step count, energy expenditure, and standing hours. This approach treats the symptoms, not the disease [81]. SportsHCI should support people in their ambitions to be physically active, focusing on the inherent factors that make sports and physical activity fun and engaging while being mindful of the barriers and enabling factors that promote physical activity. This focus requires us to change how we think about and design for physical activity [130]. Second, researchers in the field of SportsHCI should invest (even) more in collaborations with neighbouring fields (e.g., social sciences, psychology, sports science, epidemiology, physical education, etc.) to address the pandemic of physical inactivity. Such collaborations involve more than just talking to experts. It requires researchers in the field to set up multidisciplinary consortia – not only for (awarded) grants but also for teaching. Students in HCI are a valuable asset to our research infrastructure, yet rarely do they get the chance to peer past the boundaries of their scientific discipline. Researchers in SportsHCI need to fundamentally rethink how they organise their research and teaching infrastructure to accommodate the development of meaningful interventions for physical activity. Third, to evaluate the long-term effects of our designs and interventions, the SportsHCI field should emphasise longitudinal study designs. There are too many ideas and too little follow-up. SportsHCI, as a field, has an obligation to the rest of the scientific community to clearly communicate how human-computer interaction may contribute to solving the pandemic of physical inactivity. Longitudinal study designs will be the 'proof of the pudding' – acting to separate the wheat from the chaff. This approach again requires us to rethink how we organise our research infrastructure – organising studies that transcend the boundaries of singular (PhD) student projects. We challenge researchers in the field to work holistically, across disciplines, and longitudinally, on studies that positively impact the pandemic of physical inactivity.

4.5.2 Lack of evaluation criteria if a SportsHCI intervention improves physical literacy. Physical literacy and motor competence are among the chief determinants of physical activity [5, 53, 81]. *"Failure to consider motor competence as a key antecedent of physical activity and positive health and developmental trajectories in children and adolescents likely results in treating the symptoms rather than the cause of physical inactivity and ill health."* [81]. Motor competence concerns a person's ability to perform a range of motor tasks (fine and gross) [53, 57] and it is part of the broader concept of physical literacy [81, 182], which is defined as: *"the motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engagement in physical activities for life."* [6]. Physical literacy promotes physical health, well-being, participation in sports, self-esteem, and personal growth [5, 60]. Conversely, children and adolescents with low levels of neuromotor fitness can experience difficulties in participating in sports; are less

4.5 挑战5：缺乏对体育人机交互设计社会影响的长期愿景

假设我们需要说服政策制定者为体育人机交互工作提供更多资助机会；目前，我们对于如何设计体育人机交互以实现社会影响缺乏长期愿景。

体育人机交互（SportsHCI）的设计初衷是支持体育运动中的自主学习[78, 139, 152],，使地理分散的运动员能够共同参与运动[107, 110],，提升表现[20] 或预防伤害[137, 138],，并平衡游戏玩法[3, 46, 49]。这只是体育人机交互领域迄今追求的研究目标中的一小部分[43, 55, 56, 65, 162, 164]。这些工作表明，人机交互（HCI）能为体育运动做出有意义的贡献。下一步是将研究范围扩展到单一体育学科的边界之外。鉴于近期体育人机交互工作的质量和数量，我们认为该领域已发展成熟，足以应对更复杂的社会问题，例如缺乏运动、体育素养不足和体育包容性。我们需要集体且有重点的努力来解决这些问题及其他难题。体育人机交互领域的研究人员和设计师应以更系统化的方式开展工作，更大规模地应对这些社会挑战——这需要与运动科学、人体运动科学、生命科学等领域密切合作。

等等。简而言之，本节初步描绘了一个研究议程，旨在解决体育与运动领域当前面临的主要社会问题。

4.5.1 缺乏如何通过体育人机交互应对缺乏运动大流行病的理解。体育活动被定义为“由骨骼肌产生的任何身体运动，导致能量消耗”[18]。体育运动、家务和职业活动都有助于积极的生活方式。体育活动的益处已得到广泛证实。体育活动是预防非传染性慢性疾病的已知保护因素，如心血管疾病、糖尿病、癌症和抑郁症[76, 180]。

此外，研究表明体育活动对心理健康、保持健康体重以及儿童和青少年的认知功能和亲社会行为发展有益[17, 51, 52]。尽管有这些益处，缺乏运动被报告为全球第四大死亡原因[51, 76]。全球范围内，27.5%的人口运动不足[17, 51]；在青少年中，这一数字高达81.0%[52]。全球范围内，女性的体育活动比男性少8%以上[52],，并且针对这一人群的具体挑战已有描述[97, 101, 102]。此外，研究发现2001年至2016 [51]年间，高收入国家缺乏运动的流行率增加了5.9%。“鉴于缺乏运动的普遍性、全球影响及健康效应，这一问题应被恰当地描述为大流行病，具有深远的健康、经济、环境和社会后果。”[76]。

身体活动不足的流行病不易解决。这一问题确实复杂，因为体育活动的相关因素和决定因素是多维的。个体决定因素（心理和生物）、人际决定因素、环境决定因素（社会、建筑、自然）以及区域和全球决定因素都与体育活动[7]相关。世界卫生组织的全球身体活动行动计划提出了一个行动框架，旨在到2030年将全球缺乏运动的普遍性降低15%[124]。我们认为，体育人机交互领域的研究人员可以为实现这一目标做出贡献，事实上，体育人机交互中已有大量工作致力于改善体育活动。然而，许多工作的范围仍然有限。首先，体育人机交互中的许多工作旨在通过关注体育运动和体育活动的可分离结果（如步数）来改善体育活动和体育参与，

能量消耗，以及站立时间。这种方法治标不治本[81]。体育人机交互应支持人们实现积极参与体育活动的愿望，重点关注使体育运动变得有趣且引人入胜的内在因素，同时注意那些促进体育活动的障碍和赋能因素。这一焦点要求我们改变对体育活动的思考方式和设计方法[130]。其次，体育人机交互领域的研究人员应（进一步）加大与邻近领域（如社会科学、心理学、

运动科学、流行病学、体育教育等）的合作，以应对缺乏运动的流行病。此类合作不仅仅是与专家对话，更需要该领域的研究人员建立多学科联盟——不仅为了（获奖的）资助项目，也为了教学。人机交互领域的学生是我们研究基础设施的宝贵资产，但他们鲜有机会跨越自身科学学科的边界。体育人机交互的研究人员需要从根本上重新思考如何组织其研究和教学基础设施，以开发有意义的体育活动干预措施。第三，为评估我们设计和干预措施的长期效果，体育人机交互领域应强调纵向研究设计。当前存在太多想法而后续跟进不足。作为一个领域，体育人机交互

我们有责任向科学界的其他成员清晰地传达人机交互如何助力解决身体活动不足的流行病。纵向研究设计将成为“实践出真知”的关键——去芜存菁。这一方法再次要求我们重新思考如何组织研究基础设施——统筹那些超越单个（博士）学生项目边界的研究。

我们呼吁该领域的研究人员跨学科、全方位且长期地开展研究，以积极应对身体活动不足的流行病。

4.5.2 缺乏评估体育人机交互干预是否提升体育素养的标准。体育素养与运动能力是决定体育活动[5, 53, 81]的主要因素之一。

若不将运动能力视为儿童及青少年体育活动、积极健康与发展轨迹的关键前提，很可能导致仅针对缺乏运动和健康状况不佳的表象而非根源进行处理。″[81]。运动能力涉及个体完成一系列运动任务（精细与粗大动作）的能力[53, 57]，它是更为广泛的体育素养概念的一部分[81, 182],，其定义为：″动机、

自信、身体能力、知识和理解，以重视并终身承担参与体育活动的责任。″[6]。体育素养促进身体健康、幸福感、

参与体育运动、自尊和个人成长 [5, 60]。
相反，神经运动能力水平较低的儿童和青少年在参与体育运动时可能会遇到困难；且更

likely to participate in sports later in life; run an increased risk of negative health outcomes at all ages [5]; and are at risk of various psychological difficulties [53, 146]. Moreover, *"physically inactive parents tend to raise physically inactive children"* [81]. Physical literacy and motor competence are in decline among children and adolescents – impacting speed and agility, upper-body strength, and flexibility [5, 60]. This decline is problematic because lower levels of motor competence cause lower confidence and motivation to participate in sports, which can become a vicious cycle.

This perspective of physical literacy is increasingly seen as a main objective to pursue in sports and health sciences. However, we must overcome many challenges for SportsHCI to work productively on physical literacy. First, because of its multidimensional nature, it is challenging to directly assess the effects of technological interventions on physical literacy. Second, one of the core determinants of physical literacy – motor competence – can be measured but requires elaborate study designs that involve testing over time (pre-test, intervention-test, post-test, retention-test, transfer-test) for multiple conditions (test-group, placebo-group, control-group), rendering investigation both time- and labour-intensive. This complexity is further exacerbated by the fact that design processes are iterative – ideally, one would want to investigate how different design choices impact physical literacy differently. However, it seems neither practical nor feasible to carry out multiple longitudinal studies within the scope of a single design project. This impracticality hinders the field of SportsHCI from productively working on issues in motor learning and physical literacy.

4.5.3 Lack of understanding of how to overcome barriers to sports access. Sports and physical activity are fundamental human activities. In their Olympic Charter, the International Olympic Committee posits, *"The practice of sport is a human right. Every individual must be able to practise sport, without discrimination of any kind and in the Olympic spirit, which requires mutual understanding with a spirit of friendship, solidarity and fair play."* Yet, access to sports and other physical activities is far from equal. Many groups in our society are disadvantaged in the extent to which they are enabled to be physically active. Women are less physically active than men [51], and the WHO calls for more *"opportunities and safe and accessible leisure-time activities for women"* to close this gender gap. People with a low socioeconomic background are less physically active, with time, money, health concerns, lack of physical literacy, and other factors raising barriers to participation. Neurodiverse children suffer the same fate, with the barriers to participation in sports being greater for neurodiverse children than for neurotypical children [73], causing lower levels of physical activity and motor competence such as in Autism Spectrum Disorder [13, 125]. Many more such disparities may be added to this list, considering, for instance, people with a physical disability who also face greater sports participation barriers.

Most SportsHCI work exclusively targets participants with normative bodies and capabilities, and this conceptualisation is shared across much research on body technologies [147]. A few design studies focus on encouraging physical activity for individuals with a disability (e.g., lower limb disability [4]) or who are recovering from a disease (e.g., breast cancer [103]). Others address barriers to exercising motivation in various populations of recreational users [29, 98–100, 102, 104, 172, 174]. Overall, we contend that the challenge for SportsHCI is to *reduce* inequalities in sports participation – considering underrepresented bodies, disabled and non-normative bodies, and individuals of different genders and age groups as worthy subjects for research in SportsHCI. Such inclusion in our research endeavours may involve identifying and addressing political powers and ethical considerations related to participation and access to sporting activities and technology. Even when not designed for underrepresented groups, researchers in SportsHCI should be aware of the impact that their technology may have on equity, accessibility, and inclusion in sports. These matters are not merely separate, additional research topics with standalone groups working on dedicated SportsHCI for special target groups. On the contrary, all SportsHCI practitioners should be mindful of whether the systems under development adequately consider inclusivity. For one, novel technologies tend to be expensive, offering access only to those with the (financial) resources to spend time and money on sports and physical activity [35, 132]. Further, technologies might not be accessible to all due to logistic, physical, mental, or social constraints. As such, it is easy for novel systems to widen the gap of inclusive sports participation.

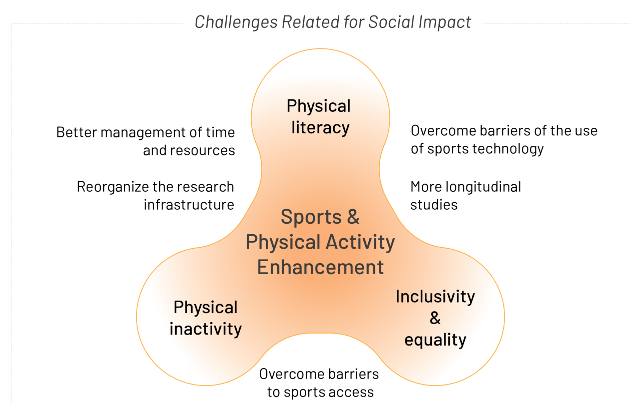

Figure 8: summarises the three challenges of the lack of vision on the design of SportsHCI for Social Impact and the points for action for SportsHCI.

5 LIMITATIONS AND FUTURE WORK

Our work has limitations, as does any that aims to steer an entire sub-field of HCI at once. The articulation of these limitations might inform future work and ultimately lead to a more complete picture of the SportsHCI field. We especially point out that our approach of conducting a week-long seminar is not the only way to articulate grand challenges for a particular sub-field. Others have held one-day workshops [21], worked in smaller teams [151], and even individually [9]. Therefore, alternative formats could result in additional grand challenges articulations that could complement our work.

Furthermore, we acknowledge that the composition of our seminar might have biased our results and that our positionality as organisers and authors influenced the outcomes to some extent.

更可能在成年后参与体育运动；在所有年龄段都面临更高的负面健康结果风险[5]；并且存在遭遇各种心理困扰的风险[53, 146]。此外，"缺乏运动的父母往往养育出缺乏运动的孩子"[81]。儿童和青少年的身体素养与运动能力正在下降——这影响了他们的速度与敏捷性、上肢力量，

和灵活性[5, 60]。这种下降是有问题的，因为较低的运动能力会导致参与体育运动的信心和动机降低，从而可能形成恶性循环。

体育素养的这一视角日益被视为体育运动和健康科学领域追求的主要目标。然而，

体育人机交互要高效地提升体育素养，我们必须克服诸多挑战。首先，由于其多维性质，直接评估技术干预对体育素养的影响具有挑战性。其次，体育素养的核心决定因素之一——运动能力——虽可测量，但需要精心设计的研究方案，包括针对多种条件（测试组、安慰剂组、对照组）随时间进行测试（前测、干预测试、后测、保留测试、迁移测试），

这使得研究既耗时又费力。这种复杂性因设计过程的迭代性而进一步加剧——理想情况下，人们希望探究不同设计选择如何差异化地影响体育素养。然而，在单一设计项目范围内进行多项纵向研究既不现实也不可行。这种不切实际性阻碍了体育人机交互领域在运动学习和体育素养问题上取得实质性进展。

4.5.3 缺乏对如何克服体育运动参与障碍的理解。体育运动是人类的基本活动。

国际奥林匹克委员会在其《奥林匹克宪章》中提出："从事体育运动是一项人权。每个人都必须能够不受任何歧视地以奥林匹克精神参与体育运动，这需要以友谊、团结和公平竞争的精神相互理解。"然而，体育运动和其他体育活动的参与机会远不平等。我们社会中的许多群体在能够参与体育活动的程度上处于劣势。女性的体育活动参与度低于男性[51]，，世界卫生组织呼吁提供更多"机会和安全、可及的休闲活动给女性"，以缩小这一性别差距。

社会经济背景较低的人群体育活动参与度较低，时间、金钱、健康问题、缺乏体育素养等因素构成了参与障碍。

神经多样性儿童同样面临这一命运，他们在参与体育运动方面的障碍比神经典型儿童更大[73]，，导致体育活动水平和运动能力较低，例如自闭症谱系障碍[13, 125]。考虑到身体残疾人士也面临更大的体育参与障碍，这一清单上还可以添加更多此类差异。

大多数体育人机交互研究仅针对具有标准身体和能力的参与者，这一概念化在众多身体技术研究中得到共享[147]。少数设计研究专注于鼓励残疾人士（如下肢残疾[4]）或疾病康复者（如乳腺癌[103]）参与体育活动。其他研究则探讨不同休闲用户群体在锻炼动机方面面临的障碍

用户[29, 98–100, 102, 104, 172, 174]。总体而言，我们认为
体育人机交互面临的挑战是减少体育运动参与中的不平等——考虑到代表性不足的身体、残障人士及

非标准身体，以及不同性别和年龄组的个体，都值得成为体育人机交互研究的对象。这种包容性

在我们的研究努力中可能涉及识别并解决
与参与和获取体育活动及技术相关的政治权力和伦理考虑。即便在
并非所有情况下，
并能参与体育活动和接触技术。即便在不
为代表性不足的群体设计，体育人机交互领域的研究人员
应当意识到他们的技术可能对
体育运动中的公平、可访问性与包容性产生的影响。这些问题并非
仅仅是独立群体专注研究的附加主题，
专门为特殊目标群体开发的体育人机交互技术。相反，
所有体育人机交互从业者都应审慎考量
正在开发的系统充分考虑了包容性。
一方面，新技术往往价格昂贵，仅能提供给那些有（经济）资源投入时间和金钱于

体育运动的人{v1}。
此外，由于物流、身体、心理或社会
限制，技术可能并非所有人都能使用。
因此，新系统很容易扩大这一差距。
关于包容性体育参与。

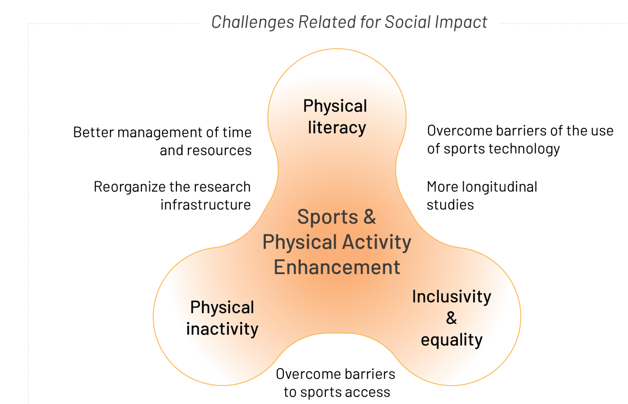

图8：总结了缺乏体育人机交互社会影响力设计的三大挑战愿景，以及体育人机交互领域的行动要点。

5 局限性与未来工作

与任何试图一次性引导整个人机交互子领域的研究一样，我们的工作存在局限性。这些局限性的阐述

可能为未来工作提供参考，并最终形成一个更完整的
体育人机交互领域的图景。我们特别指出，我们
采用为期一周的研讨会形式并非唯一途径来
阐明特定子领域的重大挑战。其他研究者曾
举办过一日研讨会[21]，以小型团队[151]，协作或
甚至个人[9]形式开展工作。因此，替代形式也可能
可补充我们工作的其他重大挑战表述
。

此外，我们承认研讨会的构成可能使结果产生偏差，且我们作为组织者和作者的立场性在一定程度上影响了研究结果。

First, our seminar participants were all experts and, hence, had a favourable view of the topic and were eager to see the field flourish. As such, our view on the future of SportsHCI might be overly positive. We might identify additional challenges that could complement our work if we involve participants with a more critical view on SportsHCI, including researchers who have left the field (perhaps because they have encountered too many roadblocks when trying to work with an industry that is seemingly only interested in elite athletes, or when trying to work with under-resourced community organisations) and non-experts.

Our seminar participants exhibited a great range of sports expertise, including conducting various sports at various intensity levels (up to representing their state, but not country or being a professional). This expertise made the seminar experience unique because participants provided training sessions before and after each day and during the breaks. Including these activities also informed our discussions, as has "body-storming" in HCI [88]. It has been argued that "moving" during creative tasks facilitates different (and seemingly better) outcomes. As such, we consider the diversity in our seminar participants' sports engagement a strength of our approach. However, we acknowledge that participants with other experiences (for example, people with an aversion to sports and people who have been injured and had to give up sports) could expand our discussions in future seminars.

We also acknowledge that we have only briefly touched upon what role HCI could play in addressing the negative consequences of sports, such as discouraging the use of performance-enhancing drugs. This could occur in the form of existing technology, such as apps that educate athletes about the associated health risks, and in future high-tech systems that detect such drugs through implanted interfaces to immediately report to the governing body (yet raising serious privacy concerns). Furthermore, we discussed the saying that sports can bring out both the best and the worst in people. We often observe the worst in the rivalries between local clubs that lead to clashes between fans and violence that goes beyond the (football) pitch. What role does SportsHCI play in these contexts? We discussed these "dark" sides of sports during the seminar, and, in this regard, we direct interested readers to prior work using "dark patterns" to investigate the negative implications of particular subfields of HCI [50].

Taken together, we acknowledge the limitations of our approach, and we have pointed out important issues that we decided not to investigate further (yet) but encourage others to explore to see what role SportsHCI could play in them. As such, our grand Challenges are not to be understood as a final list but rather as a starting point for others to build on, develop further, and critique through additional investigations and research. With this, we can paint a more vivid picture of SportsHCI.

6 CONCLUSION

SportsHCI has transformed from an HCI application domain into a standalone interdisciplinary field as a result of significant technological progress, and now comprises a growing body of literature investigating various facets. However, as SportsHCI becomes a field in its own right, certain challenges prevent it from blossoming and thriving. We believe it is valuable to articulate the nature of these challenges so that we might work together as a community to address and ultimately overcome them and advance the whole SportsHCI field. Through this articulation, researchers and industry alike will better understand the pressing issues and be better able to identify what matters to tackle next. Such a structured approach might be more beneficial than leaving individuals to work in isolation, which would risk the duplication of research efforts and the 'fixing' of problems that others have already solved.

In this paper, we have used the outcomes from a week-long seminar involving 22 experts to articulate five grand challenges and 17 sub-challenges in SportsHCI. These are our starting points. While we acknowledge that there might be more or that the challenges could be differently framed or elaborated upon, we still believe that they can be useful for others interested in starting to work to advance the whole SportsHCI field.

In conclusion, we believe that the grand challenges in SportsHCI offer the potential to revolutionise the world of sports, benefitting recreational sports participants and elite athletes, coaches, and fans alike. By collectively addressing these challenges, researchers and practitioners can advance the state-of-the-art, foster innovation, and create a positive impact. Embracing a collaborative and multidisciplinary approach will be key to realising the full transformative potential of SportsHCI in shaping the future sports experience.

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首先，我们的研讨会参与者均为专家，因此具备
对该主题持积极态度，并期待该领域蓬勃发展 .
因此，我们对体育人机交互未来的看法可能过于乐观。若能识别更多挑战，或许可以补充
我们的研究——尤其是纳入对体育人机交互持批判态度的参与者，包括已离开该领域的研究人员（可能
因为他们尝试时遇到了太多障碍
试图与一个似乎只对精英
运动员感兴趣的产业界合作，或是试图与资源不足的社区
组织）以及非专家合作时。

我们的研讨会参与者展现出广泛的体育运动专业背景，包括以不同强度进行各类体育运动
（最高至代表其所在州，但未达到国家级别或成为职业
专业背景）。这种专长使得研讨会体验独具特色
因为参与者在活动前后提供了培训课程
每天及休息期间。将这些活动纳入其中也启发了我们的讨论，正如人机交互领域中的“身体风暴”[88]。有观点认为
在创造性任务过程中“运动”能促进不同
（且看似更优）的成果产出。因此，我们认为研讨会参与者
在体育参与方面的多样性是我们的一大优势
方法。然而，我们认识到具有其他
经历的参与者（例如，对体育运动有抵触情绪的人以及
曾受伤而不得不放弃体育运动的人）可以
在未来研讨会中拓展我们的讨论。

我们也承认仅简要探讨了
人机交互在解决负面影响方面可能扮演的角色
体育运动方面，例如劝阻使用兴奋剂
这类情况可能通过现有技术实现，比如
教育运动员认知相关健康风险的应用程序，以及
未来能通过植入式接口检测此类药物
并立即向管理机构报告的高科技系统（但会引发
严重的隐私问题）。此外，我们还讨论了那句
体育运动既能激发人性最好的一面，也能暴露最坏的一面。我们经常在地方俱乐部之间的对抗中观察到最恶劣的行为，
这些对抗导致球迷冲突和超越
(足球)赛场范畴的暴力。体育人机交互在这些情境中扮演什么角色？
我们在研讨会期间探讨了体育运动的这些"阴暗面"，并
就此引导感兴趣的读者参阅先前工作中关于"阴暗
模式"来研究人机交互特定子领域[50]的负面影响。

综上所述，我们承认自身方法的局限性，
并已指出那些我们决定暂不深入
研究（但鼓励他人探索）的重要议题，
以观察体育人机交互在其中可能发挥的作用。因此，我们的重大挑战
不应被视为最终清单，而应作为探索的起点
为他人提供可借鉴、发展和批判的起点，
通过进一步的调查与研究。借此，我们能够描绘出
体育人机交互更生动的图景。

6 结论

体育人机交互已从一个单纯的人机交互应用领域，因显著的技术进步而发展成为一个独立的跨学科领域，如今包含了越来越多探究其各个方面的文献。然而，随着体育人机交互成为一门独立学科，某些挑战阻碍了它的蓬勃发展。我们认为，阐明这些挑战的本质至关重要，以便我们能够作为一个社区共同努力
应对并最终克服这些挑战，从而推动整个
体育人机交互领域的发展。通过这一阐述，研究人员与产业界
相似群体将更清晰地认识紧迫问题，并更有能力
明确下一步需要解决的关键事项。这种结构化方法
可能比让个人孤立工作更有益，后者可能导致研究努力的重复
以及‘解决’他人早已攻克的问题。

本文中，我们利用了一场为期一周
研讨会（22位专家参与）的成果，阐明了五项重大挑战
体育人机交互领域的17个子挑战。这些是我们的起点。尽管
我们承认可能还存在更多挑战，或者这些挑战
可以有不同的表述或更详细的阐述，但我们仍然相信
它们对于其他有兴趣开始致力于
推动整个体育人机交互领域发展的人士会有所帮助。

总之，我们相信体育人机交互领域的重大挑战具有革新体育界的潜力，使休闲运动参与者、精英运动员、教练和球迷都能受益。通过共同应对这些挑战，研究人员和从业者可以推动最新技术的发展，促进创新，
并创造积极影响。采用协作与多学科融合的方法，将是充分释放体育人机交互（SportsHCI）在塑造未来体育运动体验方面变革潜力的关键。

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Table 1: Five Categories of Grand Challenges in SportsHCI

Challenge 1: Lack of knowledge how interactive technology can support performance optimization	- Lack of knowledge how to design real-time bodily performance analysis systems to coach and athlete's feedback and sense-making - Lack of knowledge in designing interactive technologies for the longitudinal nature of athletic performance - Lack of knowledge how to integrate biomechanics in to SportsHCI methods - Lack of knowledge how to utilise realtime sensemaking of bodily performance analysis in novel digital-physical exercises
Challenge 2: Lack of understanding how to design interactive technologies for various parties involved in Sports Engagement	- Lack of understanding how to support the coach-athlete relationship using interactive technology -Lack of understanding how to support the intricate relationship between athletes and spectatotrs using interactive technology - Lack of understanding how to design for the athlete-oriented challenges
Challenge 3: Lack of knowledge how to design interactive technologies for the athlete being a multifaceted individual	- Lack of knowledge how to model the athlete to design interactive technologies -Lack of knowledge how to develop interaction technologies to support the athlete beyond bodily performance advice - Lack of knowledge of how take into consideration individual non-athletic performance facets when designing SportsHCI technologies
Challenge 4: Lack of knowledge how to take SportsHCI research and design into the real sporting world	- Lack of knowledge how to validate SportsHCI technology in complex and dynamic Real-World sporting - Lack of understand how to design interactive technology to supports experiencial side of sports in daily life - Lack of understanding how to design interactions to deal with multifaceted enormous sports data
Challenge 5: Lack of a long-term vision on how SportsHCI should be designed to for Social Impact	- Lack of understanding how to address the pandemic of physical inactivity through SportsHCI - Lack of evaluation criteria if a SportsHCI intervention improves physical literacy - Lack of understanding how to overcome barriers to sports access

表1：体育人机交互的五大挑战类别

挑战1：缺乏关于交互技术如何支持性能优化的知识	- 缺乏关于如何设计实时身体性能分析系统以提供教练和运动员反馈及意义建构的知识 - 缺乏针对运动表现纵向特性设计交互技术的知识 - 缺乏将生物力学整合到体育人机交互方法中的知识 - 缺乏在新型数字-物理练习中利用实时身体性能分析意义建构的知识
挑战2：缺乏理解如何为多方设计交互技术参与体育互动的各方	缺乏理解如何利用交互技术支持教练-运动员关系 -缺乏理解如何支持复杂关系运动员与观众之间通过交互技术互动 - 缺乏对如何设计面向运动员的挑战的理解
挑战3：缺乏关于如何为作为多面性个体的运动员设计交互技术的知识	- 缺乏关于如何对运动员建模以设计交互技术的知识 - 缺乏关于如何开发交互技术以支持运动员超越身体表现建议的知识 - 缺乏在设计体育人机交互技术时如何考虑个体非运动表现方面的知识
挑战4：缺乏关于如何将体育人机交互研究与设计引入真实体育世界的知识	- 缺乏关于如何在复杂动态的现实世界体育中验证体育人机交互技术的知识 - 缺乏对如何设计交互技术以支持日常生活中的体育体验方面的理解 - 缺乏对如何设计交互以处理多面性庞大体育数据的理解
挑战5：缺乏长期关于体育人机交互应如何以实现社会影响的设计	- 缺乏关于如何通过体育人机交互应对身体活动不足的流行病的理解 - 缺乏评估体育人机交互干预是否提升体育素养 - 缺乏对如何克服体育参与的障碍的理解