Grand Challenges in SportsHCI

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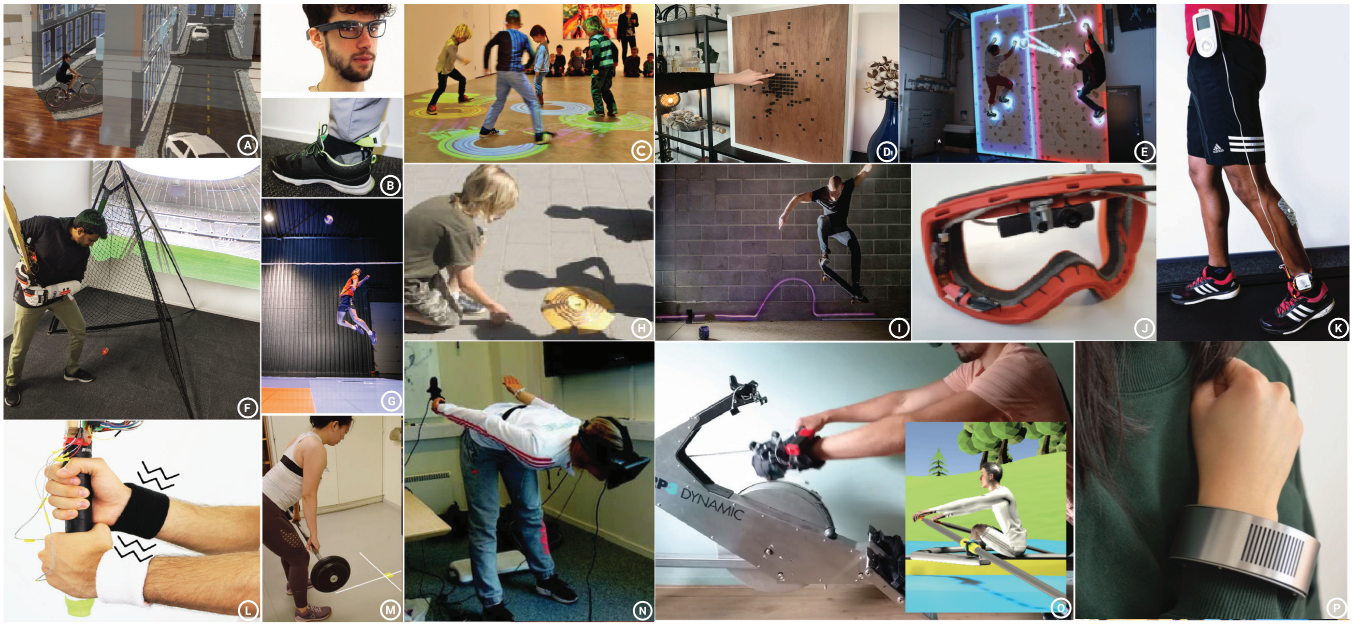

Figure 1: The image shows examples of SportsHCI systems a). BikeAR, AR bike training system to enhance safety [90] b). GymSoles, feedback system to improve posture in full-body exercises [37] c). Interactive tag playground, steering behaviour in terms of proxemics and movement [170] d). Laina, physicalizes 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 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 and discussion sessions. Examples include immersive analytics [40] and topics on food and sustainability [120], as well as broader HCI challenges [151].

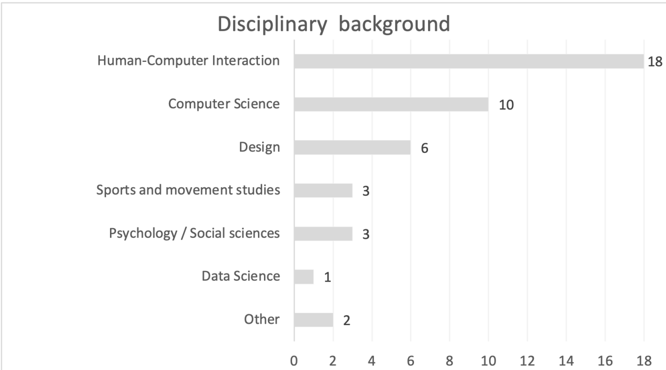

Figure 2: Disciplinary backgrounds of the workshop participants and their specific expertise in the SportsHCI domain.

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.

(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?

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

(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.

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

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

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.

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,

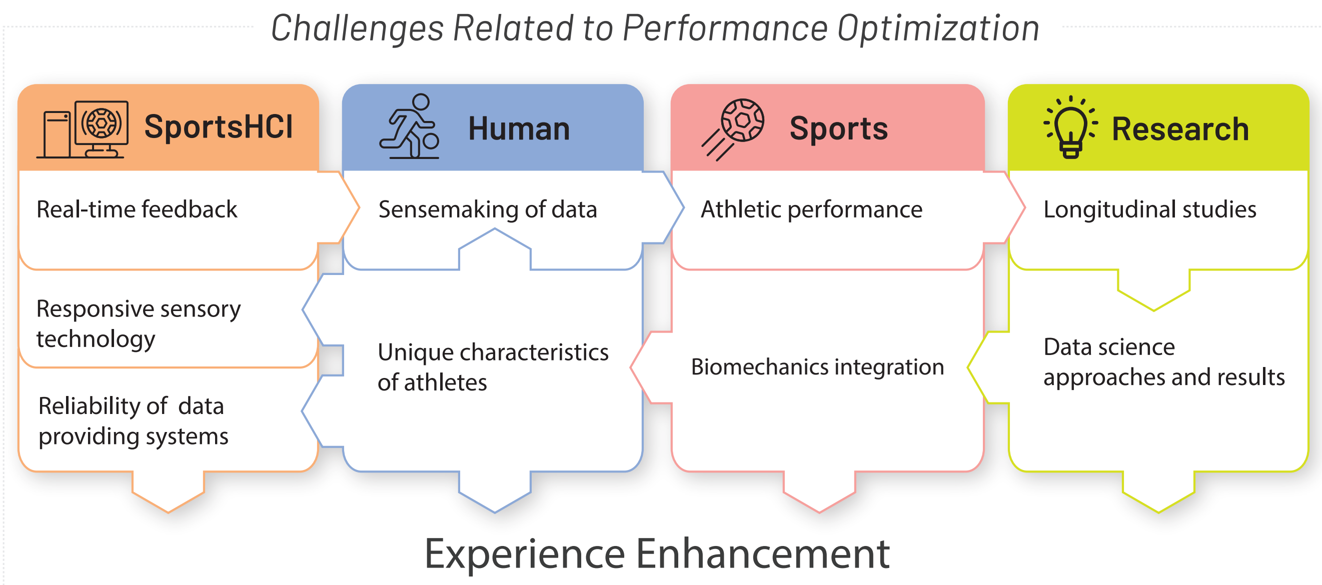

Figure 4: summarises how performance optimisation and analysis challenges arise from the interplay between SportsHCI and the human athlete doing their sports activities.

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.

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

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

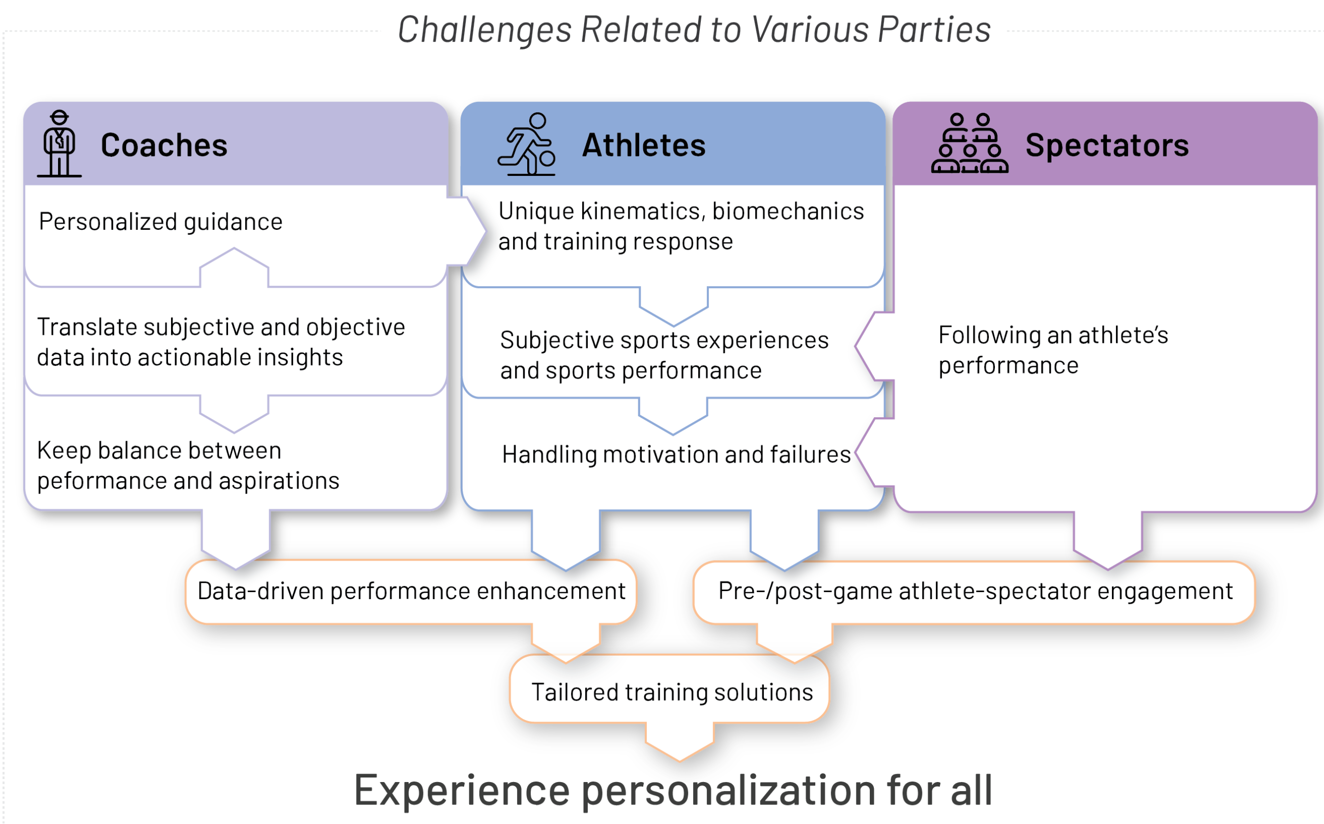

Figure 5: summarises the challenges related to the three main stakeholders and their interactions with SportsHCI, with each challenge having its own focus but cannot be seen fully independently from each other.

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 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].

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]. 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

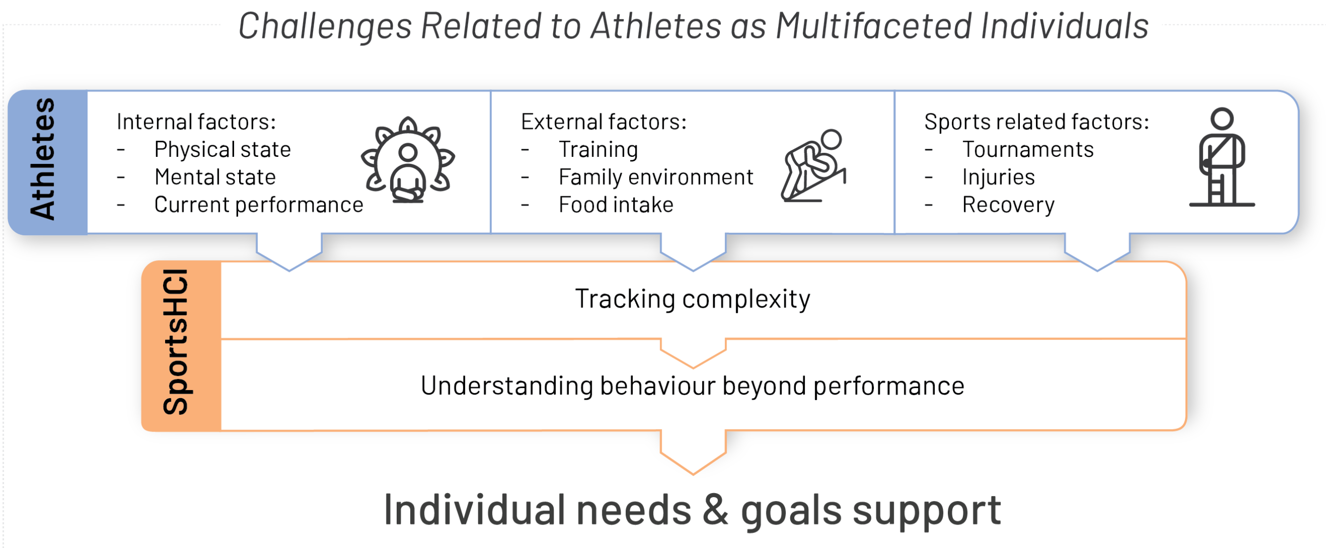

Figure 6: summarises the challenges related to athletes as multifaceted individuals. Individualised support needs to consider this wider perspective on athletes; modelling approaches must explicitly address the relationship between limited individual data and larger-scale generalised data on larger populations.

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.

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 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].

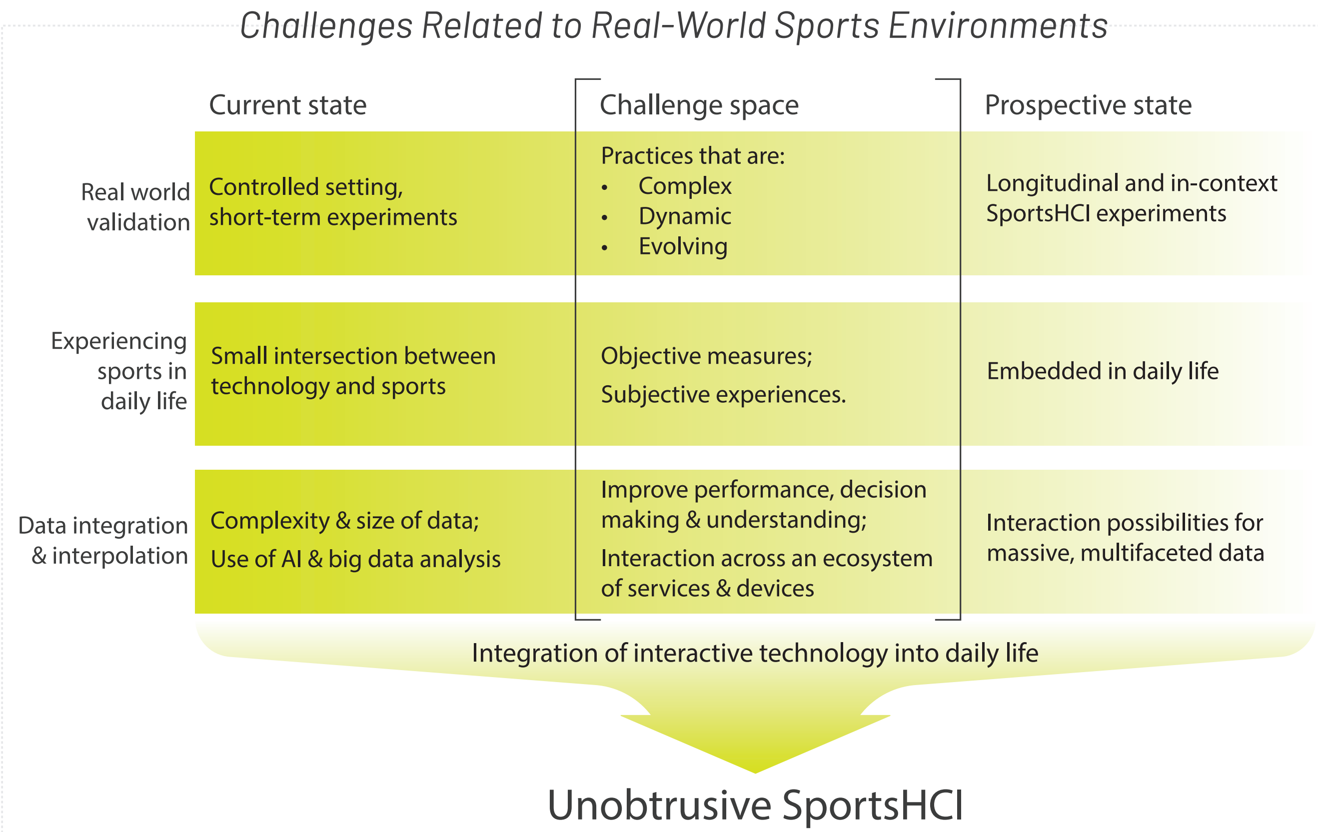

Figure 7: summarises the current and prospective states of three challenges relating to the lack of knowledge of how to take SportsHCI research and design into the real sporting world.

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 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

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

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.

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

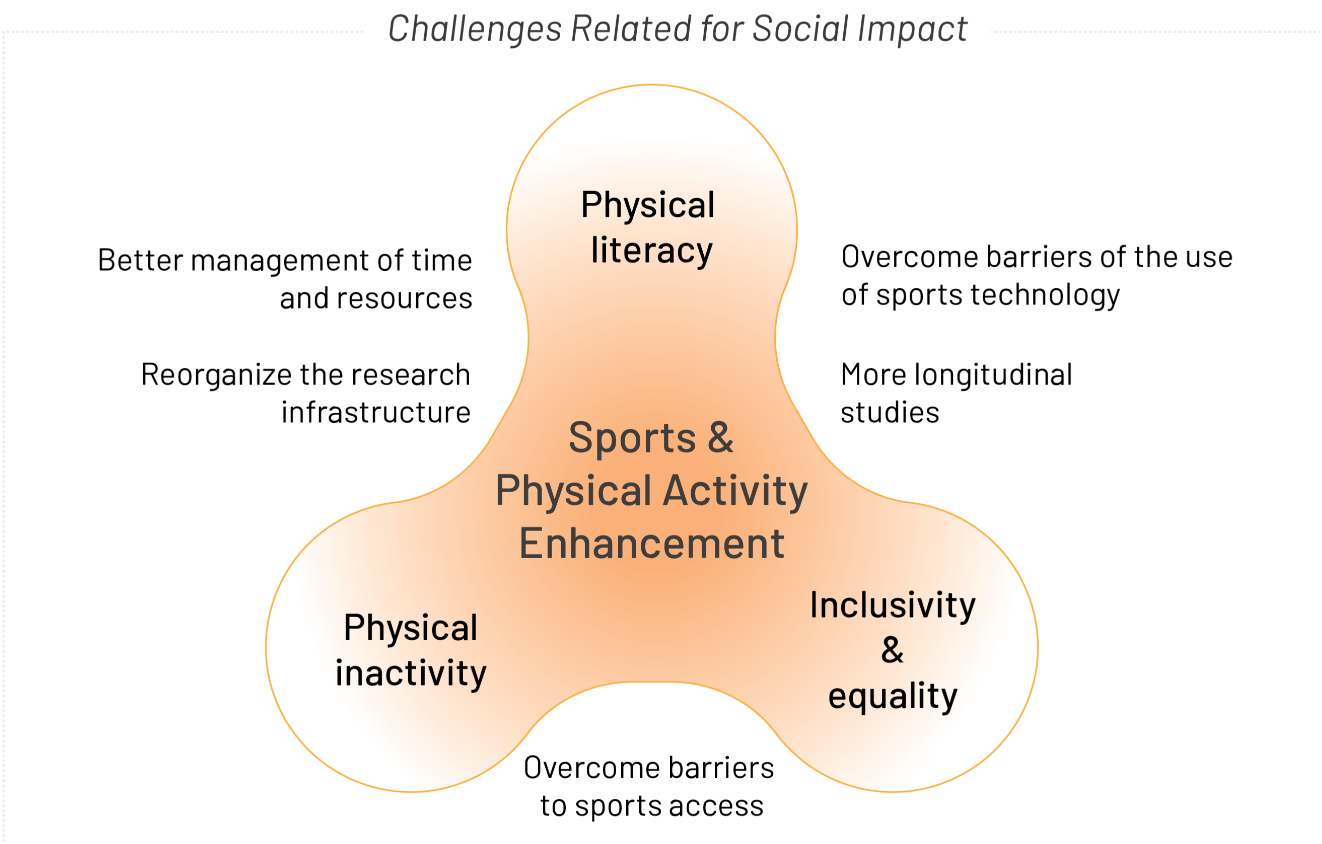

Figure 8: summarises the three challenges of the lack of vision on the design of SportsHCI for Social Impact and the points for action for SportsHCI.

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 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.

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. 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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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