The evolution of world-class endurance training: the scientist's view on current and future trends

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Abstract

Background: Elite sport is continuously evolving. World records keep falling and athletes from a longer list of countries are involved. **Purpose:** This commentary was designed to provide insights into present and future trends associated with world-class endurance training based on the perspectives, experience, and knowledge of an expert panel of 25 applied sports scientists. **Results**: The key drivers of development observed in the past 10-15 years were related to 1) more accessible scientific knowledge for coaches and athletes, combined with 2) better integration of practical and scientific exchange across multidisciplinary perspectives within professionalized elite athlete support structures, as well as 3) utilization of new technological advances. Based on these perspectives, we discerned and exemplified the main trends in the practice of endurance sports into the following categories: better understanding of sport-specific demands; improved competition execution; larger, more specific, and precise training loads; improved training quality; and a professionalized and healthier lifestyle. The main areas expected to drive future improvements were associated with more extensive use of advanced technology for monitoring and prescribing training and recovery, more precise use of environmental and nutritional interventions, better understanding of athlete-equipment interactions, and greater emphasis on preventing injuries and illnesses. **Conclusions:** These expert insights can serve as a platform and inspiration to develop new hypotheses and ideas, encourage future collaboration between researchers and sport practitioners and, perhaps most importantly, stimulate curiosity and further collaborative studies about the training, physiology, and performance of endurance athletes.

Key words: athlete health, endurance performance, sports technology, training intensity, training load, training quality.

Introduction

Elite sport is continuously evolving, as illustrated by world records being broken and the involvement of a greater diversity of countries and athletes, driving improvements in athletic performance. Explanations for this continued performance evolution are multifaceted, and likely include the optimization of athlete training and competitive periodization, as well as recent advancements in technologies, equipment, and scientific knowledge, all accessible to larger audiences. However, research on elite athletes is often constrained by underlying challenges, such as interruptions to coaching and training programs, as well as limitations in the type, quality or applicability of research studies that can be executed with elite performers. To gain complementary insight into current and future trends associated with world-class endurance training, this commentary is based on the perspectives, experience, and knowledge of an expert panel of applied sports scientists.

Methods

To capture key insights about the evolution of endurance training and performance, we solicited and aggregated expert judgements through a structured elicitation protocol. In the first step, two questions were posed by the first and last author to an expert panel of 25 acknowledged sport scientists (5 women and 20 men) with experiences of working closely with world-leading endurance athletes and coaches over the last decade(s). Collectively, this multinational panel had multidisciplinary (i.e., exercise physiology, biomechanics, sports analytics, nutrition, and sports medicine) experience of working with male and female athletes from 15 different nations and representing all Olympic endurance sports.

The two questions were: (1) *What are the most important trends related directly or indirectly to the training and improved performance of the world's best endurance athletes during the past 10-15 years?* and (2) *Which advances will contribute to further improving endurance performance during the next 10-15 years?* To allow diversity of opinion, all scientists were asked to prioritize three key points for each question individually, and to explain and exemplify their choices. Consent was given on the basis that replies could be used for the purpose of this commentary.

In the next steps, all responses were aggregated into initial thematic categories by the first and last author. Iterative refinement was undertaken by facilitated negotiation and discussion over e-mail among all authors, until final consensus on main categories, as well as representative examples and explanations was reached.

Recent and Contemporary Trends in Endurance Training

To address recent and contemporary trends, the answers to the first question were categorized into two dimensions: the underlying mechanisms driving the development (*the why*), and the effects of these factors on sport practices (*the what*).

A main driver of development in endurance training methods was more relevant scientific knowledge accessible to coaches and athletes, combined with better integration and exchange of practical and scientific knowledge. In this context, easier access to scientific and experienced-based knowledge through open-access journals, media (e.g., popular science articles, podcasts, Twitter, Instagram, YouTube, etc.) and various other communication channels (e.g., conferences/summits, webinars, workshops, personal conversations, etc.) has facilitated faster and wider learning and possibly more effective implementation into sport practice. Two potential challenges associated with effective utilization of publicly-available information are 1) the ability to filter useful versus less useful content, and 2) translation of this specific information into a holistic training process. This translation process will require close collaboration between athletes, coaches, and various domain experts.

Another main driver was the implementation of technological advances, with better equipment and more validated tools/wearables for monitoring and analyzing training, performance, and recovery. The sports science laboratory has moved out to the roads, tracks, pools, lakes, trails, rivers, and mountains, where endurance athletes train daily. A critical challenge in this context is to assure that the continuously collected data stream is as reliable and valid as possible.

Elite athlete health and performance support structures are now often organized in multidisciplinary centers or teams. This was regarded as a complementary factor facilitating effective implementation of the extended knowledge and new technological solutions into the holistic training, competition, and performance process. High-performance sports directors (or equivalent) and coaches are, in general, now more well-educated in coaching and/or sports science. In addition, they are more open to the potential benefits of multi- and intradisciplinary collaboration among athletes, coaches, scientists, and other experts.

Based on these driving factors, we discerned 5 important trends in the practice of endurance sports that have evolved over the last 10-15 years.

1) Better understanding of sport-specific demands

A more interdisciplinary and integrated understanding of physiological, technical, tactical, nutritional, and mental aspects underlying performance, on the basis of optimal mental and physical health, has evolved in sports.[1] For example, different exercise modes can elicit highly distinct metabolic, mechanical, and muscular loading, which can have significant consequences for training and recovery processes.[2] In this context, the technological possibility to measure performance, training load, and recovery under ecologically valid conditions, in combination with advanced performance modelling, has extended our understanding beyond the traditional performance-determining factors.[3] Examples of complementary concepts are the impact of resilience/durability during long-duration exercise,[4] or the implementation of various models describing aerobic and anaerobic kinetics during intermittent exercise. A better understanding of nutritional strategies has also played a significant role both for optimizing performance, and sustainable tolerance and execution of high daily training loads. This may

include optimal carbohydrate (CHO) intake (daily and during training and competition)[5] and associated nutritional periodization to meet the demands of the sport.[6,7]

2) Improved competition execution

More accurate technological measures of performance and advanced performance models have improved pacing strategies,[8] as well as the ability of each athlete (and their coaches) to identify and focus on his/her own individual strengths and weaknesses. Examples of this are the extensive use of various wearable devices, such as power meters, global positioning/navigation satellite systems (GPS/GNSS), and inertial movement units (IMUs) in many sports.[9, 10] With the combination of machine learning and domain competence, these developments have provided new insights in many sports, although the practical and ethical challenges of accumulating and processing large sets of personal data should also be acknowledged.

Without doubt, improved equipment has been vital for performance development in many endurance sports, with the clap skate in speed skating,[11] carbon fibre use in cycling, rowing, kayak and paralympic events, and "super-shoes" in running[12] being primary examples. Another factor is improved preparation strategies for competitions held in different environmental conditions such as altitude and the heat.[13] Furthermore, sport-specific and individualized nutritional intake during competitions (e.g., CHO intake and the use of various ergogenic aids)[5, 14-16] was highlighted by many of the respondents.

3) Larger, more specific, and precise training loads

Many of the scientists in the expert panel highlighted that world-leading endurance athletes now perform and tolerate higher training volumes than previously recorded. However, others had observed more precise and calculated training models, allowing a higher volume or density of competition-specific training. In both cases, the detection of individualized "sweet-spots" with respect to training volume and intensity, as well as individualized training intensity distribution and more detailed monitoring and analysis of capacity developments, were highlighted as success criteria. One of the trends observed by many of the scientists was more of the intense training being performed in a "controlled zone", thereby allowing higher volume and/or frequency of sessions at competition-relevant speeds.[17] However, the specific changes in training patterns, as well as the underlying mechanisms, need to be verified for different endurance sports.

The following aspects were highlighted as the main facilitators for athletes accumulating higher training volumes or competition-specific loads: shorter transition/recovery periods between the competition period and the following macrocycle, higher training loads both early in the training year and during the competition period, and more conscious periodization and load-recovery monitoring. Other key factors allowing more precise training loads included improved training facilities (e.g., better roller-ski tracks for cross-country skiers and biathletes, and more indoor tracks in cycling, athletics and speed skating), and improved equipment. In addition, more advanced injury prevention measures seem to provide better continuity of training.[18, 19]

More women worldwide now have the possibility to train and compete professionally in endurance sports, with a higher status of female competitions, more financial support, and better coaching available to female athletes. In addition, many sporting environments now possess greater awareness of and willingness to communicate about aspects of female physiology and health (e.g., the influence of the menstrual cycle ,[20, 21] hormonal contraception,[22] and pregnancy/post-partum[23-26]), and their potential impact on training and performance. With the increase in professional opportunities for female athletes, and an improved understanding of the specific challenges facing women in elite sport, larger, more specific, and/or precise training loads are particularly observed in female athletes.

Finally, several respondents highlighted that more systematic inclusion of environmental stressors, such as altitude[27] and heat[13], periodized in the training process has become more common, particularly when preparing for events held under challenging climatic conditions.

4) Improved training quality

Factors associated with improved training quality[28] were highlighted by many of the respondents. This list included both the quality of the holistic training process, performed in close cooperation between athletes, coaches and multidisciplinary support teams, as well as better planning, execution, and debriefing routines of single training sessions. One key factor for the latter dimension was more precise and disciplined intensity control, facilitated by greater awareness of how the variables of exercise prescription influence training tolerance and load, as well as better technologies to monitor these features in various conditions. Another example was use of better equipment in training, such as "super shoes" with new-age foams that allow for better cushioning and recovery, thereby facilitating more training at high speeds. Such developments may also contribute to narrowing the gap between training prescription and execution.

Improved training quality was also associated with more individualized training in terms of load prescription, micro-periodization, and daily session programming. For example, implementation of strength and power training based on individual profiling in relation to the physiological and technical requirements of each sport is now much more advanced in sport practice. Such individual profiling, in combination with systematic monitoring of training and testing, provides important objective information concerning how training is executed and the corresponding adaptations. In addition, the role of the coach and multidisciplinary support staff in using such information to prepare and debrief the athlete systematically, as well as how the support staff work synergistically with coaches and athletes,[29] were also highlighted as having a positive influence on training quality and performance.

5) A more professional and healthier lifestyle

Employing a more holistic approach to athlete development, by understanding and considering all factors influencing their lives, has benefited both individual and team-sport athletes.[30]

Greater professionalization of many sports has enabled athletes to pursue a full-time athletic career, which can create a healthier lifestyle through enhanced recovery. More knowledge and greater awareness of injury prevention and health management strategies are argued as important for facilitating the continuity and sustainability of training, as well as prolonging the careers of elite athletes.[18] For example, greater knowledge and awareness of the importance of energy availability, periodized and individualized nutrition, and sleep have contributed to improved recovery.[31] The same paradigm applies to the inclusion of systematic monitoring of recovery parameters such as resting heart rate, heart rate variability, and sleep metrics as part of the monitoring systems. In addition, greater focus on the mental health of athletes[32] and coaches[33] was regarded as imperative.

Future Trends in Endurance Training

The expert panel generally expected the factors underpinning improved endurance training and performance to continue to evolve in the upcoming 10-15 years. However, some perennial aspects of endurance training received particular attention, and a few new aspects were highlighted as key areas for improvement in the future.

First, more extensive and reliable use of advanced technology for evidence-based monitoring of training, recovery, and performance is expected. Importantly, these technologies and the insights they provide must be combined in a holistic, sport-specific, and integrated fashion with the individual athlete´s own developmental needs. This approach will likely allow more effective individualization of training. In this context, artificial intelligence (AI) and its associated opportunities are evolving very quickly and may permit individualized prescription of training; for example, when combined with innovative, non-invasive technologies assessing muscle fibre types and other important individual physiological characteristics. As part of this process, more detailed knowledge about how to precisely use combinations of training loads, environmental stressors and nutritional interventions to optimize physiological adaptations and performance is expected. Furthermore, a more advanced understanding of athlete-equipment interactions leading to greater tolerance of sport-specific training and improved performance is also suggested as a future trend.

A greater emphasis on the prevention of health problems[34] will allow more athletes to train with continuity over longer durations and this is clearly an area with further possibilities for improvement. A greater focus on female athletes also creates opportunities for future improvement,[35] especially given the historical lack of knowledge and support that has likely limited performance development and career longevity in this population. Programs designed to prevent injuries, illnesses, Relative Energy Deficiency in Sport (REDs) and/or eating disorders and other unhealthy behaviours need to be customized, fine-tuned and implemented broadly. Aspects relating to the preservation of mental health are also expected to receive more attention over the coming years. Overall, a more comprehensive approach to optimizing and maintaining good athlete health should permit more athletes to attain their full potential.

Finally, the continuous development and adjustment of sport science curriculums within universities and federations in many countries will translate to improved scientific knowledge among coaches, athletes, and practitioners, facilitating greater transfer of knowledge within and between multidisciplinary teams.

Practical Applications and Conclusions

From the perspective of an expert panel of 25 applied sport scientists, this commentary has facilitated the sharing of ideas, experience and knowledge between individuals involved in a variety of endurance sports, research areas, and athletic communities. These insights are summarized in Table 1 and can serve as a platform and inspiration for developing new hypotheses, encourage future collaboration between researchers and sport practitioners and, perhaps most importantly, stimulate curiosity and fruitful collaborative studies about the training, physiology, health, and performance of endurance athletes. It would be highly enlightening to pose these same questions to elite-level athletes, coaches and support staff within different sports and nations. Although most of the content in this commentary should be relevant both for Olympic and Paralympic endurance sports, the evolution of para-specific aspects should be further explored in upcoming studies.

Include Table 1 around here

Conflicts of interest statement

The first author of this commentary is the Editor-in-Chief of the *International Journal of Sports Physiology and Performance*, and several of the authors are associate editors or editorial board members in the journal. Paul Laursen is co-founder of HIIT Science Inc and Athletica Inc. The possibility of publication-bias was discussed critically and evaluated among editors, and none of the authors, including those with editorial roles, had the opportunity to influence the independent review process.

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Table 1. Summary of the present and future trends associated with world-class endurance training based on the perspectives, experience, and knowledge of an expert panel of 25 applied sports scientists.

Key drivers of development observed in the past 10-15 years	Main trends in the practice of endurance sports in the past 10-15 years	The main areas expected to drive future improvements
• More accessible scientific knowledge for coaches and athletes • Better integration of practical and scientific exchange across multidisciplinary perspectives within professionalized elite athlete support structures • Utilization of new technological advances	• Better understanding of sport-specific demands • Improved competition execution • Larger, more specific, and precise training loads • Improved training quality • A professionalized and healthier lifestyle	• More extensive use of advanced technology for monitoring and prescribing training and recovery • More precise use of heat and altitude interventions, and nutritional interventions • Better understanding of athlete-equipment interactions • Greater emphasis on preventing injuries and illnesses