New Opportunities to Advance Sport Nutrition

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Abstract

Sports nutrition is a relatively new discipline; with ~100 published papers/year in the 1990s to ~3,500+ papers/year today. Historically, sports nutrition research was primarily initiated by university-based exercise physiologists who developed new methodologies that could be impacted by nutrition interventions (e.g., carbohydrate/fat oxidation by whole body calorimetry and muscle glycogen by muscle biopsies). Application of these methods in seminal studies helped develop current sports nutrition guidelines as compiled in several expert consensus statements. Despite this wealth of knowledge, a limitation of the current evidence is the lack of appropriate intervention studies (e.g., randomized controlled clinical trials) in elite athlete populations that are ecologically valid (e.g., in real-life training and competition settings). Over the last decade, there has been an explosion of sports science technologies, methodologies and innovations. Some of these recent advances are field-based, thus providing the opportunity to accelerate the application of ecologically valid personalized sports nutrition interventions. Conversely, the acceleration of novel technologies and commercial solutions, especially in the field of biotechnology and software/app development, has far outstripped the scientific communities' ability to validate the effectiveness and utility of the vast majority of these new commercial technologies. This mini-review will highlight historical and present innovations with particular focus on technological innovations in sports nutrition that are expected to advance the field into the future. Indeed, the development and sharing of more "big data", integrating field-based measurements, resulting in more ecologically valid evidence for efficacy and personalized prescriptions, are all future key opportunities to further advance the field of sports nutrition.

Introduction

Innovation has always been at the forefront of sport. Recent examples include drafting in cycling, clap skates in speed skating and more recently, carbon plate shoes in running. Sports nutrition is a relatively young discipline with less than 100 scientific papers published per year in the early 1990s, to about 3,500 per year today and a myriad of books (**Figure 1**). Much of this progress was brought about by exercise physiologists who developed new methods and technologies within their laboratories (e.g., treadmills and ergometers) at universities around the world to study trained athletes (e.g., distance runners and cyclists) (2). Next to sports science, these developments promoted the emergence of another new discipline, that of sports nutrition. Some of the major innovations and corresponding knowledge milestones for sports nutrition research, combined with sports science research, are summarized in **Figure 2**.

In 2003 the International Olympic Committee (IOC) working group on sports nutrition concluded "The amount, composition and timing of food intake can profoundly affect sports performance. Good nutritional practice will help athletes train hard, recover quickly and adapt more effectively with less risk of illness and injury" (3). Nearing two decades later and these recommendations remain as pertinent. Despite all this progress, excitement and scientific endeavour, the ability to determine the impact of sports nutrition for different groups of athletes (e.g., different sports, ethnic groups, sex) is still elusive. For example, there is substantial evidence for carbohydrate (CHO) ingestion before, during and after exercise (4,5). However, it is difficult to separate the performance benefits of CHO ingestion *per se* versus all other variables during competition (e.g., environment, competition, technology, equipment, and psychology).

Failure to establish the impact of any sports and exercise science intervention may result in a decline in recognition of the disciplines role in supporting the health and performance of athletes. This applies not only to the elite performers but also the young athlete, the exercising public and the elderly. Therefore, this mini-review will focus on the opportunities to accelerate knowledge and practice of sports nutrition via the integration of technological innovations. We first highlight the present knowledge then propose ways of integrating technical advances and personalized prescription. Particular reference will be given to personalised prescriptions that are transforming and modernising other life sciences.

The present

Although we primarily think of innovation in sports nutrition as directed at athlete performance outcomes, we also need to be innovative in our methods of synthesizing and dispersing research. The sports nutrition research data generated to date, have been compiled in several consensus documents on general sports (6), team sports (7) and dietary supplements (8). However, a limitation of the current evidence base informing all sport science and sports medicine consensus guidelines is the lack of appropriate intervention studies (e.g., randomized controlled clinical trials) in elite populations (9) that are ecologically valid (e.g., in real-life training and competition settings). Furthermore, often in practice, sports nutrition recommendations are retrospective fitted to sports in which the original research was not completed. For example much of the research to inform "stop-and-go" type sports has primarily been completed in soccer (10). In addition, a recent audit has identified that across 1,826 nutrition ergogenic supplement studies (featuring 34,889 participants) only 23% of the participants were women, and only 3 studies (0.5%) implemented "gold-standard" female specific research methods (11); yet most ergogenic aid guidelines are "assumed" to be ideal for females as well. Furthermore, in the last 5 years, the focus has shifted from original research to reviews in the area of sports nutrition. Of the published articles, between 17.6-20.2% have been reviews (512-570), of which 4.4-6.0 meta-analyses (128-223). Some of this focus on reviews of all types rather than original research is enforced due to restrictions imposed due to Covid-19. However, there is a continuing need for original research in order to advance the discipline.

Consensus meetings and subsequent statements are fundamental in the generation of expert driven guidelines. Over the past 5 years, consensus statements in Sports Nutrition ranged between 0.3-0.5% (10-18) of the published articles. Historically, consensus statements, such as the International Olympic Committee (IOC) consensus on sports supplements (8) are drafted following in-person meetings of leading medical and scientific content experts. However, it is appreciated that such meetings can be costly in terms of budget, time and the carbon footprint of travel. More recently, major consensus statements have implemented remote online approaches, including the entire 2019 World Athletics (formerly IAAF) Nutrition for Athletics Consensus Update (featuring over 40 authors across 17 papers, e.g., 12). A remote consensus approach provides the opportunity to involve a wider contribution on topic guidelines rather than fewer selected opinion leaders. Establishing online working communication platforms as well as documents may also allow consensus documents to be updated with greater frequently or at pace with current literature. In summary, consensus statements informed by original research and meta-analyses, will require a greater reliance on new digital based approaches, while also respecting the need for in person meetings amongst experts.

Integrating technical advances to field-based metrics

Most paradigms in sports nutrition have been established using laboratory experimentation, while neglecting evidence from *in situ* or field experimentation. This results in studies with limited ecological validity. In order to establish the efficacy of nutrition parameters for performance enhancement for all relevant populations, we need to better understand the competition demands of sport (13). Recent advances in wearable technologies and real-time monitoring have accelerated the shift in research from the laboratory to the field in order to enhance ecological validity. This trend poses a real opportunity for all sport science disciplines, including sports nutrition, to embrace these technological developments. One such recent example was the implementation of live performance feedback of athletes (during 10,000m, marathon and race-walk events) competing in the heat at Tokyo 2020 (14). Briefly, the aim of implementing this wireless technology during Tokyo Olympic Games was to help characterise the physiological and thermal strain experienced by athletes, as well as determine future management of athletes during a medical emergency as a result of a more timely and accurate diagnosis. The real-time monitoring comprised a smartwatch application, designed to collect, process and transmit a wide range of physiological, biomechanical, bioenergetic and environmental data. This project was a success in terms of technological innovation but also general acceptance by athletes and sport's governing bodies. Such projects provide the opportunity for other new and valid sensors to assess performance- and health-related parameters particularly relevant to sports nutrition. One example is microfluidic technologies integrated into wearable patches to provide athletes instant feedback on sweat rate and sweat composition (15). Wider adoption of such technologies will create more symbiotic relationships between sport, health and technology by harnessing the unique demands of elite sport (e.g., the need for unobtrusive devices that provide real-time feedback).

Given their symbiotic relationship, the evolution of sports nutrition and sports science requires more holistic approaches with input from all major disciplines (e.g., coaching science, environmental physiology, sports biomechanics), stakeholders, sponsors and interested industry (16). In recent years, physiology, nutrition, and technical advances have become increasingly integrated as part of new sport performance innovation strategies. A pertinent example is the Sub2 marathon project which was a novel proof-of-concept idea motivated by the need to focus on a holistic approach whilst promoting clean sport (i.e., high performance marathon running without doping)(16). This was the first dedicated international research initiative launched in

2014 made up of multidisciplinary scientists from academia, elite athletes and strategic industry partners across many sport science and medicine domains. An exciting Sub2 innovation with particular sports nutrition focus was the carbohydrate “hydrogel” development. This innovative concept in sports drinks was tested in elite athletes training in Ethiopia and Kenya. The novel aspect of the gel was that it allowed runners to ingest and tolerate CHO concentrations much higher than would normally be possible to ingest while running (e.g., 30% CHO) (17). This was important because a common challenge for runners is to meet CHO ingestion guidelines without experiencing gastrointestinal complaints (18). This sports drink was subsequently trialled and tested in the field with positive response by elite runners during marathons and cyclists in the tour de France (19). One laboratory-based study has confirmed improved running performance, greater carbohydrate oxidation and lower GI symptoms following hydrogel ingestion compared with a standard CHO solution (20). However, other laboratory-based studies have not reported any of these advantages following hydrogel ingestion compared to the ingestion of carbohydrate-electrolyte sport beverages (21-23). Nevertheless, it is a great example of sports nutrition innovation specific to the needs of the sport in the field. The hydrogel innovation was adopted by both the breaking 2 (24-25) and INEOS 159 (26) projects to break the 2-hour marathon barrier, a reflection of the perceived value of this putative innovation.

Combining emerging technologies are ideal to better our understanding of performance and to objectively test the impact of nutritional strategies in laboratory or real performance environments (Table 1). Such innovations will also allow other sports, beyond the mainly studied endurance sports cycling and running, to be evaluated in terms of sports nutrition impact. The utilisation of these technologies, and co-ordinated research, may allow for the rapid generation of large data sets across many other types of sport that have yet to be included in sports nutrition research. As such, this approach will i) speed our knowledge of sports that are difficult to study, ii) gain data from regional populations under-represented in the literature, and

iii) inform the advice of how specific nutrition guidelines maybe transferred to the field. Accordingly, Table 1 highlights examples of existing and emerging technologies and methodologies that are "field-based" and relatively non-invasive that may continue to drive and refine sports nutrition research, interventions and recommendations.

The wearable/technological revolution promises in the near future to improve the ability to monitor a whole range of physiological parameters in the field. For example, apps, devices and entire ecosystems are being developed and destined to improve the quality of dietary intake methods and therefore the accurately of athletes' daily energy intake (EI) (27). These technological developments may enable the energy availability (EA) of individual athletes (i.e., calculated as EI – EEE/fat free mass) to be more accurately monitored. Correspondingly, a more comprehensively study of the athlete *in situ* would be possible. Thus, this approach represents an unprecedented opportunity to mitigate many unresolved issues in the field of sports nutrition such as relative energy deficiency in sport (RED-S) (28). Importantly, the recent explosion of wearable technology/apps/devices with often unsubstantiated claims require quality assurance standards for wearable devices. Such concerns have prompted the International Federation of Sports Medicine (FIMS) to create a global standard for wearable devices in sport and fitness (29-30). Organisations involved in sports nutrition also have the opportunity to engage in quality assurance processes to safeguard the credibility of the innovations in sports nutrition.

Personalised prescriptions

There is no such thing as an "average" athlete. However, a key question is if there is an added value of personalised nutrition versus general guidelines? Importantly, technology innovations will allow the individual response to a sports nutrition intervention to be determined. For instance, to find the individual recommendation of carbohydrate and fluid during exercise, we need knowledge about the energy demands of the sport, sweat losses, gastrointestinal limits, personal taste preferences and every element of the event. This needs to include research on different sport categories and target groups. This also presents the opportunity to follow athletes over a longer period of time, without associated human labour or time costs. For instance, to establish the extent to which an individual responds to different nutritional interventions, we need to conduct repeated testing in the same individual on several occasions. And the more complex the sport and its environment, the more test repetitions may be needed to establish the magnitude of impact of an intervention. It is also imperative that we determine athlete compliance with prescribed nutritional interventions. Such data will allow the evaluation of education and behaviour change strategies, which may also provide opportunity for personalisation.

The research on personalized sports nutrition will undoubtedly be the focus in the near future due to the technological advances in genomics technologies such as genetic sequencing. For instance, is has been suggested that the impact of DNA sequencing will become on a par with that of the microscope (31). Sports nutrition and sports science are encouraged to use these powerful technologies and to keep up with rapid developments to increase the chances of finding the best solutions possible. Such technologies are routinely used in biomedical research and precision medicine applications, such as for cancer, stroke and Alzheimer's disease, thus vital lessons can be learned and transferred to sports nutrition. However, it is essential that these technological developments are not "oversold" and that their application in the field is founded on evidence-based research and not driven by commercial interests. At present, the use of genetic testing in both sports nutrition and sports science is at a very early stage. The consensus in the scientific literature being that genetic testing in sport science has very low clinical utility and should not be sold (32-33). This is in contrast to the ever-increasing number of companies selling genetic testing, supported by unfounded claims (32, 34-35). The market value of genetic testing; USD 10.80 Billion in 2020, is forecast to reach USD 23.14 Billion by 2027 (36).

A more precision-based sports nutrition will also need to consider the other components of the "omics" cascade in addition to genomics (e.g., transcriptomics, metabolomics, proteomics, single cell sequencing). Furthermore, such approaches may utilise powerful bioinformatics methods, such as machine learning and artificial intelligence to integrate the different layers of biological data required for understanding the functional consequences with the real time assessment of the "phenome" using 5G and 6G, sensors, devices and applications (37). The identification of relevant non-invasive biomarkers are attractive to athletes and practitioners, due to the speed and increased frequency of collection versus traditional blood draws or questionnaires. However, these technologies should be adopted in accordance with ethical principles and within national/international regulatory frameworks, which require further development.

New approaches to fulfil knowledge gaps

Given recent technological breakthroughs, there are exciting opportunities for sports nutrition research to take gigantic leaps in the near future. Until now, most sports nutrition and sports physiology studies are performed in controlled laboratory environments and often study the effect of single nutrients. There is opportunity for sports nutrition research to embrace real world settings using real solutions and a more holistic approaches, such as performance benefits of whole foods, whole-body effects of low EA and "targeted nutritional periodisation". One example is a study using tracer technologies to compare the effect of whole eggs vs egg whites on post exercise muscle protein synthesis (38). New study designs should focus on real life settings that are strictly monitored with use of new technological advances, apps and systems. As such, with a clear overview of nutritional demands of the sport and individual factors of impact, the extent of real-life effects of sports nutrition elements can be established.

Beyond the physiological impact of nutrients, there is also opportunity for sports nutrition research to study of cognitive and mental performance (39). This shift will require sports nutrition researchers and nutritionists to adopt and further develop technological methods to allow the psychobiological determinants of performance to better defined. New research paradigms and technologies could revolutionise sports nutrition research from small landmark studies of the 1960s with mainly the authors as subjects taking muscle biopsies on themselves (40), to the use of big data and collaboration between large groups of researchers. Examples of the latter are studies identifying genes implicated in hand grip strength involving over 195,000 subjects (41) or investigating the effects of age, body composition, and sex on total expenditure by the doubly labelled water method in 6,421 participants from 29 countries (42). The field of sports nutrition has the opportunity to adopt such collaborative practices combined with the application of the new and established technologies (see Table 1). It is reasonable to suggest that this approach will inevitably become the mainstay of personalised medicine, where treating the individual will be the norm rather than the average. If sports nutrition can embrace these challenges, it will thrive as an essential discipline and its relevance recognised in other fields (43).

Limitations/perspectives

While innovations are necessary and appealing, there needs to be a considered approach to implementation. Soon almost any parameter will be able to be measured or inferred, yet the use of such data especially during live performances remains to be explored. There also seems to be a trend towards 24/7 observations (e.g., Apple watch, Oura ring, WHOOP, Biostrap). Caution is encouraged when moving from too little or no assessment to over monitored and scheduled, as a result of too much feedback and reliance on devices. For instance, the athlete should be focussing on racing/competition, not on heart rate or temperature or non-validated feedback directly from a device. Tracking may also be potentially stressful (44), albeit this remains to be determined in athlete populations. When evolving sports nutrition research with new technological advances, it is important to continuously question the application to practice as well as the reliability and reliance of devices.

Conclusions

Innovation is at the core of sports nutrition research and has pushed the field forward even before sports nutrition was recognized as a separate discipline. We are at a critical juncture in the evolution of this discipline primed to utilize new technologies to support the success of specific sports and individual athletes. Sharing data in new and more efficient ways, integrating field based physiological measures, and personalized prescriptions are key opportunities to advance sports nutrition. However, technological advances should not be used in haste and must first be evaluated to determine their functionality and value to the athletes health and performance.

Conflict of interests

IR and MK are employees of the Gatorade Sports Science Institute, a division of PepsiCo, Inc. The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc. Authors KJ, TS and YP, received speaking honoraria, for the GSSI ECSS 2021 pre-conference symposium which inspired this article. YP is the founding member of the Sub2 project (www.sub2hrs.com). The Sub2 project is affiliated to a non-trading company (Athlome Limited, UK) that is minor (<1.1%) shareholder of Maurten AB, Gothenburg, Sweden.

Figure and table legends

Figure 1. Publications in Pubmed using the search term “Sports Nutrition” as of December, 2021 (1).

Figure 2. Timeline of key innovations in Sports Nutrition and their respective influence on the field. *Including: genomics, transcriptomics, metabolomics, proteomics, phenomics, and other related omics (e.g., epigenomics).

Table 1. Examples of existing or potential "in field" non-invasive technologies or methodologies that may drive current or future nutrition studies, interventions and/or recommendations. Note: Some identified technologies / methodologies continue to have construct validity challenges and require further research validation.

References

1. https://pubmed.ncbi.nlm.nih.gov/?term=sports+nutrition&filter=years.1946-2021&timeline=expanded&sort=date&sort_order=asc
2. Hawley JA, Maughan RJ, Hargreaves M. Exercise Metabolism: Historical Perspective. Cell Metab. 2015 Jul 7;22(1):12-7.
3. IOC Consensus Statement on Sports Nutrition 2003. J Sports Sci. 2004 Jan;22(1):x. https://stillmed.olympic.org/Documents/Commissions_PDFfiles/Medical_commission/IOC_CONSENSUS_STATEMENT_ON_SPORTS_NUTRITION_2003.pdf
4. Burke LM, Hawley JA, Wong SHS, Jeukendrup AE. Carbohydrates for training and competition. J Sports Sci. 2011;29 Suppl 1:S17-27.
5. Stellingwerff T, Cox GR. Systematic review: Carbohydrate supplementation on exercise performance or capacity of varying durations. Appl Physiol Nutr Metab. 2014 Sep;39(9):998-1011.
6. Thomas DT, Erdman KA, Burke LM. American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. Med Sci Sports Exerc. 2016 Mar;48(3):543-68.
7. Collins J, Maughan RJ, Gleeson M, Bilsborough J, Jeukendrup A, Morton JP, Phillips SM, Armstrong L, Burke LM, Close GL, Larson-Meyer E, Louis J, Medina D, Meyer F, Rollo I, Sundgot-Borgen J, Wall BT, Boullosa B, Dupont G, Lizarraga A, Res P, Bizzini M, Castagna C, Cowie CM, D'Hooghe M, Geyer H, Meyer T, Papadimitriou N, Vouillamoz, McCall A. UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. Br J Sports Med. 2021 Apr;55(8):416.
8. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer DE, Peeling P, Phillips SM, Rawson ES, Walsh NP, Garthe I, Geyer H, Meeusen R, van Loon LJC, Shirreffs SM, Spriet LL,

Stuart M, Vernec A, Currell K, Ali VM, Budgett RG, Ljungqvist A, Mountjoy M, Pitsiladis YP, Soligard T, Erdener U, Engebretsen L. IOC consensus statement: dietary supplements and the high-performance athlete. Br J Sports Med. 2018 Apr;52(7):439-455.

9. McKay AKA, Stellingwerff T, Smith ES, Martin DT, Mujika I, Goosey-Tolfrey VL, Sheppard J, Burke LM. Defining Training and Performance Calibre: A Participant Classification Framework. IJSPP 2022 – ref to be published.
10. Williams C, Rollo I. Carbohydrate Nutrition and Team Sport Performance. Sports Med. 2015 Nov;45 Suppl 1(Suppl 1):S13-22. doi: 10.1007/s40279-015-0399-3. PMID: 26553494; PMCID: PMC4672015.
11. Smith ES, McKay AKA, Kuikman M, Ackerman KE, Harris R, Elliott-Sale KJ, Stellingwerff T, Burke LM. Auditing the representation of female versus male athletes in sports science and sports medicine research: evidence-based performance supplements, a narrative review. BJSM 2022 – ref to be published.
12. Burke LM, Castell LM, Casa DJ, Close GL, Costa RJS, Desbrow B, Halson SL, Lis DM, Melin AK, Peeling P, Saunders PU, Slater GJ, Sygo J, Witard OC, Bermon S, Stellingwerff T. International Association of Athletics Federations Consensus Statement 2019: Nutrition for Athletics. Int J Sport Nutr Exerc Metab. 2019 Mar 1;29(2):73-84. doi: 10.1123/ijsnem.2019-0065. Epub 2019 Apr 5. PMID: 30952204.
13. Stellingwerff T, Morton JP, Burke LM. A Framework for Periodized Nutrition for Athletics. Int J Sport Nutr Exerc Metab. 2019 Mar 1;29(2):141-151.
14. Muniz-Pardos B, Angeloudis K, Guppy FM, Keramitsoglou I, Sutehall S, Bosch A, Tanisawa K, Hosokawa Y, Ash GI, Schobersberger W, Kliniken T, Grundstein AJ, Casa DJ, Morrissey MC, Yamasawa F, Zelenkova I, Racinais S, Pitsiladis Y. Wearable and

telemedicine innovations for Olympic events and elite sport. J Sports Med Phys Fitness. 2021 Aug;61(8):1061-1072.

15. Baker LB, Model JB, Barnes KA, Anderson ML, Lee SP, Lee KA, Brown SD, Reimel AJ, Roberts TJ, Nuccio RP, Bonsignore JL, Ungaro CT, Carter JM, Li W, Seib MS, Reeder JT, Aranyosi AJ, Rogers JA, Ghaffari R. Skin-interfaced microfluidic system with personalized sweating rate and sweat chloride analytics for sports science applications. Sci Adv. 2020 Dec 11;6(50):eabe3929.
16. Pitsiladis Y, Ferriani I, Geistlinger M, de Hon O, Bosch A, Pigozzi F. A Holistic Antidoping Approach for a Fairer Future for Sport. Curr Sports Med Rep. 2017 vol. 16,4: 222-224.
17. Sutehall S, Muniz-Pardos B, Bosch A, Di Gianfrancesco A, Pitsiladis Y. Sports Drinks on the Edge of a New Era. Current Sports Medicine Reports. 2018 17(4):112-116.
18. Jeukendrup, Asker E. “Training the Gut for Athletes.” Sports medicine (Auckland, N.Z.) vol. 47,Suppl 1 (2017): 101-110. doi:10.1007/s40279-017-0690-6
19. Sutehall S, Galloway SDR, Bosch A, Pitsiladis Y. Addition of an alginate hydrogel to a carbohydrate beverage enhances gastric emptying. Medicine & Science in Sports & Exercise. 2020 Aug 52;8:1785-1792.
20. Rowe JT, King RFGJ, King AJ, Morrison DJ, Preston T, Wilson OJ, O'Hara JP. Glucose and Fructose Hydrogel Enhances Running Performance, Exogenous Carbohydrate Oxidation, and Gastrointestinal Tolerance. Med Sci Sports Exerc. 2022 Jan 1;54(1):129-140. doi: 10.1249/MSS.0000000000002764. PMID: 34334720.
21. King AJ, Rowe JT, Burke LM. Carbohydrate Hydrogel Products Do Not Improve Performance or Gastrointestinal Distress During Moderate-Intensity Endurance Exercise. Int J Sport Nutr Exerc Metab. 2020 Jul 23;30(5):305-314.

22. Baur DA, Toney HR, Saunders MJ, Baur KG, Luden ND, Womack CJ. Carbohydrate hydrogel beverage provides no additional cycling performance benefit versus carbohydrate alone. Eur J Appl Physiol. 2019 Dec;119(11-12):2599-2608.

23. McCubbin AJ, Zhu A, Gaskell SK, Costa RJS. Hydrogel Carbohydrate-Electrolyte Beverage Does Not Improve Glucose Availability, Substrate Oxidation, Gastrointestinal Symptoms or Exercise Performance, Compared With a Concentration and Nutrient-Matched Placebo. Int J Sport Nutr Exerc Metab. 2020 Jan 1;30(1):25

24. www.runnersworld.com/uk/news/a29100149/breaking2

25. www.nike.com/gb/running/breaking2

26. www.ineos159challenge.com

27. Ferrara G, Kim J, Lin S, Hua J, Seto E. A Focused Review of Smartphone Diet-Tracking Apps: Usability, Functionality, Coherence With Behavior Change Theory, and Comparative Validity of Nutrient Intake and Energy Estimates. JMIR Mhealth Uhealth. 2019;7(5):e9232. Published 2019 May 17. doi:10.2196/mhealth.9232

28. Mountjoy M, Sundgot-Borgen JK, Burke LM, Ackerman KE, Blauwet C, Constantini N, Lebrun C, Lundy B, Melin AK, Meyer NL, Sherman RT, Tenforde AS, Klungland Torstveit M, Budgett R. IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. Br J Sports Med. 2018 Jun;52(11):687-697.

29. Ash GI, Stults-Kolehmainen M, Busa MA, Gregory R, Garber CE, Liu J, Gerstein M, Casajus JA, Gonzalez-Aguero A, Constantinou D, Geistlinger M, Guppy FM, Pigozzi F, Pitsiladis YP. Establishing a Global Standard for Wearable Devices in Sport and Fitness: Perspectives from the New England Chapter of the American College of Sports Medicine Members. Curr Sports Med Rep. 2020 Feb;19(2):45-49.

30. Ash GI, Stults-Kolehmainen M, Busa MA, Gaffey AE, Angeloudis K, Muniz-Pardos B, Gregory R, Huggins RA, Redeker NS, Weinzimer SA, Grieco LA, Lyden K, Megally E,

Vogiatzis I, Scher L, Zhu X, Baker JS, Brandt C, Businelle MS, Fucito LM, Griggs S, Jarrin R, Mortazavi BJ, Prioleau T, Roberts W, Spanakis EK, Nally LM, Debruyne A, Bachl N, Pigozzi F, Halabchi F, Ramagole DA, Janse van Rensburg DC, Wolfarth B, Fossati C, Rozenstoka S, Tanisawa K, Börjesson M, Casajus JA, Gonzalez-Aguero A, Zelenkova I, Swart J, Gursoy G, Meyerson W, Liu J, Greenbaum D, Pitsiladis YP, Gerstein MB. Establishing a Global Standard for Wearable Devices in Sport and Exercise Medicine: Perspectives from Academic and Industry Stakeholders. Sports Med. 2021 Nov;51(11):2237-2250.

31. Shendure J, Balasubramanian S, Church GM, Gilbert W, Rogers J, Schloss JA, Waterston RH. Publisher Correction: DNA sequencing at 40: past, present and future. Nature. 2019 Apr;568(7752):E11. doi: 10.1038/s41586-019-1120-8. Erratum for: Nature. 2017 Oct 19;550(7676):345-353. PMID: 30948799.
32. Tanisawa K, Wang G, Seto J, Verdouka I, Twycross-Lewis R, Karanikolou A, Tanaka M, Borjesson M, Di Luigi L, Dohi M, Wolfarth B, Swart J, Bilzon JLJ, Badtieva V, Papadopoulou T, Casasco M, Geistlinger M, Bachl N, Pigozzi F, Pitsiladis Y. Sport and exercise genomics: the FIMS 2019 consensus statement update. Br J Sports Med. 2020 Aug;54(16):969-975.
33. Guasch-Ferré M, Dashti HS, Merino J. Nutritional Genomics and Direct-to-Consumer Genetic Testing: An Overview. Adv Nutr. 2018 Mar 1;9(2):128-135.
34. Vlahovich N, Hughes D, Griffiths LR, Wang G, Pitsiladis YP, Eynon N. Genetic testing for exercise prescription and injury prevention: AIS-Athlome consortium joint statement. BMC Genomics. 2017 18(Suppl 8):818.
35. Webborn N, Williams A, McNamee M, Bouchard C, Pitsiladis Y, Ahmetov I, Ashley E, Byrne N, Camporesi S, Collins M, Dijkstra P, Eynon N, Fuku N, Garton FC, Hoppe N, Holm S, Kaye J, Klissouras V, Lucia A, Maase K, Moran C, North KN, Pigozzi F, Wang

G (2015) Direct-to-consumer genetic testing for predicting sports performance and talent identification: Consensus statement. British Journal of Sports Medicine. 2015 Dec;49(23):1486-91.

36. https://brandessenceresearch.com/requestSample/PostId/1362
37. Mancin L, Rollo I, Mota JF, Piccini F, Carletti M, Susto GA, Valle G, Paoli A. Optimizing Microbiota Profiles for Athletes. Exerc Sport Sci Rev. 2021 Jan;49(1):42-49.
38. van Vliet S, Shy EL, Sawan SA, Beals JW, West DW, Skinner SK, Ulanov, AV, Li Z, Paluska SA, Parsons CM, Moore DR, Burd NA. Consumption of whole eggs promotes greater stimulation of postexercise muscle protein synthesis than consumption of isonitrogenous amounts of egg whites in young men. Am J Clin Nutr. 2017 Dec;106(6):1401-1412.
39. Habay J, Van Cutsem J, Verschueren J, De Bock S, Proost M, De Wachter J, Tassignon B, Meeusen R, Roelands B. Mental Fatigue and Sport-Specific Psychomotor Performance: A Systematic Review. Sports Med. 2021 Jul;51(7):1527-1548.
40. Bergström J, Hultman E. Muscle glycogen synthesis after exercise: an enhancing factor localized to the muscle cells in man. Nature. 1966 Apr 16;210(5033):309-10.
41. Willems SM, Wright DJ, Day FR, Trajanoska K, Joshi PK, Morris JA, Matteini AM, Garton FC, Grarup N, Oskolkov N, Thalamuthu A, Mangino M, Liu J, Demirkan A, Lek M, Xu L, Wang G, Oldmeadow C, Gaulton KJ, Lotta LA, Miyamoto-Mikami E, Rivas MA, White T, Loh PR, Aadahl M, Amin N, Attia JR, Austin K, Benyamin B, Brage S, Cheng YC, Cięszczyk P, Derave W, Eriksson KF, Eynon N, Linneberg A, Lucia A, Massidda M, Mitchell BD, Miyachi M, Murakami H, Padmanabhan S, Pandey A, Papadimitriou I, Rajpal DK, Sale C, Schnurr TM, Sessa F, Shrine N, Tobin MD, Varley I, Wain LV, Wray NR, Lindgren CM, MacArthur DG, Waterworth DM, McCarthy MI, Pedersen O, Khaw KT, Kiel DP; GEFOS Any-Type of Fracture Consortium, Pitsiladis Y,

Fuku N, Franks PW, North KN, van Duijn CM, Mather KA, Hansen T, Hansson O, Spector T, Murabito JM, Richards JB, Rivadeneira F, Langenberg C, Perry JRB, Wareham NJ, Scott RA. Large-scale GWAS identifies multiple loci for hand grip strength providing biological insights into muscular fitness. Nat Commun. 2017 Jul 12;8:16015.

42. Pontzer H, Yamada Y, Sagayama H, Ainslie PN, Andersen LF, Anderson LJ, Arab L, Baddou I, Bedu-Addo K, Blaak EE, Blanc S, Bonomi AG, Bouten CVC, Bovet P, Buchowski MS, Butte NF, Camps SG, Close GL, Cooper JA, Cooper R, Das SK, Dugas LR, Ekelund U, Entringer S, Forrester T, Fudge BW, Goris AH, Gurven M, Hambly C, El Hamdouchi A, Hoos MB, Hu S, Joonas N, Joosen AM, Katzmarzyk P, Kempen KP, Kimura M, Kraus WE, Kushner RF, Lambert EV, Leonard WR, Lessan N, Martin C, Medin AC, Meijer EP, Morehen JC, Morton JP, Neuhouser ML, Nicklas TA, Ojiambo RM, Pietiläinen KH, Pitsiladis YP, Plange-Rhule J, Plasqui G, Prentice RL, Rabinovich RA, Racette SB, Raichlen DA, Ravussin E, Reynolds RM, Roberts SB, Schuit AJ, Sjödin AM, Stice E, Urlacher SS, Valenti G, Van Etten LM, Van Mil EA, Wells JCK, Wilson G, Wood BM, Yanovski J, Yoshida T, Zhang X, Murphy-Alford AJ, Loechl C, Luke AH, Rood J, Schoeller DA, Westerterp KR, Wong WW, Speakman JR; IAEA DLW Database Consortium. Daily energy expenditure through the human life course. Science. 2021 Aug 13;373(6556):808-812.
43. Oikawa SY, Brisbois TD, van Loon LJC, Rollo I. Eat like an athlete: insights of sports nutrition science to support active aging in healthy older adults. Geroscience. 2021 Oct;43(5):2485-2495.
44. Andersen TO, Langstrup H, Lomborg S Experiences With Wearable Activity Data During Self-Care by Chronic Heart Patients: Qualitative Study J Med Internet Res 2020;22(7):e15873 doi: 10.2196/15873.

45. Nieves JW, Melsop K, Curtis M, Kelsey JL, Bachrach LK, Greendale G, Sowers MF, Sainani KL. Nutritional factors that influence change in bone density and stress fracture risk among young female cross-country runners. PM R. 2010 Aug;2(8):740-50; quiz 794. doi: 10.1016/j.pmrj.2010.04.020. PMID: 20709302.
46. Speakman JR, Hambly C. Using doubly-labelled water to measure free-living energy expenditure: Some old things to remember and some new things to consider. Comp Biochem Physiol A Mol Integr Physiol. 2016 Dec;202:3-9. doi: 10.1016/j.cbpa.2016.03.017. Epub 2016 Apr 1. PMID: 27040184.
47. Duggleby SL, Waterlow JC. The end-product method of measuring whole-body protein turnover: a review of published results and a comparison with those obtained by leucine infusion. Br J Nutr. 2005 Aug;94(2):141-53. doi: 10.1079/bjn20051460. PMID: 16115347.
48. Goffinet L, Barrea T, Beauloye V, Lysy PA. Blood versus urine ketone monitoring in a pediatric cohort of patients with type 1 diabetes: a crossover study. Ther Adv Endocrinol Metab. 2017;8(1-2):3-13. doi:10.1177/2042018816681706.
49. Surapongchai J, Saengsirisuwan V, Rollo I, et al. Hydration Status, Fluid Intake, Sweat Rate, and Sweat Sodium Concentration in Recreational Tropical Native Runners. Nutrients. 2021;13(4):1374. Published 2021 Apr 20. doi:10.3390/nu13041374.
50. Thomas F, Pretty CG, Desaive T, Chase JG. Blood Glucose Levels of Subelite Athletes During 6 Days of Free Living. J Diabetes Sci Technol. 2016;10(6):1335-1343. Published 2016 Nov 1. doi:10.1177/1932296816648344 MLA.
51. Lee EC, Fragala MS, Kavouras SA, Queen RM, Pryor JL, Casa DJ. Biomarkers in Sports and Exercise: Tracking Health, Performance, and Recovery in Athletes. J Strength Cond Res. 2017;31(10):2920-2937. doi:10.1519/JSC.0000000000002122.

52. Reisz JA, D'Alessandro A. Measurement of metabolic fluxes using stable isotope tracers in whole animals and human patients. Curr Opin Clin Nutr Metab Care. 2017 Sep;20(5):366-374. doi: 10.1097/MCO.0000000000000393. PMID: 28768294; PMCID: PMC5794022.

53. Jeukendrup AE. Carbohydrate and exercise performance: the role of multiple transportable carbohydrates. Curr Opin Clin Nutr Metab Care. 2010 Jul;13(4):452-7. doi: 10.1097/MCO.0b013e328339de9f. PMID: 20574242.

54. Décombaz J, Beaumont M, Vuichoud J, Bouisset F, Stellingwerff T. Effect of slow-release β-alanine tablets on absorption kinetics and paresthesia. Amino Acids. 2012 Jul;43(1):67-76. doi: 10.1007/s00726-011-1169-7. Epub 2011 Dec 3. Erratum in: Amino Acids. 2013 Oct;45(4):1015. PMID: 22139410.

55. Haakonssen EC, Martin DT, Burke LM, Jenkins DG. Energy expenditure of constant- and variable-intensity cycling: power meter estimates. Med Sci Sports Exerc. 2013 Sep;45(9):1833-40. doi: 10.1249/MSS.0b013e31828e18e6. PMID: 23470312.

56. O'Driscoll R, Turicchi J, Beaulieu K, Scott S, Matu J, Deighton K, Finlayson G, Stubbs J. How well do activity monitors estimate energy expenditure? A systematic review and meta-analysis of the validity of current technologies. Br J Sports Med. 2020 Mar;54(6):332-340. doi: 10.1136/bjsports-2018-099643. Epub 2018 Sep 7. PMID: 30194221.