Principles for technology use in athlete support across the skill level continuum

MCCOSKER, Chris, OTTE, Fabian, ROTHWELL, Martyn <http://orcid.org/0000-0002-3545-0066> and DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123>

Principles for technology use in athlete support across the skill level continuum

Chris McCosker [a]

Australian Catholic University

Fabian Otte [b]

German Sport University Cologne

Martyn Rothwell [c]

&

Keith Davids [c]

Sheffield Hallam University

[a] School of Behavioural and Health Sciences, Australian Catholic University, Building 211.1.26, Brisbane, QLD, Australia

[b] Institute of Exercise Training and Sport Informatics, Department of Cognitive and Team/Racket Sport Research, German Sport University Cologne, Cologne, Germany

[c] Sport & Human Performance research group, Sheffield Hallam University, A119 Collegiate Hall, Collegiate Crescent, Sheffield S10 2BP, UK

Correspondence concerning this article should be addressed to Chris McCosker, School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, Queensland, Australia;

Email: chrismccosker05@gmail.com

Abstract

A major challenge to sport practitioners working across all levels of sport is ensuring that technological platforms are integrated effectively to assist learning along the development pathway. Under the framework of ecological dynamics, we introduce technology as a *support opportunity* for athletes to learn to become better attuned to, and utilise, key sources of information to self-regulate their actions. Importantly, technology not only supports learning, but also serves as a tool to encourage active engagement in learning from early childhood to late adulthood. Coaches also need to be wary of the potential perils of the mismanagement of technology use and how it can act as a *learning rate limiter*. Misuse of technological tools may inhibit the learning process by inhibiting an athlete's ability or willingness to explore and exploit available information in the performance environment, as well as stimulate possible feelings of control and surveillance. By illustrating how technology may complement athlete learning under the guidance of the theoretical framework of ecological dynamics, it is intended that coaches may gain a better understanding of how technological tools can be used more strategically to enhance learning.

Keywords: learning, athlete support, performance preparation, coach education, feedback, technology implementation

<u>**Principles for technology use in athlete support across the skill level continuum**</u>

Introduction

The continued and rapid integration of technology into modern society provides users with the ability to access information at alarmingly fast rates, which may be a *curse* and a *blessing*. Whilst this availability of information may be useful to advance knowledge and understanding, in sports, it presents challenges to sport practitioners working closely with athletes. Technology is used in many different ways by contemporary sports practitioners to support athlete development and preparation for, and recovery from, competitive performance.[1] In these processes, technology implementation provides *augmented information* as guidance and feedback to complement the performance-based sources gained by athletes. Practitioners need to decide how best to interpret, understand and communicate this form of augmented information back to athletes. For example, live video feedback platforms may be used in training settings to guide the attention of athletes to relevant opportunities for action in competitive performance. Alternatively, this same platform may be (mis)used alongside too much prescriptive instructions, potentially detaching the athlete from the surrounding flow of information available for exploitation in the performance environment. Importantly, the trend of the continued insertion of technologies into sports performance environments is super-charged by professional sports organisations driven to find a competitive edge to meet commercial goals and sponsor requirements. A danger for coaches across the skill level continuum is *overuse* or *misuse* of technologies. Here, we argue that practitioners, could avoid this pitfall by invoking key theoretical principles, in a framework like ecological dynamics, for guiding implementation of new technologies to provide augmented information for athlete development and performance preparation.[1]

The importance of understanding how technology can be integrated in sport training environments, mirrors the challenges for everyday life, as summarised by Dreyfus and

Spinosa: 'How can we relate ourselves to technology in a way that not only resists it's devastation but also gives it a positive role in our lives?'.[2(p.159)] The difficulty in finding this 'sweet spot' with technology use can be observed through theoretical arguments which highlight the positive learning effects of technology use on skill performance.[3, 4] Simultaneously, these ideas also identify potential issues in (mis)using data for 'control' and 'surveillance' (termed *dataveillance*) of athletes,[5, 6] preventing them from innovating and exploring autonomous performance solutions.[7] This limitation is exemplified through reflections of leading professional cycling teams where the need to keep up with technology use seemingly outweighs concerns about overuse to the point where they are 'in the process of turning riders into robots', lacking agency when personally navigating demands of a competition environment.[8] Whilst difficulties in harnessing technology use have previously been discussed in the sport science literature,[9, 10] little research to date has attempted to consider the complementary role of technology in learning, guided by theoretical principles to better understand its implementation. Here, it will be discussed how an ecological dynamics theoretical rationale for athlete development and preparation for performance across skill levels positions technology as an augmented informational constraint, providing evidence to support the way that coaches, practitioners and athletes effectively navigate in competitive performance environments and develop expertise. Practical applications will also be discussed regarding the potential impact on learning, to assist theoretical understanding of how technology implementation could be achieved in sport, exemplifying how they are often actually used in coaching.

Learning under an Ecological Dynamics framework

A contemporary conceptualisation of athlete learning and development has been proposed within ecological dynamics, a theoretical framework that integrates ecological psychology and dynamical systems theory.[11-13] In this framework, behaviour emerges under a range of interacting constraints within the athlete-environment system (i.e., various personal, task and environmental features and characteristics that shape behaviour) [14]. Within this integrated system, athletes are considered to directly perceive surrounding environmental information (i.e., from spaces, gaps and locations in performance contexts, performance surfaces, events, objects, and other athletes) to guide their actions in practice and competition.[13] Consequently, learning within an ecological dynamics framework is not derived through the proliferation and elaboration of internalised representations, but is the process of athletes searching for, perceiving and attuning to surrounding information sources that specify relevant environmental properties to support their actions, enhancing function and subsequent action capabilities.[15] The concept of athletes perceiving relevant information sources to regulate actions is based on James Gibson's theory of affordances. [16] Affordances are 'possibilities or opportunities for action' which proliferate in the environment surrounding the individual, inviting interactions.[16] Seeking and using affordances in a performance landscape is a most important feature of skilled behaviour and expertise in sport which technology implementation can support and enrich.[1, 17] This ecological view of learning in sport has been conceptualised as *wayfinding*, where athletes negotiate different locations of a sporting landscape (i.e., a climber using more complex holds and grips in indoor and outdoor surfaces or a swimmer navigating outdoor waterscapes and indoor pools) with 'purposeful, intentional and self-regulated' movements. [18(p.2)]

Learning under an ecological dynamics framework, therefore, seeks to facilitate the emergence of more adaptive, functional relationships between an athlete and a specific performance environment. [19] According to these ideas, the focus of learning designs in sport practice settings, augmented by technological platforms, should not be on *acting* (rehearsing and repeating a technical action), nor *reacting* to external stimuli. Rather, technology use could be used to encourage athletes to *interact* with information designed into practice environments, searching for, and exploiting, available affordances to facilitate stable, yet adaptable, movement solutions or collective team synergies. [17, 20]

Technology in sport

Insertion of ‘state-of-the-art’ technology into coaching practices is gaining increasing consideration across sports and science. [21] This trend often appears to be exploited from a commercial perspective, leading to a ‘billion-dollar industry’ behind sports technologies. [22] However, it is questionable to what extent sports coaches follow a theory-driven framework in implementing and using such technologies in practice. [1, 23] This potential lack of understanding leads to a fundamental concern regarding coaches’ approaches towards functionally integrating technology around training session designs and competition.

Figure 1 provides a depiction of an ecological perspective on technology use to enhance skill adaptation and learning, with the aim of supporting coaches in better understanding the implementation of various categories of technology into practice. The central section of Figure 1 provides a theoretical framework for viewing the roles of practice co-design (i.e., continuous athlete-coach collaborations in designing practice environments) and holistic athlete-environment integration (i.e., considering the mutual and inseparable relationship between individual athletes and their environment). Figure 1 implicates four categories which we will detail in the section on technology implementation under and ecological dynamics framework below. The proposed categories aim to provide an introductory overview and thus, the figure does not claim to be exhaustive.

[Figure 1 here]

1) Technological equipment modification and training machinery. Innovative training tools and equipment modification may guide athletes' use of perception, increasing perceived task complexity, and driving the exploratory search for functional movement solutions within the practice landscape.[24] For example, use of stroboscopic visual devices, eye movement/gaze behaviour registration technology, [25, 26] or technically modified balls, rackets or clubs [27] may provide insight into athletes' perceptual attunement to environmental information that is coupled with their adaptations to events in the performance context. [28] The assumption is that the orientation of eye movements in the practice landscape captures visual focus and attention. On the other hand, advanced training technologies, such as robotic (football) training machines like the 'Footbonaut' [29] or VR-based training systems [17] may allow researchers, coaches and athletes to manipulate various task and environmental constraints and co-design practice contexts, based on data from performance analytics.

2) *Physical management/ tracking technology*. Motion tracking technologies aim to collect performance data using (wearable) devices and integrate this information into analysis via computer-based data processing solutions. For example, whilst junior coaches may use 'Garmin' sports watches to collect movement data, elite coaches may access data collected from heart rate monitors, global positioning systems or accelerometers which could further be processed and managed on platforms, such as 'SAP Sports One' or 'Kitman Labs'. Often, such devices involve data collection on critical performance metrics including running velocities; distances (at various speeds and intensities); practice volumes; player and force loadings; and frequency of ball contacts and collisions. [30]

3) *Performance analysis technology*. Use of performance analysis technology to support data scientists and performance analysts displays a common trend in high-performance sport. [31] For example, technology can assist performance analysis through sophisticated video analysis software (e.g., 'Hudl Sportscode' or 'Metrica'), graphic video enhancement

programmes (e.g., ‘Coach Paint’ or ‘KilpDraw’) or (*big data*-driven) recruitment and scouting platforms (e.g., ‘Wyscout’ or ‘Statsbomb’). While some performance-driven technology may appear to be rather suitable for sports organisations at the elite level, more accessible software for a wider range of coaches, independent of sport and performance level, is constantly emerging (e.g., ‘Focus X2’ or ‘Nacsport’).

4) *Video-based feedback technology*. The use of video technology applied to training sessions for both team and individual sports can play a major part for athlete-coach interactions (e.g., ‘Dartfish’ or ‘Coaches eye’). [32] In a recent ecological conceptualisation concerning various coaching intervention methods, Otte and colleagues elaborated on the use of (live) video feedback for tactical analysis, (real-time) self-video feedback and model learning. [33] Here, video feedback could be used to guide athletes’ exploratory activities during practice by constraining the perceptual search space and guiding attention towards relevant affordances. Recorded video footage of performance by teams or individuals, often without any further verbal guidance by coaches, may provide augmented feedback for athletes to visualise and adapt (movement) solutions, and to successfully solve goal-oriented problems. In addition to this theoretical framing of coaches’ external feedback and instruction methods, practical implementation of video-based technology and filming equipment, including point-of-view cameras, mobile tablets and drone technology offer exciting avenues for developing *softer* (i.e., less prescriptive and directing) pedagogies engaging athletes in co-designing relevant practice task constraints.

Technology use in an ecological dynamics framework

Technology use involving concepts in ecological dynamics for learning design, highlights the inseparability of athletes and their environments (central section in Figure 1). [13] While traditional views emphasise the top-down ordering and isolation of “movement-regulating sub-systems, such as perception, action, cognition and emotion", [31 (p.4)] an ecological view (on technology use) stresses the mutual and reciprocal interactions of these sub-systems under emerging constraints. [13] Successful performance interactions between technology, athletes and their environment are multidirectional and thus, do not originate internally in the isolated brain. [34] Put simply, technology affords coaches an important avenue to provide augmented information, assist athletes' search processes during practice, and to guide their attention towards functional movement solutions. Under this perspective, technology is viewed as a *support opportunity* for athletes to learn to perceptually attune to, and utilise, relevant affordances and environmental information that sustain self-regulated actions. In this way, information from technological platforms serves as a critical informational constraint influencing athlete performance behaviours. This additional information may be made available to athletes and teams explicitly through data streams of snapshots or implicitly to be detected as invariants in surrounding information for regulating their actions. Technology also provides an opportunity for coaches to co-design representative practice tasks, analyse competition demands to enhance future practice interventions and assess skill effectiveness based on quantifiable data. [12, 21]

Integration of technology can assist learning across the skill level continuum

A major challenge to sport practitioners working across all levels of sport is ensuring that technological platforms are integrated effectively to assist learning along the development pathway (i.e., an athlete's journey from novice to high performance athlete). Sport practitioners are faced with many barriers and challenges to effectively integrate technology, including: 1) an appreciation of how technology can be used in practice to enhance learning, 2) ensuring that specific technological platforms support the current skill level and needs of the athlete/s, and 3), how a range of sub-discipline specialists in high performance environments collaborate to integrate technology functionally and coherently in practice. [35]

Traditionally, the coach's role in the athlete learning process is conceived as one where high levels of prescriptive instruction and concurrent feedback are provided to learners[36] moving them towards an optimal movement template. The one-way process of the coach continuously transmitting knowledge to the passive athlete is outdated and can reduce their responsiveness to critical information sources offered within performance environments. [37] In advocating a move away from such *coach-centred* approaches, Woods and colleagues have argued that a role re-conceptualisation is needed for sport practitioners to one of *learning designer,* where coaches facilitate athlete exploration of performance landscapes. [38] This idea of athletes self-regulating to *find their way* aligns with the arguments of the prominent ecological psychologist, Edward Reed, who suggested that individuals do not seek to construct internalised knowledge structures (as discussed previously) but seek values (affordances) and meanings (information) when negotiating a performance environment. [39]

A source of information more aligned to wayfinding is transition information. This category of augmented information acts as a control parameter (a key source of information) to guide athletes in a process of searching, discovering, and exploiting affordances situated in performance landscapes. Available opportunities for action can be used to realise task goals. [40] For example, at the expert end of the skill continuum, experienced mountain climbers can collaborate using action cameras such as GoPro units, to share route transition information to help each other detect and utilise affordances (i.e., useable grips, finger combinations and holds in the rock structure) to find their way across a surface efficiently and effectively. [41] However, the process of a coach or athlete sharing transition information may be a challenge in dynamic sports when the sporting landscape is situated in large and diverse space (e.g., a young child playing on a soccer pitch for the first time or a seasoned cyclist preparing for a multi-stage race). These regulatory information sources may not be perceived without first exploring and navigating through the space to experience interactions with them (even simulated in VR). Here, technology can be a very useful tool in providing transition information to wayfind a path through a challenging context (e.g., cyclists could use Garmin Connect or Strava data of previous routes to identify accelerations in speed, heart rate spikes, or sustained periods of high watt outputs that may indicate race strategies or when to conserve energy). This approach can enculturate athletes into a lifetime habit of learning to search for value and meaning through the process of attuning to transition information available in a performance environment.

To effectively integrate technological tools into the coaching process, it is essential that practitioners first identify the current needs of athletes and differentiate between skill development and skill refinement, and consider where athletes are in the search, discover, and exploit stages of learning. [42] It is important to note here, that an athlete reaching a certain stage of learning does not automatically imply that technology should be integrated within their training sessions. Rather, and as promoted by the ecological dynamics framework, coaches need to understand the implications of using this form of augmented informational constraint from an individual-environment level of analysis. Less experienced coaches working with less skilful athletes are encouraged to focus on carefully implementing technology with the aim of helping athletes to co-design opportunities for utilising affordances and performance enrichment, based on augmented information provided by performance feedback systems. To exemplify, a coach working with junior middle distance track athletes who have spent much of their practice history focusing on developing physical capacities, may be unresponsive to challenges for identifying *attacking* opportunities (affordances) or situations they may have to *respond to* during competition and could therefore, lack race intelligence. [43] This emergent problem could be addressed through an integrated approach whereby: 1) video feedback for tactical race analysis can be used to identify transition information to attune the athlete's attention to affordances for attacking in a race, 2) the coach and athlete can then co-design practice race simulations based on these key affordances, and 3), depending on the agreed physiological response, manipulate load demands based on lap times and heart rate data. Approaching technological use through the co-design concept early in an athlete's development can provide useful opportunities for self-regulation during performance and development. Technologies can invoke the positive connections of athletes with coaches, and lead to feelings of competence when mastering new skills.

How technology can interfere with learning

A common thread through the discussion thus far has been how technology use by coaches can help facilitate key search processes and act as a *support opportunity* for athletes when viewed through an ecological dynamics lens. It is important, however, to recognise how technology, in providing augmented information, can *interfere* with learning if used incorrectly or mismanaged. In this section, we draw attention to the misuse of technology and how it can act as a *learning rate limiter* rather than a *support opportunity*. Two specific potential issues will be explored: (1) Impact of explicit instructions, and (2) Issues of control and surveillance.

(1) Impact of explicit instructions

According to James Gibson [16] *knowledge about* the performance environment is related to verbal descriptions often accompanied by exposure to images, abstract depictions, pictures and/or video analysis. [23] It can be a powerful platform for shared knowledge that coaches can use to direct an athlete's attention to certain features of an opponent's play or team defensive structures, for example. Questions arise over the nature of the responses elicited from athletes in sharing this knowledge, especially when verbal responses from athletes (telling) are preferenced over interactions with a practice environment (doing). [44] Issues can surface, however, when coaches supplement video feedback, for instance, with the explicit prescription of specific movement solutions rather than encouraging exploration of learning strategies. [4] In this respect, context is everything for coordinating such interactions. For example, a coach may use video feedback with a junior long jump athlete during training, but supplement its use with explicit instructions on key technical positions with no regard to jump distance or the key variables of performance contexts that athletes need to navigate within competitive performance. [43, 45] In contrast, professional cyclists can have *knowledge of* [16] the environment relayed to them via earpieces in real-time or via computer screens on their handlebars during both training and races (i.e., positions of rivals in the peloton, power output). This information is often used to highlight how to coordinate interactions with a performance environment, through augmented information on specific points of attacks or to optimise physiological training loads during training. Importantly, both examples here may reduce an athlete's ability or willingness to explore and exploit available information in the performance environment when trying to *find their* way. Coaches need to be attuned to when it is appropriate to incorporate technology into the learning journey of athletes and recognise that sports performance is more than just (re)producing a technical performance. [43] It is important to ensure that technological tools are accompanied by appropriate verbal guidance that encourages and supports athlete wayfinding. For example, instead of providing ball by ball analysis to a mid-handicap golfer using sophisticated ball tracking devices such as Trackman, the coach may use an initial swing analysis alongside carefully targeted questioning and guidance that supports the athlete's learning and encourages exploration. If the focus of the session is on controlling ball flight, then example questions/verbal guidance to frame interactions during practice may include: Can you hit this 7-iron at a low trajectory into the target? How did that feel off the club face? Do you think moving the ball back/forward in your stance will impact trajectory? Can you now hit the ball as high as you can using the same club?

(2) Issues of control and surveillance

The constant integration of technology into the coaching process can elicit feelings of athlete lack of control by *dataveillance*, if mismanaged. [5, 6, 46] For example, use of wearable GPS technologies during training and competition to monitor athlete load during sports such as rugby league or American football may be creating environments where athletes are consciously ‘completing the work to hit imposed performance goals’. Furthermore, feelings of mistrust amongst teammates may also develop. For example, use of instrumented gates in the sport of rowing, where publicly available metrics such as force data and stroke length can be produced in real-time for every stroke and for every athlete in a boat, may lead to team disharmony and mistrust. In observing a reduction in force production by a fellow team member, an athlete may question their team member’s position in the team. Constant feelings of surveillance through technological use can, therefore, serve to ‘dehumanise the athlete experience’, [47 (p.321)] reducing the athlete to just a ‘number’ (likened to a *chess piece* or *robot* manipulated by an external agent), contributing to orchestrated performance. Notably, this notion of extensive control may be extended by the danger of athletes becoming (too) dependent on software, devices and related coaching feedback. Whilst coaches traditionally may feel the need to overly control and guide athlete learning, encouraging athletes to become better attuned to their own feedback systems to support their own self-regulation when wayfinding is critical. Hence, technology should be used carefully: only as an augmented informational source for learning and development.

Summary

Continued growth in the sports technology industry poses interesting challenges for coaches and practitioners charged with preparing athletes for the dynamic nature of sports competition. A thorough understanding of how best to harness these technologies is important to enhance the continued development and improvement of athletes. A theoretical framework, such as ecological dynamics, could provide principles for technology implementation in coaching across the skill level continuum. Under this framework, we introduced technology as a *support opportunity* for athletes to learn to become better attuned to and utilise key sources of available information in the performance environment, which they may use to self-regulate their interactions. Importantly, for the effective integration of technology tools, understanding the current needs of athletes and where they are in the search, discover and exploitative stages of learning is essential. This is a key facet of understanding the coach as a learning facilitator, moving away from the 'one-size fits all' approach commonly used in traditional coaching methods. If technology is used in this manner, it not only supports learning, but it also serves as a tool to encourage active engagement of athletes in learning from early childhood to late adulthood. Coaches also need to be wary of the potential perils of technology mismanagement and how it can act as a *learning rate limiter*. Potential negative associations with continued observations of augmented information and constant feelings of control and surveillance (during and away from performance) may develop with misuse of technological tools inhibiting self-regulation. By using technology to complement learning, ecological dynamics provides coaches with better understanding of how such tools can be used more strategically to enhance athlete preparation and development. A future challenge for coach education developers is to consider the integration of technology alongside learning frameworks within coach education curricula. In modern life, where athletes are constantly exposed to technology use, it is important that sport organisations avoid turning athletes into ‘docile and compliant robots’, categorising them as a mere commodity in the drive for organisational success.

References

1. Araújo D, Couceiro MS, Seifert L, Sarmento H and Davids K. *Artificial intelligence in Sport Performance Analysis*. London: Routledge, 2021.

2. Dreyfus H and Spinosa C. Highway bridges and feasts: Heidegger and Borgmann on how to affirm technology. *Man and World*. 1997; 30: 159-77.

3. Baudry L, Leroy D, Thouvarecq R and Chollet D. Auditory concurrent feedback benefits on the circle performed in gymnastics. *J Sport Sci*. 2006; 24: 149-56.

4. Potdevin F, Vors O, Huchez A, Lamour M, Davids K and Schnitzler C. How can video feedback be used in physical education to support novice learning in gymnastics? Effects on motor learning, selfassessment and motivation. *Physcial Education and Sport Pedagogy*. 2018; 23: 559-74.

5. Jones L, Marshall P and Denison J. Health and well-being implications surrounding the use of wearable GPS devices in professional rugby league: A Foucauldian disciplinary analysis of the normalised use of a common surveillance aid. *Performance Enhancement & Health*. 2016; 5: 38-46.

6. Manley A and Williams A. ‘We’re not run on Numbers, We’re People, We’re Emotional People’: Exploring the experiences and lived consequences of emerging technologies, organizational surveillance and control among elite professionals. *Organization* 2019: 1-22.

7. Renshaw I and Chow JY. A constraint-led approach to sport and physical education pedagogy. *Physcial Education and Sport Pedagogy*. 2019; 24: 103-16.

8. Madiot. We're turning riders into robots. *Cyclingnews*. 2021.

9. Giblin G, Tor E and Parrington L. The impact of technology on elite sports performance. *Sensoria: A Journal of Mind, Brain & Culture*. 2016; 12.

10. Phillips E, Farrow D and Ball K. Harnessing and understanding feedback technology in applied settings. *Sports Med*. 2013; 43: 919-25.

11. Davids K, Handford C and Williams M. The natural physical alternative to cognitive theories of motor behaviour: An invitation for interdisciplinary research in sports science. *J Sport Sci*. 1994; 12: 495-528.

12. Woods C, Rothwell M, Rudd J, Robertson S and Davids K. Representative co-design: Utilising a source of experiential knowledge for athlete development and performance preparation. *Psychol Sport Exerc*. 2021; 52: 1-9.

13. Button C, Seifert L, Chow JW, Araújo D and Davids K. *Dynamics of Skill Acquisition*. 2nd ed. Champaign, Ill: Human Kinetics Publishers 2020.

14. Araújo D, Hrishtovski R, Seifert L, Carvalho J and Davids K. Ecological cognition: expert decision-making behaviour in sport. *Int Rev Sport Exer P*. 2019; 12: 1-25.

15. Hacques G, Komar J, Dicks M and Seifert L. Exploring to learn and learning to explore. *Psychol Res*. 2020; 1.

16. Gibson JJ. *The Ecological approach to visual perception*. Boston, MA: Houghton Mifflin, 1979.

17. Stone J, Strafford B, North J, Toner C and Davids K. Effectiveness and efficiency of virtual reality designs to enhance athlete development: an ecological dynamics perspective. . *Movement & Sport Sciences - Science & Motricité*. 2018: 51-60.

18. Woods C, Rudd J, Robertson S and Davids K. Wayfinding: How Ecological Perspectives of Navigating Dynamic Environments Can Enrich Our Understanding of the Learner and the Learning Process in Sport. *Sports Medicine - Open*. 2020; 6: 1-11.

19. Araújo D and Davids K. What exactly is acquired during skill acquisition? *Journal of Consciousness Studies*. 2011; 18: 7-23.

20. Araújo D and Davids K. Team synergies in sport: theory and measures. *Front Psychol*. 2016; 7: 1449.

21. Farrow D and Robertson S. Development of a Skill Acquisition Periodisation Framework for High-Performance Sport. *Sports Med*. 2017; 47.

22. Harris DJ, Wilson MR and Vine SJ. A systematic review of commercial cognitive training devices: implications for use in sport. *Front Psychol*. 2018; 9: 709.

23. Renshaw I, Davids K, Newcombe D and Roberts W. *The constraints led approach: Principles for Sports Coaching and Practice Design*. London: Routledge, 2019.

24. Otte F, Millar SK and Klatt S. Skill training periodization in "Specialist" sports coaching—An introduction of the "PoST" framework for skill development. *Frontiers in Sports and Active Living*. 2019; 1: 71-93.

25. McGuckian T, Cole M and Pepping G. A systematic review of the technology-based assessment of visual perception and exploration behaviour in association football. *J Sport Sci*. 2018; 36: 861-80.

26. Wilkins L and Appelbaum L. An early review of stroboscopic visual training: insights, challenges and accomplishments to guide future studies. *Int Rev Sport Exer P*. 2019; 13: 65-80.

27. Brocken J, van der Kamp J, Lenoir M and Savelsbergh G. Equipment modification can enhance skill learning in young field hockey players. *Int J Sports Sci Coa*. 2020; 15: 382-9.

28. Davids K, Button C and Bennett S. *Dynamics of skill acquistion: A constraints-led approach*. Champaign, IL: Human Kinetics, 2008.

29. Otte F, Millar SK and Klatt S. What do you hear? The effect of stadium noise on football players' passing performances. *Eur J Sport Sci*. 2020.

30. Lutz J, Memmert D, Raabe D, Dornberger R and Donath L. Wearables for Integrative Performance and Tactic Analyses: Opportunities, Challenges, and Future Directions. *Int J Environ Res Public Health*. 2020; 17.

31. Otte F, Rothwell M, Woods C and Davids K. Specialist Coaching Integrated into a Department of Methodology in Team Sports Organisations. *Sports Medicine Open*. 2020; 6.

32. O'Donoghue P. The use of feedback videos in sport. *International Journal of performance analysis in sport*. 20016; 6: 1-14.

33. Otte F, Davids K, Millar SK and Klatt S. When and How to Provide Feedback and Instructions to Athletes?—How Sport Psychology and Pedagogy Insights Can Improve Coaching Interventions to Enhance Self-Regulation in Training. *Front Psychol*. 2020; 11.

34. Woods C, Robertson S, Rudd J, Araújo D and Davids K. 'Knowing as we go': a Hunter-Gatherer Behavioural Model to Guide Innovation in Sport Science. *Sports Medicine - Open*. 2020; 6.

35. Rothwell M, Davids K, Stone J, et al. A department of methodology can coordinate transdisciplinary sport science support. *Journal of Expertise*. 2020; 3: 55-65.

36. Cope E, Partington M, Cushion CJ and Harvey S. An investigation of professional top-level youth football coaches' questioning practice. *Qual Res Sport Ex Health*. 2016; 8: 380-93.

37. Rothwell M, Stone J and Davids K. Investigating the athlete-environment relationship in a form of life: an ethnographic study. *Sport, Education and Society*. 2020: 1-16.

38. Woods C, McKeown I, Rothwell M, Araújo D, Robertson S and Davids K. Sport practitioners as sport ecology designers: How ecological dynamics has progressively changed perceptions of skill 'acquisition' in the sporting habitat. *Front Psychol*. 2020; 11.

39. Reed ES. *Encountering the world: Toward an ecological psychology*. Oxford University Press, 1996.

40. Newell KM. Change in Motor Learning: A Coordination and Control Perspective. *Motriz, Rio Claro*. 2003; 9: 1-6.

41. Seifert L, Cordier R, Orth D, Courtine Y and Croft J. Role of route previewing strategies on climbing fluency and exploratory movements. *PLoS One*. 2017; 12: e0176306.

42. Renshaw I, Araújo D, Button C, Chow JY, Davids K and Moy B. Why the Constraints-Led Approach is not Teaching Games for Understanding: a clarification. *Physcial Education and Sport Pedagogy*. 2016; 21: 459-80.

43. McCosker C, Renshaw I, Russell S, Polman R and Davids K. The role of elite coaches' expertise in identifying key constraints in long jump performance: How practice task designs can enhance athlete self-regulation in competition. *Qual Res Sport Ex Health*. 2019.

44. O'Sullivan M, Woods C, Vaughan J and Davids K. Towards a contemporary player learning in development framework for sports practitioners. *International Journal of Sports Science and Coaching*. 2021; 0: 1-9.

45. McCosker C, Renshaw I, Greenwood D, Davids K and Gosden E. How performance analysis of elite long jumping can inform representative training design through identification of key constraints on competitive behaviours. *Eur J Sport Sci*. 2019.

46. Williams S and Manley A. Elite coaching and the technocratic engineer: thanking the boys at Microsoft! *Sport, Education and Society*. 2016; 21: 828-50.

47. Cronin C, Whitehead AE, Webster S and Huntley T. Transforming, storing and consuming athletic experiences: a coach's narrative of using a video application. *Sport, Education and Society*. 2019; 24: 311-23.

Figure Captions

Figure 1. Overview model of technology use in coaching including key pedagogical principles under the framework of ecological dynamics and four proposed technology categories.