Effectiveness and efficiency of virtual reality designs to enhance athlete development: An ecological dynamics perspective

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Effectiveness and efficiency of Virtual Reality designs to enhance athlete development: An ecological dynamics perspective

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Abstract

A rapidly developing area of research is focused on the use of Virtual Reality (VR) systems to enhance athlete performance in sport. The assumption is that implementation of such technologies will enhance skill acquisition and expedite athlete development. However, application of such technologies for enriching athlete development and performance preparation needs to be efficiently and effectively used by coaches and athletes to save time, energy and other resources in practice and training. Here, we argue that implementation of VR systems needs to be grounded in theory, with learning designs informed by a clear scientific rationale. We discuss how the full potential of VR systems can be utilised through implementing a theoretical framework, like ecological dynamics, to shape their application. We outline how an ecological dynamics framework can underpin research and applications of VR in athlete development through: (i) individualised training and assessment programmes, (ii) supporting exploration of variable and creative practice environments, and (iii), ensuring context-dependent perception and decision making, and actions, where technology permits. An ecological dynamics rationale proposes how VR systems, when carefully implemented, can enrich and enhance learning designs, but can never replace coaching support for learning during physical practice.

Key Words: Ecological dynamics, Virtual Reality, sport performance, perception-action coupling, interactive learning designs, practice enrichment

Abstrait

Un domaine de récherche en développement rapide est axé sur l’utilisation des systèmes de réalité virtuelle (RV) pour améliorer les performances des athlètes dans le sport. L'hypothèse est que la mise en œuvre de telles technologies améliorera l'acquisition de compétences et accélérera le développement des athlètes. Cependant, l'application de ces technologies pour enrichir le développement de l'athlète et la préparation à la performance doit être utilisée efficacement par les entraîneurs et les athlètes. Ceci qu' afin de la nécessité d''économiser du temps, de l'énergie et d'autres ressources pour la pratique et l'entraînement. Nous soutenons ici que la mise en œuvre de systèmes de réalité virtuelle doit être ancrée dans la théorie, avec des conceptions d’apprentissage reposant sur une justification scientifique claire. Nous discutons de la manière dont tout le potentiel des systèmes de réalité virtuelle peut être utilisé en mettant en œuvre un cadre théorique, tel que la théorie de "dynamiques écologiques", pour façonner leur application. Nous décrivons comment un cadre de "dynamiques écologiques" peut sous-tendre la récherche et les applications de la réalité virtuelle au développement des athlètes à travers: (i) des programmes d'entraînement et d'évaluation individualisés, (ii) en soutenant l'exploration d'environnements de pratique variés et créatifs, et (iii), en garantissant une perception dépendante du contexte, ainsi que la prise de décision et les actions, où la technologie le permet. Une logique de "dynamiques écologiques" suggère comment les systèmes de RV, lorsqu'ils sont soigneusement mis en œuvre, peuvent enrichir et améliorer les conceptions d'apprentissage. Mais, elles ne peuvent jamais remplacer le soutien de l'entraîneur pour l'apprentissage pendant la pratique physique.

Introduction

Since the introduction of virtual reality (VR), rapid growth and emergence of new technologies has enabled individuals to behave and interact in more immersive environments with relative ease and at relatively low cost (e.g., Occulus Rift and HTC Vive) (Düking, Holmberg, & Sperlich, 2018). In sport, increased accessibility and mobility of VR systems has led to a growing interest in their application to develop athlete performance (Cotterill, 2018). However, despite the number of sports organisations investing in VR systems, there is currently limited scientific evidence to inform and underpin its application (Neumann et al., 2018; Düking et al., 2018). Most importantly, it is unclear whether VR systems develop skills and expertise beyond the specific practice context in which it is implemented, and how the effectiveness of VR compares to other methods of learning and training. While there may be some benefits for athletes, a judgement needs to be made as to whether VR systems are worth the time, money and effort involved in their implementation. It is important to understand whether such time, money and effort may be better invested in developing enhanced learning designs for athletes during traditional practice designs.

In this position statement, we argue that to enable the full potential of VR systems in enhancing athlete performance and development in sport, a theoretical framework is necessary to rationalise applications of such systems to ensure effective and efficient designs of VR environments for athlete development and learning. To achieve this aim, we build on the ideas of Craig (2013), who applied concepts from *ecological psychology* to inform the design of experimental research on perception-action coupling using virtual reality systems. We further these discussions using the relevance of key concepts in *ecological dynamics* (i.e. an integration of concepts from ecological psychology, dynamic systems theory, complexity sciences, constraints-led practice, representative learning design) to inform the design and the application of VR technologies to enrich the training programmes of elite and developing athletes. Finally, we propose future empirical research which is required to support evidence-based implementation of VR in athlete training.

An ecological dynamics approach to guide implementation of Virtual Reality systems in athlete training programmes

Craig (2013) suggested how the application of virtual reality could be guided by key concepts from ecological psychology which proposes a "direct" solution to perception and action to help athletes become attuned to specifying information in the environment which is coupled with action possibilities. In this theoretical rationale, perception and action are considered to have a direct and cyclical relationship to support performance (Kugler & Turvey, 1987; Handford, Davids, Bennett, & Button, 1997), the strengthening of which VR training systems can potentially enhance. In this respect, the role of VR technology in learning could be to help learners become attuned to specifying information in a simulated performance environment. This central theoretical principle informs the design of learning environments to facilitate athlete exploration of lawful relationships between perception and action emerging during interactions with a performance environment. An extensive body of research has provided support for the reciprocal relationship between perception and action in sport performance (e.g., Dicks, Button, & Davids, 2010a, 2010b; Pinder, Renshaw, & Davids, 2009; Stone, Panchuk, Davids, North, & Maynard, 2015). For this purpose, investigators have worked on the development and integration of novel methods, for example in *in-situ* representative designs (e.g., Dicks et al., 2010a, 2010b), virtual environments (Craig, 2013) and integrated video-ball projection systems (e.g., Stone et al., 2014). These research programmes have all demonstrated the importance of continuous coupling of informational constraints and actions during experimental research programmes and sports practice. Key research findings have shown how athletes can continually integrate perception and action during performance, driven by theoretical advances in skill performance and learning, to inform sports practitioners about the design of practice environments (Davids, Araújo, Vilar, Renshaw, & Pinder, 2013).

With regards to the implementation of VR systems in athlete training programmes, a recent systematic review by Neumann and colleagues (2018) indicated that current evidence for their value was less than compelling. While they argued that: "The research findings to date indicate that VR can be a promising adjunct to existing real-world training and participation in sport", they did also note that "Future research would benefit from a theoretical framework of VR application to sport…." (Neumann et al., 2018, p.196). A key problem with existing research on implementation of VR systems in sport, identified by the systematic review of Neumann et al. (2018), was the provision of opportunities for athletes *to interact* with key variables in the designed digital performance environments.

How VR systems can support interactions of athletes with task and environmental constraints in preparation for performance

Here, we propose how implementation of VR systems in sports training programmes could be enhanced by a theoretical conceptualisation from ecological dynamics, emphasising how athletes can interact with task and environmental constraints of a specific performance environment. This theoretical rationale builds on Craig's (2013) ideas for guiding VR research underpinned from ecological psychology. We integrate key concepts and ideas from ecological psychology with those from scientific sub-disciplines of complexity sciences and dynamical systems theory to conceptualise athletes and sports teams as complex, highly integrated, adaptive systems composed of many degrees of freedom (Chow, Davids, Hristovski, Araújo, & Passos, 2011). An ecological dynamics rationale proposes that cognition, perception and action are deeply intertwined in regulating athlete performance in satisfying key constraints (individual, environmental and task see Figure 1). This deeply intertwined relationship is most prominent in skilled individuals such as expert athletes as it supports their continuous interactions with task and environmental constraints (Orth, Davids & Seifert, 2018). Gaining this intertwined relationship between sub-systems of action, cognition and perception, which support interactions with a performance environment, is the fundamental basis for using technologies like VR systems to enrich athlete learning and performance. Interactions with key informational variables in a performance context act as boundaries that shape emergent patterns of behaviour (Anson, Elliott, & Davids, 2005). Interacting constraints designed into a representative simulation of a performance environment provide a framework for the acquisition of functional, goal-directed behaviours in learners. This conceptualisation from ecological dynamics provides a clear rationale for understanding how task and environmental constraints, designed in VR environments could guide each individual performer's interactions and learning possibilities.

In an ecological dynamics rationale, dynamical systems theory contributes a functionalist framework proposing how coordination in neurobiological systems emerges between components of multiple independent, but interacting, subsystems (Duarte, Araújo, Correia, & Davids, 2012). The concept of *degeneracy* outlines how system elements that are structurally different can perform the same function or yield the same output (Edelman & Gally, 2001). Hence, degeneracy in sport performance indicates that functionally equivalent actions of athletes can be achieved by structurally different movement system components. Neurobiological degeneracy has been revealed in tasks such as football kicking (Chow, Davids, Button, & Koh, 2008) where participants adapted their use of limb segments to continue to successfully perform a task (e.g. height of a football chip) as constraints were manipulated. Such research evidences how skilled performance is achieved via a dynamical process, regulated by perceptual information available to performers in a performance environment (e.g., for reviews see Vilar et al., 2012; Orth et al., 2012). Hence, practitioners should not be looking for one optimal pattern of coordination towards which all developing learners should aspire, but instead, training should be concerned with a process of individual-constraints coupling (Seifert et al., 2013). Importantly here, this theoretical account proposes how each individual may solve the same movement tasks in a unique way. Hence a standard "one-size fits all" practice schedule could be avoided by using VR systems to individualise task and environmental constraints away from the practice context before athletes engage in physical training. Enhancing athlete self-regulation (of emotional, psychological, perceptual and physical sub-systems) through exploiting adaptive variability is an important performance area that use of VR systems has the potential to enrich in practice.

Dynamical system theory also proposes that, alongside individualised movement patterns, variability of movement is functional for performance and should not be seen as detrimental to performance. Movement system variability indicates the functional flexibility needed to respond to dynamic performance constraints. Viewing learners as complex adaptive systems promotes awareness in sport practitioners that an individual learner's coordination solutions emerge from harnessing intrinsic self-organisation tendencies and that periods of movement variability (or instability) should be viewed as an important part of the learning process (Chow et al., 2007). Therefore, the use of VR systems could allow practitioners to manipulate relevant task, environment and performer constraints to facilitate the acquisition of functionally relevant coordination solutions via performer-environment interactions. Next, we outline how such principles could shape the future of VR research and learning design guided by these ecological dynamics principles.

Figure 1 about here

Representative Learning Design for VR systems training

Implementation of VR systems needs to achieve learning designs that will support learners, over time, becoming attuned to information through practice in varying performance environments, creating relationships between actions and specific sources of perceptual information (i.e. perception-action couplings; see Gibson, 1979; Michaels & Carello, 1981). 'Representative learning design' is a term which theoretically outlines how practitioners designing learning environments might use insights from ecological dynamics to ensure that training task constraints are representative of a particular sport performance context toward which practice conditions are intended to generalize (Davids, Araújo, Vilar, Renshaw & Pinder, 2013). Designs underpinned by a representative learning framework enable the utilisation of affordances (i.e. opportunities for action invited by objects, surfaces, features and terrains) perceived by individuals (Gibson 1979) which are available in specific performance environments. Affordances conceptualise the combining of perception and action, since "perception is an invitation to act, and action is an essential component of perception" (Gibson, 1979, p. 46). Hence, to enable the use of functional perception-action couplings, individuals must identify specifying information variables (i.e. be perceptually attuned to constraints of a performance environment), but also have the ability to scale information to their own action capabilities (Fajen, 2007; Jacobs & Michaels, 2007). A challenge for implementation of a functional framework for VR learning design in sports training and practice (see Figure 1) is to ensure that principles of representative learning design are met by careful consideration of the constraints which are present within such environments (see Pinder et al., 2011b).

Pinder, Davids, Renshaw and Araújo (2011a) highlighted two critical features to ensure a representative design, *functionality of perceptual information* and *action fidelity*. Functionality of perceptual information enables performers to regulate actions with information sources that are representative of their performance environment, with action fidelity being achieved when participants' movement responses remain the same between the simulated (e.g., experimental or training) environment and the performance environment (Pinder, Davids, Renhsaw & Araújo 2011a). These concepts emphasise that applications of VR for skill learning need to implement technology and devices to display information (functionality) and support continuous interactions (fidelity) of a learner in a simulated performance environment. These interactions should be underpinned by integrated cognitive, perceptual and action sub-system involvement within specific task constraints designed in a digital simulation of a performance setting. That is, learners in VR training environments should have intentions to achieve specific task goals, informational variables to perceive and affordances to utilise and actions to regulate during practice. A lack of representativeness in VR learning designs may lead to less faithful simulations of performance environments, inhibit acquisition of skills, and weaken transfer to performance in competitive environments similar to those observed in previous practice designs tasks (e.g. Barris, Davids & Farrow, 2013). Clearly, less representative learning designs in VR practice contexts will lead to less efficient and effective use of training time for athletes and coaches.

Functionality of task constraints enables performers to regulate interactions with available information sources that are representative of those sources found in a performance environment. For example, learning environments should include perceptual variables that sample informational constraints which performers use to regulate their interactions within a performance environment. Functional sampling of representative perceptual information in sport training environments is a considerable challenge for coaches and researchers. For example, in cricket, a bowler's kinematic information during the run-up, which is critical for anticipation (Müller, Abernethy, & Farrow, 2006), is often removed because of ubiquitous use of ball projection machines and concerns related to overuse injuries in bowlers (see Pinder, Davids, Renshaw & Araújo, 2011b). Use of VR systems has the potential to overcome such issues, through regulation of the perceptual information presented, while enhancing representativeness by presenting visual information of the run-up from a performer's viewpoint. For example, VR technology could be used to avoid the limitations of a fixed allocentric viewpoint of participants (see Williams, Davids, Burwitz, & Williams, 1994; Helsen & Pauwels, 1993). Researchers have previously demonstrated that participants make faster and more accurate decisions when they are presented with a viewpoint from a performer's perspective (egocentric viewpoint) compared to viewing a live broadcast (allocentric viewpoint) (Petit & Ripoll, 2008).

Realistic behavioural responses in virtual environments are suggested to occur when the system induces a sense of presence and the perception that the events are actually occurring (Slater, 2009). A functional VR display solution for enhancing quality of perception-action couplings involves use of a computer automatic virtual environment (CAVE) or head-mounted displays (HMD) (Neumann et al., 2018). Typically, CAVEs are large cubes created with display screens, which the user physically enters and is enveloped by a virtual environment simulating the surrounding informational constraints of performance environments. However, such systems can be expensive and require large amounts of physical space, so HMD, which are smaller, portable and more cost-efficient, but still share similar immersive environments, could be more beneficial (Slater, 2009). Nevertheless, HMD require large amounts of space for athletes to move around in or require the use of equipment such as treadmills to enable movement within a smaller space which can be hazardous because vision of a moving treadmill belt is not available (Neumann et al., 2018). In addition, head movements and perspiration of the athlete during actions can make the HMD uncomfortable to wear, which can itself impact the level of action fidelity and presence. Therefore, while HMD are normally cheaper than CAVE systems, the constraints placed on the athlete using such systems may limit the effectiveness of such learning designs due to limitations on the affordances available for athletes to utilise. However, with the continual development of technology, including wireless high-quality headsets (e.g., HTC Vive Pro) and haptic suits (e.g., Teslasuit), opportunities will emerge to develop more perceptually faithful VR simulations of sport performance environments that meet the first component of effectiveness (functionality of perceptual information) of representative design.

Despite advances in visual displays, a fundamental weakness in current implementations is that researchers still typically neglect the importance of action components in analyses. The importance of action in functional behaviour is underlined by Gibson's (1979) statement that: "We must perceive in order to move but we must also move in order to perceive" (p. 223). Here, Gibson (1979) highlighted that, not only is perception of information critical for effective movement, the ability to move is critical to change the perceptual information available to performers. That is why it is critical that VR designers focus on the perceptual information presented in these environments, and the cognitions that athletes use to frame their performance intentions while they are moving within these environments. This recognition of the ongoing, intertwined relations between an athlete's cognitions, perception and action implies how the design of VR performance environments can be adapted according to the task and environmental constraints of a specific sport context. Pinder et al. (2011a) recognised the importance of actions in creating representative environments with the concept of *action fidelity*, which requires the performer being able to re-organise motor system degrees of freedom in practice in the same way as would be required in competitive performance. This key idea questions the use of VR responses like finger movements on digital controlling systems, use of wands in hands or verbal responses to simulate actions (Pinder et al., 2011a). Evidence for the importance of capturing actions was highlighted by Oudejans, Michaels, and Bakker (1997) who examined performance of expert and novice baseball outfielders during two catching tasks. In the first, participants attempted to catch a ball, and in the second participants were merely required to point to where a projected ball would land. Skill differences between participants were only observed when they could act on ball flight information, rather than merely pointing to a landing location. It is critical, therefore, that designs and application of VR systems allow opportunities for regulation of faithful, full body actions/responses. Whilst the extent of some actions may be somewhat limited by current VR technologies, an important future challenge for engineers and technologists is to continue to design and develop systems which can support more representative actions of athletes under different task and environmental constraints.

Despite action fidelity (i.e. faithful actions/responses) being a critical component of VR design, importantly, it is not only the ability of VR systems to enable representative movement responses, but also the ability of participants to directly interact with and shape these environments through their movements. Learning is founded on continuous interactions of a learner with a performance environment in successful sport practice programmes. Current VR designs, which limit interactive movements of learners can be circumvented by using immersive technology that affords the capacity for individuals to navigate through an ever-changing environment (Sherman & Craig, 2002) and (re)organise actions relative to information available in the virtual environment. These interactions can enhance athlete self-regulation under different task and environmental constraints in sport by forcing adaptations of emotional, cognitive, perceptual and action sub-systems in individual learners, depending on their needs. It is vital that VR systems provide an interactive environment that invites the perception of presence by ensuring that elements within the VR environment can move or change in response to the ongoing actions of a learner (Baños et al., 2000; Sherman & Craig, 2002). For action fidelity to be maintained in practice, technology needs to be non-obtrusive and light-weight as this allows athletes to interact with environments without behaviour modifications due to such restrictions.

For this reason, a key requirement for VR systems is to ensure informational constraints of performance are faithful in the representativeness of athlete-environment interactions over time. In this way, VR systems could be used to constrain the acquisition of appropriate perception-action couplings for an individual athlete, accounting for uniqueness and variability of his/her interactions with sport performance contexts (see Correia, Araújo, Cummins, & Craig, 2012; Craig, Bastin, & Montagne, 2011; Watson et al., 2011).

Future research areas of VR for skill development

With the continued rapid development of VR systems (Neumann et al., 2018), we envisage that task functionality and action fidelity will continue to improve, enabling more effective and efficient learning designs, predicated on a clear theoretical rationale which supports a close coupling of perception and action sub-systems in athletes. The use of VR enables sport practitioners to control and manipulate both the environmental and task constraints in specific and reproducible ways (Hoffman, Filippeschi, Ruffaldi, & Bardy, 2014). These advances will enable athletes to interact with varying affordance landscapes within the learning environment (Davids, Güllich, Araújo & Shuttleworth, 2017). In the next sections of the paper we outline the potential advantages of VR to supplement and enrich current training programs, by careful manipulation of constraints, to enable: (1) individualised training and assessment, (2) development of variability and creativity in interacting with an affordance landscape, and (3), enhance context dependent decision making in representative performance conditions.

Individualised training and assessment

Ecological dynamics emphasises that coaches need to individualise training designs which can specify the parameters of functional interactions of an athlete with a simulated competitive performance environment. Equally, elite coaches have highlighted the importance of individuality within training as individuals respond differently to the task and environmental constraints manipulated (Greenwood, Davids, & Renshaw, 2012). Although individualisation is important, it is expensive in terms of human resources and time (effectiveness and efficiency), and would take almost as many coaches as players. For this reason, most sports organisations cannot fully exploit the full potential of an individualised training approach, relying instead on group-based sessions. If VR systems can be developed to understand the performance solutions needed by individual athletes, then key constraints can be identified and manipulated to facilitate skill development by encouraging exploration of individual movement solutions. Hence, for VR systems to be effective they must be able to consider the unique interaction of physical, physiological, cognitive and emotional characteristics of individual learners, which shape how an athlete solves performance problems (Araújo, Davids & Hristovski, 2006). Because of variations in each athlete, individual rates of skill development are likely to progress at different time scales (Liu, Mayer-Kress & Newell, 2006). Therefore, VR training systems need to take into account the different rates of learning, growth and maturation processes experienced by individuals during skill development. This could be achieved with feedback provided by continuous learning algorithms to each athlete directly in real time (Kim, Prestopnik, & Biocca, 2013). One area which could start to explore the effectiveness of such features are self-paced tasks such as rowing and cycling where VR systems are more easily designed to ensure coupling of perception and action (for a review see Neumann et al., 2018). Therefore, research could focus on how best to individualise training systems while ensuring a representative learning design.

A particular focus in developing individualised training programs could involve use of VR in injury rehabilitation. The use of VR systems may enrich rehabilitation programmes so that athletes avoid the boredom of over-using repetitive muscle-exercising regimes which dominate current methods. For example, overuse and repetitive strain injuries could be reduced by athletes strengthening coupling of cognition, perception, and nuanced, subtle movements, without the need for physical loading movements (e.g., repetition of problem solving opportunities without excessive physical loading on the skeletomuscular system). In professional sport, an injured player costs money but does not directly contribute to team performance, which can lead to pressures to accelerate the rehabilitation work or rushing a player back with danger of relapse (Akenhead & Nassis, 2016). Although rehabilitation procedures may focus more extensively on physical exercises, psychological components such as perceptual, cognitive or decision making skills have been shown as important factors in injury rehabilitation (Heaney et al., 2015). With VR, functionality of skill (re)acquisition may be enhanced by working on perceptual skills, developing decision making and cognition, as well as self-regulation through simulation of competitive performance scenarios from a first-person perspective (Craig, 2013). Use of VR can help each athlete to maintain functionality of movement during rehabilitation, although with reduced loadings on specific action sub-systems (Gokeler et al., 2016). In this case, reduced action fidelity may be beneficial during the rehabilitation period by reducing (re)injury risk. Indeed, some learning may be better than no learning at all during this highly specific phase of rehabilitation. In VR performance simulations there is no possibility of physical contact with other performers and athletes can use non-injured limbs and fewer degrees of freedom, significantly reducing risk of (re)injury. Use of VR could enhance effectiveness and efficiency of an individualised training program for a rehabilitating athlete before returning to practice on field with other players (often referred to in team sports as 'game conditioning'). However, further research is required to demonstrate the value of such an implementation of VR to facilitate rehabilitation specialists, athletes and coaches adopting the methodology to enrich their practice (Katz et al., 2006; Akenhead & Nassis, 2016).

An essential element of the application of VR in sports training is transfer from VR environments to competitive performance. Many perceptual training tools assume improved on-field performance, yet investigations of transfer are rare (for an exemplar transfer investigation see Gabbett, Rubinoff, Thorburn & Farrow, 2007). Underpinning VR implementation with representative learning design should enhance transfer between practice and performance. For example, Fitzpatrick, Davids and Stone (2018) demonstrated how manipulations to constraints in training underpinned by a representative learning design could afford the development of the backhand shot in children's tennis. However, transferability of skills, tactical understanding, creative behaviours and diagnostic procedures from the virtual environment to performance context is arguably the important challenge to be evidenced and aligned with existing data on transferability of skills (Tirp, Steingröver, Wattie, Baker, & Schorer, 2015).

Development of variability and creativity in practice: Designing specific affordance landscapes

An area of potential for VR is facilitating innovative performance behaviours in individual athletes, helping them to explore and develop a wider movement repertoire (Santos, Memmert, Sampaio, & Leite, 2016). An ecological dynamics rationale emphasises the design of affordances for innovative behaviours (thinking, adapting actions and decisions and the pick-up of varied information sources) under carefully managed task constraints, before seeking transfer to practice and then performance in a playing area (Davids et al., 2017). The design of a landscape of affordances for learning, using VR systems, is based on the potential to precisely manipulate specific virtual informational constraints, such as space, time, number of other performers, and locations in a performance area, in an almost infinite number of ways to individualise learning opportunities for athletes. For example, Figure 2 provides a scenario which seems simplistic but offers footballers a wealth of opportunities to explore intentionality, perception, action and decision making in utilising affordances in a performance landscape. This scenario could be used to develop subtle preparatory movements, such as (re)positioning, (re)orienting and adapting body angles to receive and pass the ball quickly according to the precise locations of defenders collectively trying to deny opportunities for a penetrative pass. Designing practice tasks to enhance player interactions can support the flow of movement, for example, helping players perceive emergent affordances of the biggest (most inviting) gap left by mobile defenders working together (Correia et al., 2012; Watson et al., 2011). The essential element for VR design here is to ensure availability of a landscape of affordances which promote what Bernstein (1967) called 'repetition without repetition' to enhance dexterity, problem-solving and exploratory behaviours of athletes as performers seek to solve problems and make decisions across subtly different scenarios. From this theoretical rationale, it is argued that subtle variations in VR practice environments will promote the necessary flexibility in performance through continued exploration and self-organisation of action responses as the performer adapts to these changing constraints. Through this continued exploration of their environment, performers will be encouraged to interact and discover different movement solutions to reach the same outcome (system degeneracy).

Figure 2 about here

In terms of coaching practice through use of immersive virtual reality, the convergence of (virtual) task, environment and organismic constraints contributes to the regulation and dynamics of human behaviour and can be manipulated to produce exploration of movement variability (Newell, 1986; Araújo et al., 2006). This process is founded through adaptive movement behaviours caused by the establishment, reestablishment and refinement of information movement couplings inherent to the performer (Araújo et al., 2006). Manipulating informational constraints in VR systems could induce phase transitions in individual performers by creating learning environments which drive individuals to a meta-stable region of the perceptual-motor landscape of practice where a strategy of co-adaptation can underpin the emergence of creative behaviours. In this process, the athlete is guided to search appropriate areas of the perceptual-motor landscape during practice, not instructed to form a specific movement pattern considered to be optimal by a coach. If an extensive range of affordances can be designed into learning environments, this could enable learners to explore and develop the intertwined relationship between cognition, action and perception without the physical demands of repetitive actions in a sport. Importantly, despite VR systems offering a range of potential learning environments and manipulations to those environments which could enhance creativity, currently the limited availability of haptic feedback or ability to interact with physical objects such as balls still limits the scope of such training environments. While, currently, vibrations can be designed into VR system technology to simulate haptic information from interacting with objects, this is an area that future researchers may target for enriching feedback in VR systems.

Context dependent decision making

Sport coaches currently attempt to simulate aspects of competitive performance environments in practice so that athletes can attune to performing in specific situations against particular opponents. Research has proposed the benefits of affective learning designs to enhance the self-regulation of athletes (see Headricks, Renshaw, Davids, Pinder, & Araújo, 2015; Runswick, Roca, Williams, Bezodis, & North, 2018). To maximise the potential benefits of VR, the systems could be used to simulate not only representative perceptual information, but also challenging situations which require self-regulation, such as different cultural and social contexts, crowd abuse and noise, varying weather conditions, emotional pressure from specific opponents, and even performing in conditions that require increased levels of self-motivation. For example, VR has been used to facilitate simulations of high pressure environments, such as by inducing anxiety in a cohort of soccer players during a penalty-kick shooting task (Stinson & Bowman, 2014). Introducing elements of competition or pressure in VR learning environments could facilitate individualised management of stress and specified dimensions of competitive anxiety (Parsons & Rizzo, 2008). Through practice in a VR environment, athletes can train for competitions under the specific conditions predicted for an actual event in representative simulations. In this way VR could be a prominent training tool for enhancing specific self-regulation skills in individual athletes, which warrants further investigation.

The use of perceptual and cognitive process training has been introduced in many sporting and research environments (Harlow, Panchuk, Mann, Portus, & Abernethy, 2018). For example, research has attempted to train attention towards specific features of a performance environment by occluding or artificially highlighting key performance features, such as postural cues of penalty takers when training anticipation skills in soccer goalkeepers (Murgia et al., 2014). However, much of the data generated from these measures have been taken from a reductionist method which removes much of the context (e.g. score line, history of playing against an opponent) from the decision making task. Use of VR environments which introduce varying contextual factors while concurrently measuring gaze and movement behaviours have potential to further understanding of expert perceptual processes (e.g., scanning, attentional and anticipatory behaviours) in representative, context specific performance environments.

Conclusion

Use of VR systems in learning design could provide a suitable vehicle for specificity of practice to enrich athlete interactions with simulated performance environments, encompassing cognition, perception and actions in practice. An ecological dynamics framework can underpin the design of virtual environments to support effectiveness, efficiency and efficacy in developing a deep integration of cognitive, perceptual and movement skills during these simulated interactions. The use of VR systems can specify training for individuals by focusing their attention on specific fields within an affordance landscape (Davids et al., 2017). For example, investment in a VR system oriented for the acquisition of expertise in youth football could: (1)enrich athlete performance by individualising training programs which can be complemented with group-based, physical practice contexts, (2) reduce the time to achieve 'game conditioned' status when returning from an injury, and (3), help promote engaged (i.e., motivated and invested) players in their development over prolonged periods of practice. The use of virtual reality in training is not intended to replace the role of sport practitioners, such as a coach, but to assist them and complement on field training by enriching the learning of athletes.

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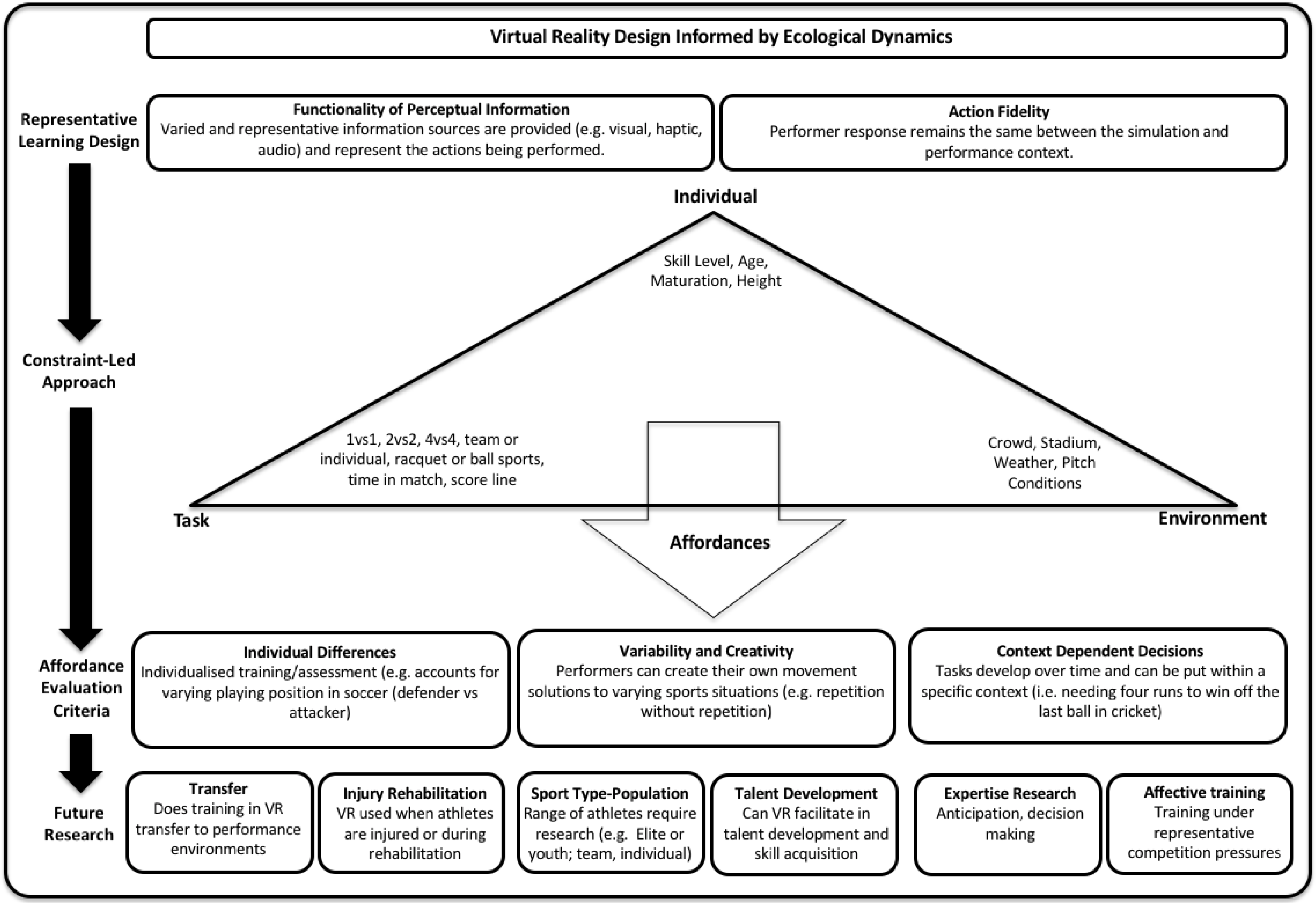

Figure 1. An Ecological Dynamics framework to guide the use of Virtual Reality in sport and highlight potential future research

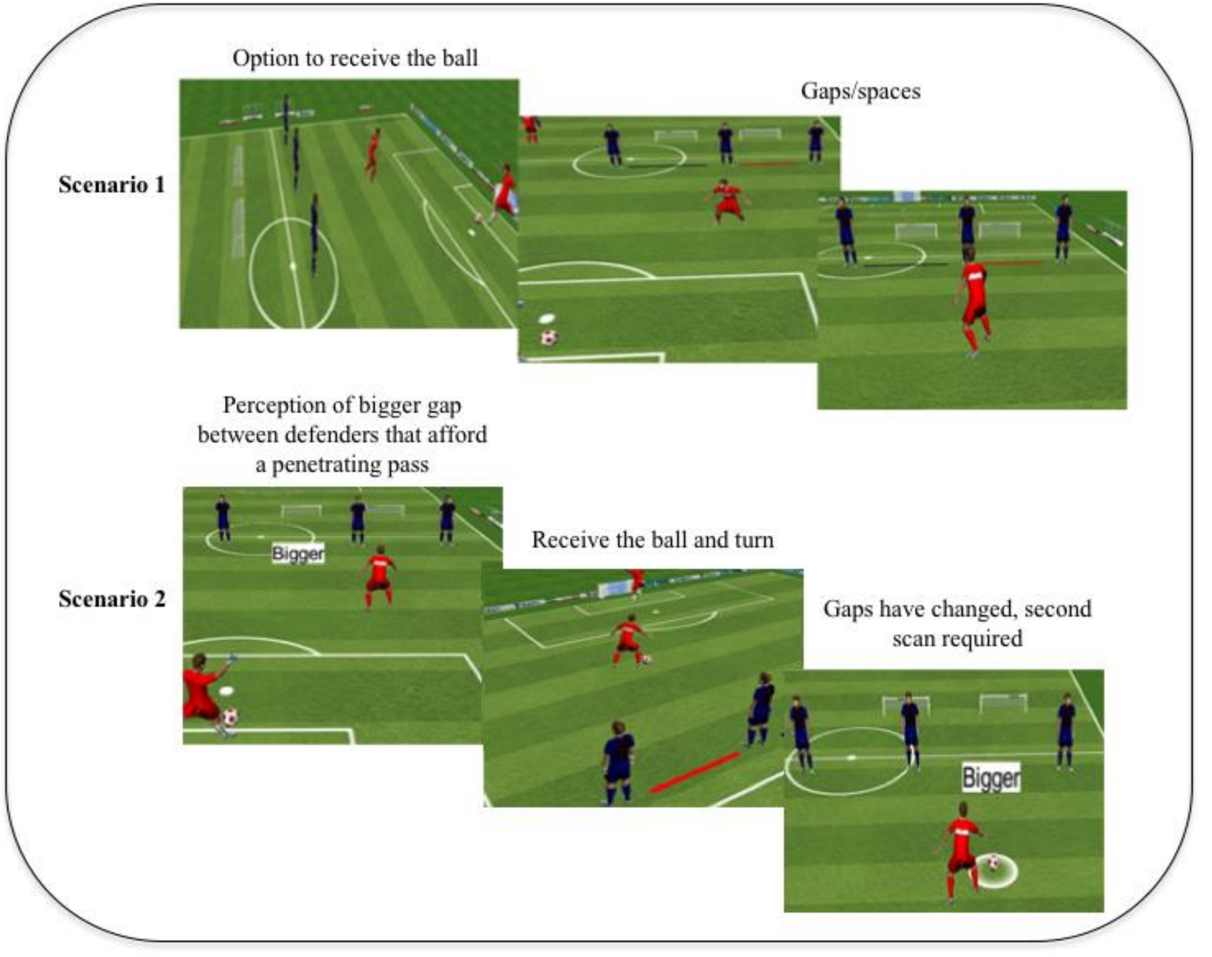

Figure 2. Virtual Reality practice scenarios. Scenario 1: The receiver in red must control the pass from a teammate and turn to play the ball into either small goal area. The task is to find the biggest affordance (gap/space) and play the penetrative pass. Here, the distance between the defender is fixed over time. Scenario 2: The distance between defenders changes over time with more advanced learners needing to perceive the biggest emerging gap.