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EXPERT PERFORMANCE IN SPORT AND THE DYNAMICS OF TALENT DEVELOPMENT

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Abstract

Research on expertise, talent identification and development has tended to be mono-disciplinary, typically adopting adopting neurogenetic deterministic or environmentalist positions, with an over-riding focus on operational issues. In this paper the validity of dualist positions on sport expertise is evaluated. It is argued that, to advance understanding of expertise and talent development, a shift towards a multi-disciplinary and integrative science focus is necessary, along with the development of a comprehensive multi-disciplinary theoretical rationale. Here we elucidate dynamical systems theory as a multi-disciplinary theoretical rationale for capturing how multiple interacting constraints can shape the development of expert performers. This approach suggests that talent development programmes should eschew the notion of common optimal performance models, emphasise the individual nature of pathways to expertise, and identify the range of interacting constraints that impinge on performance potential of individual athletes, rather than evaluating current performance on physical tests referenced to group norms.

Key words: Expertise, Talent Development, Talent Identification, Skill Acquisition, Dynamical Systems Theory, Sport Performance

Research on expertise and talent identification and development has been dominated by opposing geno-centric or environmentalist positions.[1] Recently, Dunwoody[2] has challenged psychologists to look beyond the individual, suggesting researchers have neglected the role of the environment and focused on organism structure and process in isolation. This position has been criticised for emphasising neurogenetic determinism by Rose, due to its focus on identifying genetic or neural codes deemed 'responsible' for behaviours. Although there is a need to move away from the cognitive psychology asymmetric–organismic focus[2], the tendency to over-emphasise the role of environmental constraints on expertise acquisition also needs to be eschewed. For example, Ericsson and colleagues[3] emphasised an environmental perspective, advocating that expertise is acquired as performers specialise at an early age and engage in deliberate practice.[3] Other investigators have associated the hereditary nature of physiological, anthropometric and psychological characteristics with elite performance in sports.[4] For example, early anthropometric research on Olympic athletes advocated a close relationship between physical characteristics and specific Olympic events.[5] This line of evidence has been somewhat over-interpreted, leading to the questionable practice of anthropometric profiling of adolescents to identify potential for early specialisation in a sport. Consequently, anthropometric profiling of physical dispositions has tended to skew the rationale for talent identification models in sport, despite a lack of supportive evidence and the unstable nature of anthropometric and physical parameters during adolescence.[6, 7]

Recently, there have been proposals to integrate polar perspectives on sports performance and expertise into a multi-disciplinary approach, to enhance understanding of the athlete–environment relationship as exemplifying a complex, dynamical system. In this position paper we identify limitations of existing research on expert performance and talent development, and provide evidence-based arguments for adopting a multi-disciplinary research perspective for the comprehensive study of sport expertise. To support our argument we review and evaluate extant literature on expertise in psychology and sport science. The search reference terms used included 'talent development', 'talent identification' and 'sport expertise' in PubMed, SportDiscus and Ovid databases.

A major reason for adopting polarised, mono-disciplinary positions on the acquisition of sport expertise has been the absence of a powerful multi-disciplinary theory to act as an integrative conceptual framework. Although some models have advocated a multi-disciplinary approach to talent identification and development, such as Simonton's[8] model of talent as a multiplicative, dynamic process and the Differentiated Model of Giftedness and Talent,[9] these approaches tend to be operational and propositional in nature. These models have not provided a detailed, explanatory theoretical rationale underpinning a dynamic and multi-dimensional basis for expertise and how it may support the process of identifying and developing talent.

One suitable theoretical approach to the study of performance, expertise and talent development in sport conceptualises the athlete as a complex, dynamical system. In such systems there is great potential for interactions between system components and the environment, often leading to rich and unique patterns of behaviour. To date, studies of complex system behaviour in sport include match play and behaviour during competitions,[10, 11] decision-making,[12, 13] motor learning,[14, 15] coordination,[16, 17] human gait and injury[18, 19] and medicine in sports.[20] In this article relevant theoretical concepts and insights from dynamical systems theory, complex systems theory, ecological psychology and evolutionary sciences are identified and their implications for the acquisition of sports expertise and talent development are discussed.

1. Traditional Expertise Approaches

As noted, much research has focused on the role of environmental constraints in expertise acquisition, including participation in play and practice activities, and the role of family and environmental contexts.[21, 22] For example, Ericsson and Smith's[23] expert performance approach explored the contribution to expertise of specific practice environments. Ericsson and colleagues'[24] deliberate practice approach has highlighted the importance of structured activities involving goal directed skill learning which require effort and concentration. It was estimated that experts spend typically about ten years or 10,000 hours in deliberate practice to attain exceptional performance.[25] The uni-dimensional nature of the deliberate practice approach led Starkes[26] to label it a 'very environmentalist' theory of expertise acquisition, while others (e.g.,[27]) have proposed it has an organismic bias. Additionally, researchers studying deliberate practice in sport have encountered some incongruities with the theory's main tenets. For example, in contrast to previous findings, many athletes tend to find appropriate practice and training enjoyable and motivating across all development stages.[28] Moreover, early specialisation has not been found to be essential for acquisition of expert sport skills in adulthood.[29-31] Time spent in sport-specific training does discriminate between experts and non-experts in some sports, although the relationship between practice and performance is non-linear.[21] Further, retrospective analysis of historical data on time spent in practice has been criticised by Yarrow et al.., For example, this method was unable to clarify differences between experts and novices based on micro-structure of practice activities.[32] For example, Weissensteiner, Abernethy, Farrow and Müller[33] examined the practice histories of under-15, under-20 and adult cohorts of skilled and less skilled cricket batsmen and found that hours spent in practice explained only a small proportion of variance in the development of anticipation skills. A particular methodological concern in this approach is the proliferation of ‘weaker’ data from a plethora of cross-sectional studies, relative to the lack of longitudinal research. More evidence on putative benefits of deliberate practice is needed, following cohorts of young athletes through developmental pathways. To summarise, although numerous hours of training are necessary for success in sport at the elite level, research suggests that attainment of expert level is not always accomplished by engaging in deliberate practice alone.

In another polarised approach to elite sports performance, some research has investigated the genetic makeup of individual athletes. Molecular testing has attempted to identify single gene variants deemed ‘responsible’ for performance in specific sports (e.g., a gene responsible for physical power or endurance capacity). This ‘single gene as magic bullet’ philosophy has been eloquently criticised for its determinist stance (Rose, 1995) although it has led to claims that elite performers are born to succeed. For example, there have been attempts to identify sprinters and endurance runners on the basis of differing alleles (i.e., forms) of a single gene known as alpha actinin-3. [34, 35] Besides obvious ethical issues, reports of gene-profiling and gene-transfer technology raise more general theoretical and practical questions about the nature of genetic and environmental constraints on skill acquisition and performance.[36] Research on human behaviour has yet to reveal that the function of a single gene variant can be inferred from identifying performance phenotypic variance (e.g., power athletes and endurance athletes), supporting the notion of non-specificity of genetic constraints.[37]

1.1 Methods for assessing expert performance in traditional research

Empirical expertise research has typically been conducted with two main methods involving: (i) quantitative analyses, which include implementation of multiple test batteries on developing athletes; and (ii) qualitative examination of developmental histories of past or present elite athletes, with methods such as interviews, questionnaires or self-reported, retrospective recall of practice histories.

1.2 Outcomes of research with quantitative methodologies

Attempts to distinguish athletic expertise based on skills testing have been unsuccessful or have been confounded by the over-riding importance of maturational factors on observed performance.[7] The over-use of ‘closed-skill drill tasks’ to elucidate athletic potential has been a major weakness in extant research because they lack task representativeness, resulting in a failure to identify skilled players from lesser skilled individuals. For example, Gabbett, Georgieff and Domrow[38] attempted to assess skills of passing (digging), setting, serving, and spiking as part of a test battery to discriminate between junior volleyball players of different abilities. The only test that revealed differences between selected and non-selected players was passing. This may have been because skills in volleyball (digging, setting, spiking and blocking) are not performed in stable environments but are dynamic and characterised by marked temporal and spatial variability dependent on preceding play (e.g. quality of contact of the ball by teammates and opponents). In other work, Hoare and Warr[39] assessed talented athletes (non-football players) aged 15-19 years to identify and develop female football players. Initial screening required coaches to grade players by assessing skill performance such as ball juggling, dribbling (around cones) and passing. Players were grouped by performance test scores for playing small-sided games before progressing to full-size games for coach observation and selection. Hoare and Warr[39] used an innovative quasi-applied research model to identify and develop talent in women’s soccer, and highlighted the need to assess athletes over a longer time period than typical in sport talent assessment, suggesting that two to three months is necessary for coaches to make a valid assessment of athlete potential. They also proposed that components of performance require different weightings since the importance of speed and acceleration was underestimated in their tests. Finally, the need to develop an objective test of game sense was suggested as some athletes performed well on physical tests, but weakly in terms of general tactical understanding.

Other quantitative approaches in empirical talent identification research have attempted to examine sport-specific, relevant performance characteristics, through anthropometric, physical, technical, tactical and psychological testing.[39-43] In the main, these tests have been limited in utility for identifying talented performers in sport. For example, test batteries focusing on discrete performance measures have provided limited information of athletic potential and adaptability in different performance environments.[6, 40] Questions on the data of these studies, and the efficacy of traditional talent identification practices, arise due to constraints on individuals like growth, maturation, development and training.[41] To exemplify, Elferink-Gemser, Visscher, Lemmink and Mulder[42] employed a test battery to examine 30 elite and 35 sub-elite youth hockey players over three competitive seasons. Their research established differences in technical and tactical variables between skill levels at 14 years as well as variations in endurance capacity in the subsequent two years. However, the task demands of the technical test did not provide a valid representation of the competitive performance setting (cf. the importance of representative experimental design in studies of human behaviour).[43] The use of closed skill proficiency tests, without opposition and in a static environment, and physical performance measures considered in isolation need to be carefully evaluated, because they have a low correlation with the specific demands on an individual during a dynamic competitive situation. Several studies have highlighted the importance of using more sports-specific assessments of tactical and technical competence rather than generic physical measures such as strength or endurance tests.[39, 44]

Skill-based differences in perceptual-cognitive skills such as anticipation and decision-making have been successfully identified in a number of studies (see Williams & Ward).[45]

Although a number of generalised visual training programmes are predicated on the idea that a superior visual hardware system provides perceptual advantages to skilled performers, research evidence does not support this view. Rather it has been argued that expertise advantages emerge as a result of sport-specific practice and experience.[45-47]

Despite the large volume of studies examining the role of perceptual-cognitive expertise in sport, there has been some confusion over whether research has actually demonstrated the true extent of expertise. Van der Kamp, Rivas, van Doorn, and Savelsbergh[48] criticised the lack of precision in perceptual-cognitive research, highlighted the magnitude of errors reported in many occlusion-based studies of anticipation skill, and suggested a weakness in a popular experimental methodology. In a popular approach, liquid crystal spectacles permit information sources available to participants to be manipulated by limiting vision during key moments of performance.[49] It was argued that high levels of error observed in these studies may have been due to the failure of the methodology to capture the complementary efforts of the ventral and dorsal cortical visual systems in regulating perception *and* action. This is important since, as Williams and Ericsson[50] indicated, the first stage in determining expertise is that 'performance be observed *in situ* in an attempt to capture the essence of expertise in the domain of interest and to design representative tasks that allow component skills to be faithfully reproduced in the laboratory' (p.286). Van der Kamp et al.[48] also argued that a weakness of previous work was requiring participants to undertake non-representative actions such as pressing buttons, marking crosses on images of court surfaces, and verbally reporting findings. Another common error is the provision of video footage that does not replicate the view of performers in action, thereby limiting understanding of the true extent of the expert advantage. Some researchers, such as Müller and Abernethy,[49] have developed and incorporated what they termed as an 'ecologically valid' batting test to measure a batsman's perceptual-action coupling and found skilled players utilised prospective ball flight information to a greater extent than less skilled players.

1.3 Outcomes of research using qualitative methods

Qualitative studies on the development histories of elite athletes have been somewhat limited in number, examining physical, psychological, environmental and social factors that shape performance.[51, 52] They have established the importance of environmental constraints including support from family or friends and the opportunity to participate in residency development programmes. A range of individual constraints including mental preparation, focus and commitment, and clear goal setting have been found to contribute to the development of expertise.[6] Durand-Bush and Salmela[52] examined qualitatively the development and maintenance of expert performance in Olympic and world championship competitions. Their data revealed that athletes did not all follow the same pathway to become world and Olympic champions, highlighting how individuals can take different routes to expert status, use various resources and strategies, and be innovative and creative as they develop and maintain their expertise in sport. However, some common factors were observed including: (i) all athletes underwent stages described as the sampling, specializing, investment and maintenance years;[53] (ii) high levels of self confidence and motivation; and (iii) high levels of creativity and innovation during the maintenance years, a continuous drive to learn and improve, and a strong work ethic.

2. Dynamics Systems Theory and Constraints on the Acquisition of Expertise in Sport

In contrast to more traditional approaches to studying expertise, a potentially valuable conceptual framework for modelling the acquisition of expertise exists in understanding performers as complex, dynamical systems. Complexity sciences have been used to study and explain the rich patterns formed in complex systems such as animal collectives, weather systems, the human brain and movements in team sports, where patterns emerge from seemly random component trajectories.[54-56] From this description an emerging expert can be viewed as a complex system, composed of many degrees of freedom on many system levels. The potential for interaction between system components provides the platform for rich patterns of behaviour to emerge as individuals interact with dynamically changing environments. This new perspective reveals that adaptation in performance occurs as the result of system trade-offs between specificity and diversity of behaviours.[57] Dynamical systems theory emphasises the influence of interacting constraints on performance and provides a framework showing how expertise can be achieved in diverse ways as individual performers attempt to satisfy the unique constraints on them.[20]

Some current models of talent development are harmonious with these theoretical ideas, although their tenets are not necessarily predicated conceptually on these insights. For example, Simonton[8] proposed that talent emerges from multidisciplinary, multiplicative and dynamic processes and is likely to operate as an intricate system beyond the scope of the polar nature–nurture debate. He pioneered mathematical equations to operationalise the potential components that contribute to talent development. These components were weighted by relevance and included reference to genetic dispositions (e.g. height or endurance capacity), environmental (e.g. social and familial support) and developmental constraints. Subsequently the model was described as emergenic and epigenetic, comprising components that interact and change with time[8]. The emergenic aspect proposed that potential talent consists of multiple components, including all physical, physiological, cognitive and dispositional traits that facilitate the manifestation of superior expertise in a specific domain. Beyond individual differences, Simonton's [8] model captured the dynamics of epigenetics. Epigenetics were seen in the diverse components that make up talent which slowly appear and differentiate over time in an individual and ultimately depend on underlying neurological, muscular, cultural, skeletal, social, psychological, physiological and environmental variables.[58] However, they emerge gradually during the course of long-term interactions between the internally developing organism and appropriate environmental constraints.[8] This system is complicated, as it includes the evolutionary interaction of components, and any examination of talent development that utilises this model needs to be holistic, impartial and sophisticated.[8] Although this mathematical model is a useful starting point for sport scientists since it attempts to operationalise key concepts such as multidisciplinary talent development practices and multiple developmental trajectories towards potential expertise,[6] it lacks theoretical power as it is not conceptualized within a theoretical framework. This weakness could be mediated by including dynamical systems theory as a viable rationale for talent development as an emergenic and epigenetic process. Furthermore, on a practical level, adopting Simonton's[8] model may be extremely difficult as its efficacy is predicated on identifying *all* components that contribute to expertise in any one specific sporting domain. Identification of every component is essential because the model is proposed to be multiplicative, and any score of zero for any specific factor signifies that expertise cannot be achieved.

Vaeyens et al.[7] provided an insightful model of talent identification, capturing the dynamic nature of talent and its development, and focusing on potential for development and inclusion rather than early identification. Such a model can be strengthened with a dynamical system theoretical approach also, and in the next section we elucidate key ideas in this framework.

2.1 The Role of Neurobiological Degeneracy in Expertise Acquisition

Athletes considered as complex, neurobiological systems are comprised of many interacting parts and levels, which self-organize under constraints.[59] These systems have been conceptualised recently as pleiotropic and degenerate with the ability to adapt to different task and environmental demands.[60] Pleitropy provides neurobiological systems with a variety of alternate performance solutions.[61] Neurobiological degeneracy refers to the ability of structurally different components to be coordinated together to achieve the same behavioural goal.[57] At the level of gene networks, degeneracy promotes evolutionary fitness by ensuring that genetic diversity supports functional adaptation to variable environments.[62] The degenerate relationship between system components and system output in developing experts implies that there are many different pathways to achieving expert performance. Genetic diversity is responsible for a portion of training or performance response differences between individuals, and when there is a favourable interaction with important environmental constraints, performance benefits may be observed. Given differences in genetic contributions, performance variations are more likely to assert themselves under intensive practice regimes.

The characteristics of pleiotropy and degeneracy in athletes highlight the need for a systems-oriented, multidimensional framework.[22] Expertise attainment in a particular sport depends on many additional constraints outside the cognitive domain, including but not limited to genetics, social and physical environment, opportunity, encouragement and the effect of these variables on physical and psychological traits.[63] Mono-disciplinary approaches to the acquisition of expertise (e.g., Yarrow et al., 2009) have failed to capture the complementary nature of the relationship between individual, task and environmental constraints.[6, 22, 64] For these reasons, Davids and Baker[22] highlighted the need for an interactionist explanatory framework to examine performance attainment in sport. As we note in the following sections of this paper, this theoretical approach provides a viable platform for explaining the dynamic relationship between an individual's genetic disposition and the environment and the acquisition of expertise in sport through variable pathways and processes.

2.2 Constraints on Acquiring Expertise

In sport, the expression of expertise is limited or shaped by interacting constraints at many system levels. The concept of constraints (boundaries that constrain the interactions of system components) in human movment science was readdressed by Newell.[65] He classified them into organismic, task and environmental constraints.[65] Constraints in the expertise acquisition context can be conceived of as the numerous variables that form each individual expert's developmental trajectory, and itis important to identify the range of constraints on the acquisition of expertise. Given that an individual is born with distinguishing physical characteristics (with a degree of genetic influence), expertise research is concerned with how environmental constraints interact to affect the development of skill and the expression of genotypes.

Performance emerges from the intrinsic dynamics of experts, the preferred behavioural tendencies which arise from the interaction of environmental, task and organismic constraints (including development, experience, genes and learning of each performer).[66] Kelso[66] proposed that intrinsic dynamics reflect the organisational tendencies of an individual. Thelen[67] referred to intrinsic dynamics as "the preferred states of the system given its current architecture and previous history of activity" (p.76). The intrinsic dynamics of each individual are unique and shaped by many constraints including experience, learning, development, morphology and genes which interact to shape performance and the acquisition of expertise in sport.[68] In developing experts, these contributions can lead to significant variations in performance solutions. The manner in which each developing expert attempts to satisfy constraints during performance and learning is determined by the matching of his/her intrinsic dynamics with the specific task dynamics.[69] By knowing an individual's intrinsic dynamics one can specify what in the performance repertoire actually changes due to environmental, learned or intentional influences.[70]

Due to variations in intrinsic dynamics, expert performers are able to generate different types of functional performance solutions. This idea fits with data, in cricket fast bowling reported by Pyne, Duthie, Saunders, Petersen & Portus[71] who examined the relationship between junior and senior high performance athletes' anthropometric and strength characteristics and bowling speed. They observed differences in the variables and strength of correlation of predictors of peak ball speed between age groups and suggested growth and biological maturation largely accounted for greater peak ball speed in seniors. This line of thinking could be followed in a comprehensive performance analysis including technical/coordination variants under a variety of conditions, such as different delivery types, to gain an understanding of the relationship between the intrinsic dynamics and performance solutions of individuals in developmental groups.

Therefore, understanding the nature of each individual's intrinsic dynamics is central to understanding how expert performance develops in sport. Due to different relationships between an individual's intrinsic dynamics and a set of task dynamics, each athlete may harness system variability in a different way implying that expertise may develop in quite unique ways. As individuals progress towards a state of expertise and explore different performance solutions, their intrinsic dynamics will alter and diversify. If the behavioural requirements of a task provide a close match with the pre-existing intrinsic dynamics of an individual learner, the rate of expertise acquisition is likely to be enhanced. The matching of intrinsic and task dynamics may explain precocial behaviour in sport when some athletes can perform incredibly well from an early age and forms the basis of talent transfer in sport. In contrast, acquiring task dynamics which are dissimilar to those of a previously learned task (e.g., tennis and squash movement pattern dynamics) may lead to a longer process of learning because the specific learner's intrinsic dynamics may need to be significantly re-shaped.[72]

These ideas in dynamical systems theory have important implications for understanding the development and maintenance of expert performance. How the intrinsic dynamics of developing experts are continually shaped by genetic and environmental constraints needs to be understood. The effects of environmental constraints on phenotypic gene expression suggests that athletes with what may be perceived as less favourable genetic dispositions may still achieve expert levels of performance given an appropriate skill acquisition environment.[73] Alternatively, genetically gifted athletes may fail to achieve expert status without an environment that allows rich interactions for acquiring and practising skills (for a discussion of rich learning environments see ideas of Hammond and Bateman).[74] Rich learning environments provide many opportunities to engage in continuous interactions with skilled peers, mentors, skilled coaches and supportive parents as athletes acquire movement skills and knowledge in specific sports. In Australia, Abernethy[75] discussed the disproportionate success of athletes from rural locations as the 'Wagga-effect'. Wagga Wagga is a rural town with a population of 46,735 people,[76] where children typically play many different sports, often engaging in senior or adult competition prior to specialisation. It has produced an inordinately high number of international and professional athletes, more than any other urban conurbation in Australia. Côté, et al.[77] suggested that smaller cities (defined as having populations <100, 000 people) provide advantageous opportunities for talent development, because the populace is large enough to support the need for facilities, different sporting codes, club networks and competition infrastructure, and allows early exposure to adult competition. Côté et al.[77] referred to the 'birthplace effect' where the quality and quantity of play and practice interactions afforded by the physical environment of smaller cities is favourable for talent development. These data highlight the need to undertake more research examining appropriate environmental cultural constraints underpinning development of expertise. The range of unique constraints on athlete performance and behaviour have made predictions of expert performance difficult due to the dynamic nature of sport performance contexts.[22]

To summarise so far, it seems unlikely that a singular common optimal pathway to performance expertise exists because of the degenerate neurobiological system characterising each individual performer and the effect of interactions between environmental and personal constraints on the intrinsic dynamics of each learner. Expert performers are able to generate different types of functional performance solutions, depending on differences in their intrinsic dynamics. Future research needs to provide a more comprehensive examination of influential constraints including technical/coordination variants under a variety of tasks' demands. For example in cricket fast bowling, investigating different delivery types, would allow greater insight into the individual dynamics and movement solutions of such a group (e.g., varying ball speed or type and line and/or length in cricket fast bowling).

3. A Complex Systems Approach to Talent Development

Conceptualising expertise acquisition as a complex system has several implications for talent development programmes. First, the aim of talent development is to aid individuals in gaining the expertise needed to satisfy the unique constraints impinging on them in specific performance domains. This can be achieved by measuring intrinsic dynamics of each individual athlete, identifying key constraints on him/her and facilitating development by manipulating these constraints to encourage exploration of movement solutions. [68, 78-80], Second, talent development programmes can harness existing system nonlinearities by developing strategies to induce phase transitions in individual performers. This aim might be met by understanding how to force individuals into the meta-stable region of the perceptual-motor landscape of practice where a strategy of co-adaptation can underpin the emergence of creative behaviours (typical of the profile of expert performers in line with the findings of Durand-Bush and Salmela).[52] Meta-stable regions of a performance landscape are areas where the system is poised in a state of dynamic stability which allows it to rapidly undergo phase transitions to new, more functional states of organisation as constraints change. If this strategy were aligned with observations of critical developmental periods in young athletes, abrupt phase transitions in expertise and performance may be induced. An implication of this approach for coaches is to incorporate tasks that promote adaptability and creativity in performers. In cricket, this aim could be tested through the implementation of carefully designing games that require batters to probe the boundaries of their skill set and force co-adaptive behaviours in learners as long as the design of game tasks are based on grounded principles of the game .[72]

Third, these ideas signify the nonlinear nature of expertise acquisition. Traditional models of talent development need to be adjusted to consider the different rates of development of potentially talented athletes.[6] Sub-system behaviours continually shape an individual athlete's intrinsic dynamics. Because of variations in each athlete's intrinsic dynamics, individual rates of skill acquisition are likely to progress at different time scales.[14] Talent development models need to take into account the different rates of learning and growth and maturation processes experienced by individuals on their pathway to expertise (not least it must take into account the relative age effect to maximise the available talent).[81] These different rates of learning can be influenced by key constraints which act as 'rate limiters' causing systems to find new functional performance solutions.[78] Rate limiters can be defined as system controllers, i.e. components or sub-systems which limit the development of an individual in sport.[79] For example, children's strength in key muscle groups may act as a rate limiter which inhibits them from demonstrating the skills that they have acquired already through practice and experience in sport. An important task is to identify the rate-limiting constraints which are acting on an expert system in order to manipulate them and facilitate transitions to a new performance level.

4. The Role of Meta-stability in Acquiring Expertise

Two important characteristics of complex systems mentioned already include meta-stability and co-adaptation. These features are important for talent identification and development but need to be conceptualised in the sport performance domain. Emerging expert athletes exhibit complexity and meta-stability due to the potential for interaction between their sub-systems. In this way, the whole dynamical landscape of expertise can suddenly change with small variations in responses to constraints impinging on the developing athlete. Critical periods have been identified as brief windows of time and space during which a complex system's organisation is most open to modification from external and internal constraints. It has been argued that motor learning can be enhanced when developing athletes are located within these critical periods[82].

The challenge for coaches and sport scientists is to identify when individual athletes enter meta-stable regions and/or critical periods while developing their expertise levels so that performance paradigm shifts in expertise and skill acquisition might be triggered, as we exemplify in this section. For the individual to utilise technical and cognitive variability and find new performance solutions and cope with instabilities (meta-stability) requires complementary cognitive attributes (e.g. confidence, sacrifice, dedication, and perseverance). By ensuring exposure to meta-stable regions of the performance landscape during development, experts can discover new modes of behaviour to satisfy interacting perceptual, affective and task constraints. These new modes of performance are likely to emerge as novel solutions to performance problems as developing athletes co-adapt their responses to challenging constraints imposed by opponents, coaches or performance environments.

Co-adaptation is an evolutionary strategy that has implications for the way that constraints can influence the process of talent development by forcing the developing expert to find new functional performance solutions. It may represent a useful expertise development strategy for practitioners, as different performers and/or technologies attempt to pressurise individuals to seek unique performance solutions. Furthermore, the process occurs naturally as a sport develops (i.e., through technique changes, rule changes or equipment change or as athletes pose each other new performance problems). New solutions to performance problems emerge as talented individuals learn how to assemble creative movement solutions during practice.

In cricket, fast bowlers can make the ball “swing”, which is the curved trajectory of the ball’s flight path, thereby making the task of hitting the ball more difficult for the batter. A cricket ball will swing when asymmetrical aerodynamic forces are acting on the ball, conventionally achieved by angling the ball’s seam obliquely to its direction of travel and caring for the ball so that one side is shiny and smooth and the other dull or rough. A more modern variant of this flight characteristic is “Reverse swing”, which originally gained prominence in Pakistan in the 1970s, with the success of players such as Sarfraz Nawaz, Imran Khan, Wasim Akram and Waqar Younis. These players experimented with ball care and grips and found they could achieve reverse swing, by focussing less on keeping the ball smooth and shiny on one side, and bowling the ball with the rough side forward (rotating the ball 180^{o} from the traditional position for swing bowling).[83] The prominence of this technique in Pakistan has been attributed to the specific environmental conditions such as hard dry grounds resulting in balls enduring greater wear and tear at a faster rate.[83] Reverse swing fast bowling is now considered one of the most potent forms of attacking bowling in cricket, seldom mastered but often aspired to in elite level fast bowling.

In other sports, performance paradigm shifts have been created by:

(i) equipment changes (e.g., the change from bamboo to fibre glass pole vaults leading to the World record increasing from around 4.5m to 6.14m in a vault by Sergey Bubka in 1993);

(ii) changes to playing surfaces (such as international hockey matches on artificial turf instead of grass), which may explain the ebb and flow of current performance standings and international rankings between countries; and

(iii) rule changes, such as the turn-over law in rugby union or the distance of the three-point line in the Olympics versus the NBA.

In elite sport, the drive for success means that performers are being challenged constantly to co-adapt to succeed. Through co-adaptation, players need to add new skills or strategies in the off-season in order to continue to challenge opponents with new problems.[84] Essentially, players have to constantly re-invent themselves or demonstrate an ability to adapt to the strategies developed by opponents. A good example of this adaptation was observed in 2008 in cricket when the use of ‘switch hitting’ by Kevin Pieterson (a current English test batsman) was first formalised. He developed a strategy of changing his stance (from his typically right-handed position) as a bowler was in the process of delivering a ball, by 'jumping' into a left-handed stance in order to overcome the restrictive field placings of opponents in one-day cricket.

The idea of sub-systems co-adapting to constraints imposed by other sub-systems of the body is influential in a dynamic systems analysis of motor development across the lifespan.[80] For example, during children's motor development, dynamic systems analysts emphasise the idea that specific behaviours may not have yet appeared in developing children, because specific sub-systems act as system 'rate limiters' and are 'lying in wait' for another critical sub-system to reach a critical level (e.g., changes in the muscle to fat ratio in infants to enable upright postural control). In the performance of specific sports, various sub-systems could be critical to the performance development in athletes, such as strength, speed, mobility, or game understanding as a result of numerous experiences.

5. Conclusion

Historically, expertise research has typically focused either on the role of nature (genes) or nurture (environment) as mechanisms for understanding how experts emerge in performance domains such as sport. This dualist approach has failed to emulate the complementary nature of the relationship between individual and environmental constraints. Although numerous hours of training are needed at the elite level, attainment of an expert level of skill is not accomplished by hours of deliberate practice alone. Similarly, the importance of an individual's genetic make up has been accentuated with biased interpretation of genomic studies. In recent years sport performance research has encompassed a move toward multi-dimensional models of performance and learning in sport, with significant implications for understanding processes of expertise and talent development. In this article we have shown how dynamical systems theory and the complexity sciences might provide the basis of an interactionist perspective on expertise acquisition in sports.

Dynamical systems theory is an appropriate functional framework for expert performance research because it can be used to consider developing athletes as nonlinear, complex neurobiological systems. It avoids the organismic asymmetry which can be observed in traditional models of expertise acquisition and talent development, addressing questions that other frameworks do not have the language and tools to pose. This paper has highlighted several concepts with important implications for expertise and talent development researchers, including the concepts of self-organisation under constraints; emergence; meta-stability, creativity; degeneracy; system stabilities and instabilities over different timescales. Within this overarching theoretical framework it has been argued that the same performance outcomes can be achieved in diverse ways as individual performers attempt to satisfy the unique constraints on them.[20] Genetic diversity may be responsible for a small part of training or performance response differences between individuals, and only when there is a favourable interaction with important environmental constraints are performance benefits observed. Phenotypic expression of behaviour might be best understood at the level of individual interactions with key environmental and task constraints. Given differences in genetic contributions, performance variations are more likely to assert themselves under intensive practice regimes. Common optimal pathways to performance expertise are not expected because of neurobiological degeneracy characterising each individual performer and the effect of interactions between environmental and personal constraints on the intrinsic dynamics of each learner.

The acquisition of expertise is domain specific and involves adaptation to performance environments through satisfying unique constraints which impinge on each developing expert.

Expertise acquisition emphasizes the changing nature of the performer-environment relationship through development, and gaining experience through training, practice, coaching and competing. A comprehensive examination of expertise involves identifying the intrinsic dynamics of each individual and the specific rate limiters and constraints which shape their behaviour. Each individual athlete comes to a performance context with a particular set of intrinsic dynamics which has already been shaped by genes, development and early experiences. Individualised pathways to expert performance are expected because of the uniqueness of these dynamics constraints.

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