The Second International Congress of Complex Systems in Sport

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Many sport scientists are starting to apply the tools and concepts of non-linear dynamics, dynamical systems theory, chaos theory, and thermodynamics to analysis of sport behavior. One aim of this meeting was to encourage and promote such applications. Four main themes recurred throughout the conference: nonlinear dynamics of individual movement coordination (self-organization and metastability in athlete movement patterns, new techniques to collect and analyze the movement patterns of individual sports performers, and differential training); complex techniques to analyze team dynamics (emerging techniques to collect and analyze the movements of players in competition, and high-level variables that characterize team game dynamics); creativity and decision making (how training environment encourages or prevents emergent decision-making, the coach's role in developing creative athletes, and techniques to analyze creativity); and training perceptual skills and multimodal perception (individual factors relating to perceptual skill, perception and action coupling, adding noise to perceptual information, and training strategies). Implications for scientists: complex systems may be useful in team dynamics, differential learning may enhance learning, visual search studies should be done in-situ, and virtual reality may overcome shortfalls of video based perceptual studies. Implications for coaches: constraints should be manipulated to optimize learning, task difficulty influences motivation and skill development, and creativity stems from metastable states.

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The second International Congress of Complex Systems in Sport (ICCSS) was held in Funchal, Portugal, November 4-8, 2008. The meeting included delegates of the tenth European Workshop on Ecological Psychology. There were 220 attendees from 24 countries, and the program consisted of five keynote addresses, 14 symposia, 10 free communication sessions, two poster sessions, and a pre-conference workshop. Abstracts of the keynote addresses are available at the conference site, and selected abstracts are to be published in the International Journal of Sport Psychology. The next ICCSS conference will be held in Lithuania, September 14-18, 2010.

Nonlinear Dynamics of Individual Movement Coordination

The keynote by Keith Davids on *The athlete-environment relation as a complex system: implications for sport pedagogy* was presented in absentia as a pre-recorded video. This interesting talk highlighted the emergent nature of movement patterns, cognitions and decision-making during practice. An important message was that coaches need to identify and manipulate pertinent informational and task constraints so they can push athletes into a region of self-organized criticality during practice! In layman's terms, creative patterns of movement behavior can result from athletes learning to adapt their skills to continual changes in practice conditions. For example, it was noted that elite sports performers like Don Bradman and Tiger Woods have engaged in a large amount of *creative* and highly challenging practice in order to hone their extensive skill base. Hence encouraging movement variability during practice can be beneficial for long-term motor learning, leading to novel, creative behaviors. Davids also pointed out that attaining expertise for many athletes involves reaching a *metastable state*, where a number of movement options can be used for a given circumstance. The challenge for pedagogists is to understand how to design optimal learning environments to encourage athletes to achieve technique metastability. Specific examples of the ideas presented by Davids were seen in subsequent presentations on tennis serving (Moreno), swimming (Seifert), and ball-catching tasks (Tijtgat).

On the third day of the conference, we attended a symposium titled *Complex movement analysis for complex training approaches*. Presentations were made by Schöllhorn, Beckmann and Janssen. Initially they highlighted the importance of exploratory data analysis approaches, like linear cluster analysis and nonlinear artificial neural nets, in revealing previously unidentified structures in human movement dynamics. The traditional method of analyzing movement patterns by comparing previously selected variables ignores these structures.

Schöllhorn also introduced an innovative practice concept termed differential training, which appears to improve skill acquisition. In differential training, "noise" (random irrelevant movements) is introduced during practice of a target skill. An example of a differential training drill was provided where soccer players in a shooting drill were asked to make a different unrelated action (e.g., hop, skip or jump) while preparing to shoot the ball. The aim of differential training is to induce continuous changes in movement executions by avoiding repetitions, removing corrective instructions and emphasizing discovery practice. Positive benefits of differential training (largely by Schöllhorn and colleagues) have been reported with shot putting, soccer skills, basketball and skiing.

On the final day of the meeting, Jia-Yi Chow presented on the role of practice in learning coordination patterns. He argued that skilled performers exploited different solution spaces to meet the same task goal. Such observations support the concept of degeneracy in the control and coordination of human movement. Interestingly, some evidence of increased variation in movement patterns existed during learning but it was not a pre-requisite for a switch between preferred movement patterns. Chow pointed out that informational and intentional constraints can guide the learner's search for effective movement solutions particularly whilst practicing self-paced, complex skills (in this case, a soccer-chipping task). Future research needs to map or scan the intrinsic dynamics of individual learners and examine changes to those dynamics after a learning intervention. Chow and colleagues have referred to ongoing work based on key concepts from nonlinear dynamics and ecological psychology as *nonlinear pedagogy*.

A keynote presentation from Yeou-Teh Liu on *Bifurcation and self-organized criticality in motor learning* was provided on the first full day of the meeting. Liu categorized two motor learning phenomena: acquiring a new motor skill, and improving an exiting motor skill. Most of the theoretical and empirical research literature in motor learning has been concerned with the latter phenomenon. However, acquiring new coordination patterns exists more often in practice.

Liu reminded us that although practice time is an important variable in the motor learning process, task difficulty also plays a crucial role in modulating the learning dynamics. In the motor learning process, a critical point occurs when a learner experiences the transition from failure to success. At a given task difficulty, increasing practice time may cause a transition from failure to success. However, increasing task difficulty may lead to a point where the *success* mode is no longer stable and a transition to the *failure* mode occurs. When the skill level is low (lack of practice) or the task difficulty is high the probability of success is very low, which reduces motivation and thus the effectiveness of learning. On the other hand, when the probability of success is very high, the challenge and the motivation are reduced. Liu showed that, when learners have control over the selected task difficulty during practice, there is an attractive critical manifold in the skill/difficulty space that has the optimal success rate of 50%. A self-organized practice condition also provides a higher improvement rate in performance outcome than a traditional, progressively increasing difficulty condition.

How can the findings described above be interpreted by sport scientists and coaches? Informal discussion with experienced coaches attending the meeting suggested that they were aware of *skill matching difficulty* principles. A better understanding of this concept may allow us to anticipate when these conditions will occur and therefore help organize and optimize individualized, skill-focused practice schedules.

Summary

The take home messages in relation to the nonlinear dynamics of movement coordination were:

- Nonlinear analysis of technique provided evidence that movement patterns are constantly varying (even in skilled performers) because coordination is dependent on many factors, such as general behavior, intentions (e.g., to deceive an opponent), task difficulty, fatigue, and emotion.
- The coach/sport scientist should be aware of influential constraints on performance. Manipulating constraints in practice can be an effective way of preparing the performer to succeed.
- One hot discussion topic at the meeting was the differential learning approach, which is characterized mainly by randomly adding variable elements to the target movement. In contrast to classical learning approaches, differential learning studies have indicated better progress in learning even during the retention phase.
- The effectiveness of motor learning is affected by the size of movement variations within practice.
- Skill progression/improvements can be monitored by measuring variability and monitoring for irregular patterns (which often precede change).
- The skill-matching-difficulty principle is vital for coaches to understand. By manipulating task difficulty appropriately coaches can enhance the athlete's motivation.

Complex Techniques to Analyze Team Dynamics

Movement patterns exhibited by teams on the field of play undoubtedly represent a complex system that is often difficult to interpret. A symposium chaired by Duarte Araújo focused on the analysis of team games as complex systems. The purpose of such analysis is to identify collective (high-level) variables that describe, characterize, and explain the game. Description of patterns may enable researchers to predict transitions that lead to changes in the dynamics of play. A prominent researcher in this endeavor is Tim McGarry who presented his work on squash and basketball. McGarry showed that athletes can identify patterns of play from simple, point-like representations of players moving around on a court. He argued that complex team sports are composed of multiple, dynamic couplings among *dyads* of players and that these groupings are underpinned by similar principles of coordination dynamics. For example, all defensive players in basketball attempt to maintain a spatio-temporal relationship between themselves, their opponents and the area they are defending. In squash, this relationship can be observed as an anti-phasic (alternating) relationship of the players about the T-location of the court until the stability of this pattern is disrupted.

Unfortunately, Peter Beek could not present at the symposium. In Beek's abstract he noted that for match analysis to mature, more global measures are required that capture higher-order features of unfolding or played matches–features that are colloquially referred to by soccer professionals as *connection between lines*, *space or distance between lines*, *defense-attack transitions*, *effectiveness of ball circulation*, and the like. From a behavioral perspective, Mendes and colleagues suggested that players can be considered *linked* when a player passes the ball to a teammate or when players change position on the field due to teammate's displacement. Using footage from elite water polo matches to provide evidence, Mendes proposed that these two levels of linkage allow innumerable possibilities of interactions amongst players on a team. Whilst at an early stage of development, the ultimate goal of such research is to understand the dynamics of both teams during competition.

Two different approaches to analyzing team dynamics emerged at the meeting. The first, exemplified by Martin Lames, involved a rudimentary analysis of all player positions. Positional data of 22 players in the 2006 final of FIFA World Championship were used to calculate the *centroid* position of all a team's players and its variability. There was a tight in-phase coupling up and down the pitch between the centroids of the two teams with approximately 10 meters between them. Defenders and attackers move at all times in the same direction. In addition, the range of the team (the spread of the players) was also tightly coupled.

The second, more common approach concentrated on small-sided games. The advantage of such situations include: less volume of data, representation of sub-units within a game, and focus on finding variables that explain breaks in game play. Passos and colleagues used the analogy of free-flow and congestion in traffic jams in an attempt to explain collective patterning in rugby. In situations where the distance between attack and defense sub units is below some threshold, the ball carrier and support players seem to adjust running trajectories and speed to avoid defenders and maintain proximity with teammates. It is possible that some combination of inter-player distances may be useful in predicting game breaking situations. Correia, another PhD student within the same group, ,attempted to explain transitions in play near the try line using angles between best fit lines through player positions of each team. They hope this measure of system symmetry will predict movement of play up toward the goal line. Frencken tracked soccer players in small sided games and highlighted the limitations encountered by himself and others seeking to analyze full team sports.

One data collection and analysis tool that received some attention at the meeting was TACTO, which was discussed in a symposium chaired by Orlando Fernandes. TACTO or Tool for Applied and Contextual Time-series Observation is a software package written in Matlab that uses manually recorded virtual position coordinates and applies approximate entropy (ApEn) to measure the regularity of patterns. A time series containing many repetitive patterns has a relatively small ApEn; a less predictable (more complex) process has a higher ApEn. Folgado and colleagues used this approach in football to show that different players on the pitch exhibit different, characteristic ApEn values and that ApEn can be used to evaluate performance fluctuations.

A related symposium explored alternative ways to analyze team sports based on player positional data. Koen Lemmink articulated that the potential for multiple player tracking was increasing across a number of sports and that the dynamical systems approach is ideally placed to model and analyze such complex datasets. However, his presentation only covered 1 vs 1 situations in sports such as tennis, basketball and rugby. Passos and colleagues used the TACTO software to track Portuguese rugby union matches. They were interested in comparing the rate of change of relative position between teammates for the intra-team analysis and between attackers and defenders for the inter-team analysis. They found that players adjusted their relative positions to the specific performance setting, using information such as positions of the opponents or teammates, rather than in some stereotypical planned fashion. It was concluded that players' decisions and actions were governed by local emergent rules rather than by outside agents or predetermined action sequences.

From a technological aspect, Rick Shuttleworth presented a practical method for tracking multiple players in real time using wireless radio-frequency technology. As an example, he showed results from a dynamic 2 vs 1 netball task where the goal was to make as many passes as possible in a fixed time. The movement patterns of netball players differed from those of other team sport athletes.

Summary

The take home messages in relation to analysis techniques for measuring team dynamics were:

- Analysis tools of nonlinear dynamics shows early but promising signs in improving our understanding of complex team dynamics in performance situations.
- At present, most research is limited to analyzing how small groups of players interact, but the ultimate goal is to analyze complete full-sided games.
- A number of player-tracking techniques are being explored, each with strengths and weaknesses. Researchers in many countries are striving to develop an accurate, reliable and non-invasive tracking technique that can be used in competition.
- The relationships or loose couplings that players and sub-groups of players develop in team sport are self-organizing features of a complex system. Rudimentary variables (e.g., relative phasing, centroid, approximate entropy) are being applied and developed to measure such features.
- For match analysis to mature, more global methods and measures are required that can capture higher-order features of unfolding or played matches.

Creativity and Decision-Making

Two symposia of note were devoted to creativity and decision making. Daniel Memmert presented a new tool to analyze creativity called *Game Test Situation*. GTS involves setting up a context-dependent real world setting that can provoke creative behavior in recurring comparable situations. In the test *using gaps*, four attackers have the task of playing the ball past three defenders in the midfield into an opposite part of the field. The GTS allowed for two different kinds of passing skill (hand and foot) in a system where the players took turns (two rounds for each person). For the future, GTS may be of some use in the training of children and youth (diagnostics of development and talent) and the evaluation of theories on the training of tactics. Jurgen Perl presented a new neural network approach for analysis of creative behavior in representative situations of team sports. The concept called *Dynamically Controlled Neural Gas* combines two existing neural net techniques. The analysis was able to separate main process types and reproduce creative learning processes by using simulation. It achieved a surprisingly high correspondence between simulated learning profiles and those obtained from the creativity tests of 43 children. The network could simulate the types of the 9-step learning profiles and also reproduce good, medium and bad levels of creative learning. This approach has potential to explain how spontaneous decision-making emerges in sports situations. Finally, Robert Hristovski talked about *Metastability and situated creativity in sport*. Existing research has shown that novel and creative behaviors can spontaneously emerge when a complex system is poised in the metastable state. In this presentation Hristovski argued that novel actions might emerge by enabling an athlete or team to explore the metastable region of the action workspace through carefully manipulating key practice task constraints. He used an example in boxing where manipulating the distance of the target to be punched led to spontaneous alterations in preferred punch sequences. Whilst creativity in sport is a challenging and not particularly well understand concept, creativity researchers have potential to influence high-performance athletes in the future.

An interesting symposium on *Collective decisions and actions - New challenges for research, training and match analysis* described techniques used by Pedro Passos and colleagues to analyze collective decisions made in Rugby Union. In an intra-team analysis the interpersonal distance between players within the sub-unit over time was used to define the geometric centroid. For the inter-team collective variable they calculated the angle of vector-linked centroids (from the defense sub-unit to the attack sub-unit) with an imaginary horizontal line parallel to the try line. The authors (and members of the audience) identified a number of limitations with each collective variable, and other variables are likely to be the focus of future work. For example, Milho suggested variables such as the sum of the players' interpersonal distance, and the spatial distribution of the players in the sub-unit that defined the polygonal area (i.e. the shape and size of this area may describe the level of connection amongst teammates).

Training Perceptual Skills and Multimodal Perception

The ICCSS and EWEP combined meeting brought together many presentations on human perceptual skill. The underlying theoretical foundation throughout the meeting was an ecological psychology approach to perceptual skill. In particular, the keynote presentations given by prominent researchers Professor Michael Turvey (*The ecological perspective, past and future*) and Professor David Lee (*Natural solutions to complex problems*) gave the audience an overview of some the main tenets of this theoretical approach.

In short, the goal of experimenters conducting research from an ecological perspective is to understand the relationship between information held within the environment and its role in directing perception and controlling actions. As emphasized by Turvey, there is necessity in understanding the complementary relationship between an animal and its environment. In sport, each competitor is seen as having different action capabilities (e.g., body composition, height, strength, speed, technical proficiency, etc.) that are thought to influence the information they seek as they exploit affordances or opportunities for action offered by a set of environmental conditions. There is no optimal recipe of perceptual information (e.g., "watch the ball") or perceptual search strategy that will suit all athletes.

In skill acquisition research there is currently a concentrated effort to accurately sample the task environment to which an athlete is typically exposed during competition. This ensures that the information available for perception and action in experiments represents the information performers would attend to during actual competition.

Another key message was allowing participants to move in direct response to the perceived information during experiments. While perception is believed to provide information for action, the resulting movement is thought to generate further information (e.g., a golfer may not be able to accurately judge the slope of a green from one perspective, so they move to generate more information). Such behavior is abundant in everyday life and couples the relationship between information and movement in a flowing, perception-action cycle.

Considering the brief overview given above, it is obviously important to ensure fidelity between competition and training conditions, with emphasis on replicating the information for perception and action. For example, in his keynote Keith Davids presented data demonstrating some of the performance differences present in skilled batsmen when facing deliveries from a bowling machine in comparison with a live bowler (live conditions are also termed *in situ*). When opposing a bowler, batsmen were shown to initiate their shots prior to the bowler's ball release, because their movements become tightly geared, with practice, to information from the bowler's delivery. However, when facing the bowling machine there is no information available from the bowler's run-up and delivery action, implying that under these task constraints, batsmen have to rely on ball flight information alone. These tasks differ considerably in the nature of the information present, which ecological psychology proposes as instrumental in forming specific information-movement or perception-action couplings. For another example demonstrating how differing task constraints influence coordination in triple-jump training, see Wilson et al. (2009).

Further implications for cricket batsmen training with bowling machines were discussed in the presentation by Croft, who measured the effect of different ball speeds on the ability of batsmen to track the ball once released from a bowling machine. The preliminary data suggested that there was no global perceptual strategy used by all batsmen, implying the importance of accounting for the functional variability of perceptual strategies in any training instruction or practices. Also in cricket, Mann examined the counter-intuitive idea of blurring the vision of batsmen by fitting them with over-corrected contact lenses. Initial data suggested that a condition that left the batsmen with short-sighted vision did not actually decrease performance when compared with normal vision. Interestingly, anecdotal comments from some of the skilled batsmen participating in the study indicated that they actually preferred batting in the blurred vision condition! Such suggestions are consistent with the differential training concept discussed earlier. A training intervention research study is now needed to evaluate the significance of any potential learning that may be present after wearing contact lenses.

Perhaps some of the most fruitful contributions to understanding perceptual skill acquisition were presented in the symposium titled *Calibration and the education of attention in perception-action coupling.* Acquiring perceptual skill is a process of learning to attend to the most useful information in directing perception and controlling actions. The environment is believed to contain a manifold or continuum of informational variables that differ in the degree to which they are useful to a player. The nature of this information differs relative to the action capabilities of the respective athlete. For example, in rugby a fast and agile player may search the playing field for information specifying gaps in a defensive line that they could use during an attacking break, whereas a slower player requires more space or time to break a defensive line and so may search for comparatively larger gaps or weaker tacklers in the opposition team.

In team sports, this environmental information is likely to be held within the kinematics of the opposing players. While there are numerous plausible information sources that a player may draw upon to guide their actions, van der Kamp emphasized that an informational variable can be considered more useful if it can be exploited across a larger variety of situations without resulting in performance decrements. In contrast, information is considered less useful if its use leads to accurate performance in only one or a few situations. Furthermore, during learning, it is likely that players will switch between different information sources within the environment as they seek to explore alternative information-movement couplings. Therefore, during the design of training practices, Jacobs suggested that it would be more beneficial for athletes to learn under *constantly variable* conditions. This strategy would provide exposure to variable task constraints in which players must adapt their behavior to constantly changing information. Learning is variable, and it is important to design training drills that reflect this learning process.

Over the past three decades, experimenters have used eye-movement systems as a means of recording visual search strategies of athletes. Savelsbergh presented work from a research study that examined the effect of an innovative video-based training intervention on recreational football players. Inexperienced goalkeepers observed film clips presented on a life-size video display and judged the direction of penalty kicks by moving a hand-held joystick. The perceptual learning (education of attention) group practiced with film clips that were edited to include a spotlight that moved over the relevant information during the penalty taker's run-up. The training group practiced with the same film clips without any editing, and the third group served as control. There was a change in visual search behavior for the perceptual training group, although this was not significant compared with the training or control groups. Similarly, performance accuracy did not improve for the perceptual training group in comparison with either of the other groups. It is difficult to conclude whether the study demonstrated any evidence of video training providing a benefit to perceptual skill. Furthermore, there was no transfer test, meaning that it is not possible to evaluate whether such training intervention improves performance for in situ constraints. Indeed, much of the current perceptual training literature is relatively inconclusive with regards to the transfer and applicability of laboratory training protocols. Those studies that have included transfer tests thus far are mixed with regard to their effectiveness.

A possible explanation of the equivocal application of video training may be indicated by findings presented by Dicks, who compared the gaze and movement behaviors of goalkeepers for video simulation and in situ conditions. Goalkeepers faced penalty kicks distributed across five different experimental task constraints: video-simulation verbal response, video-simulation anticipatory response, in-situ verbal response, in-situ anticipatory response, and in-situ interceptive response. Goalkeepers were more accurate in anticipating the direction of the penalty kick for the in-situ in comparison with the video-simulation conditions. The more accurate performance for the in-situ conditions coincided with significantly more efficient visual search strategies in comparison with the video conditions. Goalkeepers spent more time fixating upon body based locations in comparison with the ball for all anticipatory and verbal response conditions, whereas the opposite was found in the in-situ interceptive condition.

A possible interpretation of these findings is that the video simulation conditions force players to rely on information presented by the penalty taker to anticipate kick direction, as only minimal ball-flight information was available for these conditions. The resulting simulation of the task constraints is not representative of those that are normally encountered in situ. Indeed, the findings further suggest that the two anticipatory in-situ simulations fail to adequately represent the task requirements for the in-situ interception condition. The results exemplify the importance of specificity in the design of training practices that emphasize the learning of functional information-movement couplings. Failure in the design of training drills to fully capture the nature of information available to players during match performance conditions may result in the acquisition of a diminished set of perceptual skills that are not compatible with the precise coordinated actions that are replete in expert sports performance.

Also using the penalty kick task, Lopes reported data on the relationship between the penalty taker and the goalkeeper. This study offered a representative experimental approach in which the behaviors of goalkeepers and penalty takers were manipulated under in-situ conditions. For example, the placement of the goalkeepers within the goal was altered to offer more *space* in one particular side of the goal. In addition, the penalty taker was given instruction to either base their kick direction on the behavior of the goalkeeper or independent of their opponent's action. The initial data presented indicated different results in comparison with a similar experimental set-up (e.g., Masters, van der Kamp & Jackson, 2007) that had previously been conducted under video simulation conditions. Manipulation of both players' behaviors in sporting dyads may prove a fruitful approach for development of representative task designs in sport.

So where does this leave video simulation tasks as a potential training method? Should such practices be ignored completely when designing future learning conditions? A body of research in its infancy that may suitably replace any need for video training is the application of virtual reality replications of sports environments. For example, the poster presentations of Watson and Craig (*Collision detection in rugby union: What variables are key in assessing whether or not a gap is "makeable"?*), and Brault, Kulpa, Bideau and Craig (*1 vs 1: How do we anticipate the direction in which a player will run?*) both considered the development and application of interactive immersive virtual reality techniques to study 2 vs 1 and 1 vs 1 situations in rugby union. Watson and Craig required participants to judge with a yes/no button response whether they perceived it possible to run between two approaching defenders. The starting and finishing distance between defenders was varied, as was the moment the virtual display was terminated. A critical gap of 1.1 m brought about errors in judgment: defensive gaps above or below the 1.1 m value were largely judged correctly by participants as being either passable or non-passable. Moreover, the players were able to pick up information about end-gap size ahead of time from the dynamics of gap closure. However, the authors acknowledged that a limitation of the research program was a failure to ensure that the participants produced an action response.

Brault and coworkers simulated the attacking run of a rugby union player in a virtual environment to measure how the kinematics of the attacking player's movements influenced the defender's anticipatory judgments about future running direction. A complementary biomechanical analysis study showed that during an attacker's deceptive movement, the shoulder rotation was exaggerated and the centre of mass was higher at the start of the movement, resulting in a large overall drop towards the end of the movement. The exaggerated shoulder movement in deceptive movements entrained a significantly greater percentage of false responses than in the non-deceptive trials. The findings from the two highlighted poster presentations indicate the potential of virtual environments as a means of measuring the perceptual skill of athletes. To date, verification is still required to understand whether there is fidelity in athletes' perceptual behaviors for virtual environments and in-situ conditions. Similar to video simulations, a current weakness in the above studies is a failure to ensure that players produce a movement response that is relative to the actions of the opponent/s in the observed display.

Frisoli and coworkers attempted to overcome these criticisms in a study using a rowing ergometer with a virtual reality simulator. The project focus was development of a rowing simulator for elite athletes that is integrated into a virtual reality environment. The research team is conducting a detailed and thorough set of analyses to ensure that the simulator closely matches the exact conditions of rowing on water. Additional to the two virtual reality studies described in rugby, the simulator being developed by Frisoli et al. aims to replicate the auditory and haptic information available for perception in addition to visual information. Thorough steps are being taken to verify whether the kinematic action and force generation that characterize the rower's performance on water is replicated when performing in the simulator. The presentation gave only an overview of some of the work, making it difficult to evaluate the potential impact of the virtual environment as a training tool, although the technology used in the simulator set-up certainly appeared to be impressive. Links: more on this project and on some of the current virtual reality technologies.

Summary

This part of the meeting covered considerable ground in relation to perceptual skills and training. Some take home messages were:

- Owing to each athlete having their own physical capabilities, there is no optimal recipe of perceptual information or perceptual search strategy that will suit everyone.
- While perception provides information for action, the resulting movement is thought to generate meaningful information. This cyclical process has profound implications for training.
- Training environments should replicate the information for perception and action present in competition
- Adding noise to perceptual information may benefit skill acquisition.
- A source of perceptual information may be

more useful if it can be exploited across a larger variety of situations without resulting in performance decrements.
- There is at best inconsistent support for the concept of video simulation training. We don't know enough about whether improved visual search characteristics (for example) lead to improved performance.
- Virtual reality training environments (in which an athlete's movement is linked in real time to their perceived environment) may soon replace the concept of video-based perceptual training.

Implications for Scientists

- Analysis of game sports as complex systems may enhance understanding of how performer/team dynamics are organized. Investigate current match analysis techniques and seek advice on how to implement complexity science approaches.
- Whilst promising, the concept of differential learning demands rigorous testing at different skill levels. What mechanism underpins improvement, and is it an effective, safe way to learn motor skills? Prioritize funding for research to examine the concept of differential learning.
- Match-analysis techniques are evolving quickly. A multidisciplinary approach is required in which sport scientists and computer scientists/mathematicians work together to develop high-order procedures which characterize complex game dynamics. Explore and develop new collaborative team approaches to match analysis.
- Visual search research performed in-situ is required to verify/generalize existing knowledge about perceptual skill in sport. Utilize representative designs in perceptual skill research.
- Virtual reality environments have significant potential to address many concerns associated with typical perceptual training environments. Investigate use of virtual reality in training perceptual-motor skills
- Objective variables that can characterize effective decision-making and creativity are required to advance research in this area. Explore the link between biomechanics and decision making particularly in deceptive movements.

Implications for Coaches

- Athletes should be encouraged to learn to adapt their skills to continual changes in practice conditions. Devise training activities that challenge the stability of athlete's movement patterns through manipulation of constraints.
- Athlete motivation is directly influenced by task difficulty. Manipulate task difficulty regularly to maintain optimal levels of motivation. If a task is too easy for an athlete, they won't progress.
- Athlete creativity demands metastable coordination patterns and conducive practice environments. Avoid over-reliance on repetitive, prescriptive training. Encourage athletes to take ownership of their learning.
- Perceptual training research is inconclusive regarding benefits for performance. Determine and highlight information sources that athletes can use to support a variety of actions (e.g., proprioception, sense of balance, auditory cues, vision)

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