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**The Effectiveness of Constraint-led Training on Skill Development in
Interceptive Sports: A Systematic Review (Clark, McEwan & Christie) – A
Commentary.**

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Introduction

Clark, McEwan and Christie's systematic review [1] offers a timely examination of current literature assessing effects of a constraints-led approach to training on 'technical and cognitive skill in sport', in comparison to traditional training methods. They concluded that, currently, there is strong evidence to advocate for the effects of training interventions that espouse benefits of constraints-led training on acquiring skill in interceptive actions. Clark et al. reported that 18 studies satisfied their proposed inclusion criteria and, of these studies, 77% provided evidence of the effectiveness of the constraints-led approach (CLA). Consequently, Clark McEwan and Christie argued that a "the implementation of the constraints-led approach within interceptive sport can be advocated." (p.17). This is a revealing insight, which supports their claims that this finding "provides the opportunity for researchers to collect more compelling evidence to answer the question: '*Does constraint-led training assist with the development of technical skills within interceptive sport?*'". While we endorse their call for more empirical evidence on the effectiveness of a CLA to practice and training design, we qualify it by highlighting some limitations of Clark McEwan and Christie's systematic review.

In this commentary we discuss key issues including: lack of a complete assessment of methodological validity of the reviewed papers; inherent difficulties with the research methodologies employed in the studies; theoretical understanding to ensure that constraint-led approaches are distinguishable from other pedagogical approaches; veracity of the intervention in each study; sampling of the environment [2] and assessing performance; sample size (students versus elite populations); intervention length; and further areas of research that need to be addressed.

Risk of bias and procedures for assessing methodological validity of studies

An initial challenge is assessment of putative constraint-based methodologies in interventions that may not have been clearly aligned with the theoretical

principles of ecological dynamics, underpinning CLA. There is little evidence presented that the reviewed studies clearly adhere to the philosophical and theoretical underpinnings of the CLA, especially with respect to how practitioners and researchers have applied the key concepts and ideas to their experimental design. Clark and Christie confirmed that they used the Cochrane Collaborations tool for evaluating the risk of bias [3]. Domains of assessment include sequence generation, allocation concealment, blinding of participants, personnel and outcome assessors, incomplete outcome data, selective outcome reporting and other sources of bias. Summary outcomes of all studies for a particular domain need to be categorised as “low risk of bias”, “high risk of bias” and “unclear risk of bias”. However, as part of this procedure, there was no evidence provided that the studies sampled actually were valid with respect to the underpinning theoretical rationale of ecological dynamics (ED) in their application of a constraints-led approach. To exemplify our argument, Table 1 shows our assessment of the abstract and keywords of the sample studies. Of the 18 studies, only two, Farrow and Reid [4] and Oppici et al. [5], mentioned the word 'constraints' in the keywords or abstract, and that was in isolation from other key concepts of ecological dynamics, rendering some doubts about its theoretical conceptualisation. Importantly, none of the 18 studies mentioned constraints in relation to other key concepts from the theory of ecological dynamics which underpin a constraints-led approach, such as: affordances, perception-action coupling, task, organismic or environmental constraints, self-organisation, co-adaptation, metastability, or system dynamics. It is essential that researchers and practitioners alike are consistent with their understanding and application of CLA based interventions, predicated on key concepts in the theoretical framework of ecological dynamics, from which it emanated [6].

Table 1. Abstract and keywords of the sample studies

#	Title	Abstract	Key Words
1	Caserta, R., Young, J., & Janelle, C. Old Dogs , New Tricks : Training the perceptual skills of senior tennis players. <i>Journal of Sport & Exercise Psychology</i> . 2007;29:479–497.	The purpose of the study was to determine whether multidimensional perceptual-cognitive skills training, including situational awareness, anticipation, and decision making, improves on-court performance in older adults when compared with a physical training program, including stroke and footwork development. Senior tennis players (N= 27) were randomly assigned to one of three groups: perceptual-cognitive skills training, technique-footwork training, or no training. Results indicated that participants receiving perceptual-cognitive skills training had significantly faster response speeds, higher percentage of accurate responses, and higher percentage of performance decision making in posttest match situations. Findings provide clear evidence that perceptual-cognitive skills can be trained in aged individuals. Implications and suggestions for future research are offered.	situational awareness, anticipation, decision making, aging, cognitive impairment, intervention
2	Farrow, D., & Reid, M. The effect of equipment scaling on the skill acquisition of beginning tennis players. <i>Journal of Sports Sciences</i> . 2010;28(7):723–32.	In this study, we examined the effectiveness of equipment scaling (tennis ball modification and court size) on beginner tennis player skill acquisition and associated psychological responses within a structured competitive development/participation programme. The participants' ability to rally and their stroke proficiency were recorded before and after a 5-week acquisition phase. Coupled to these dependent measures were within-practice session recording of hitting opportunities, resultant success, and the affective measure of session happiness. The participants who practised using a standard ball and standard court (adult constraints) were afforded a significantly poorer learning experience relative to the other ball/court scaling combinations. In particular, the adult standardized intervention group recorded significantly less hitting opportunities on the forehand and backhand side than the scaled-court intervention conditions. The decreased hitting opportunities experienced within the standardized adult condition then flowed into significantly poorer hitting success relative to the scaled court groups. The modified ball/scaled court intervention group rated their experience significantly happier than the standardized adult group. Discussion centres on the stronger learning effect generated by court scaling relative to the influence of ball type and the broader application of these findings to skill acquisition theory and practice.	Equipment scaling, skill acquisition, tennis, constraints
3	Hagemann, N., Strauss, B., & Cañal-Bruland, R. Training perceptual skill by orienting visual attention. <i>Journal of Sport & Exercise Psychology</i> . 2006;28:143–158.	A major element in expert sports performance, particularly racket-and-ball games, is excellent anticipatory skill. A prestudy combined the temporal and spatial occlusion paradigms to ascertain which key stimuli badminton players use for anticipating the direction of overhead shots. The main study then evaluated a program for training anticipatory skills; 200 video clips were employed to orient attention toward these key stimuli. Participants were 63 badminton novices, 20 national league players, and 21 local league players. A transparent red patch (exogenous orienting) was used to orient attention toward the trunk up to 160 ms before racket-shuttle contact; the arm, from 160 ms to 80 ms before contact; and the racket, from 80 ms before to actual contact. Results showed that badminton novices who trained with this program significantly improved their anticipatory skill between post- and retention test compared with controls. Whereas local league players improved from pre- to	anticipation, training, badminton, temporal occlusion

		posttest, training had no effect on expert national league players. It is concluded that using red transparent patches to highlight the most informative cues in perceptual training programs is a promising way to improve anticipatory skill.	
4	Hernandez-Davo, H., Urban, T., Sarabia, J.M., Juan-Recio, C., & Moreno, F.J. (2014). Variable training: effects on velocity and accuracy in the tennis serve. <i>Journal of Sports Sciences</i> . DOI: 10.1080/02640414.2014.891290	Variable practice has been shown to be an effective strategy to improve open motor skills. However, the usefulness of this procedure in closed motor skills remains controversial. The following study has the objective of analysing the effects of variability practice in the improvement of a closed skill. The skill studied has been the tennis serve. Thirty young tennis players (13 ± 1.52 years), divided in two groups, took part in this study. One group practiced in variable conditions and the other group in consistency conditions. Both groups performed 12 training sessions (60 serves/session). The variable practice group improved their accuracy significantly compared with the consistency group ($F_{3,25} = 3.078$; $P = 0.035$). The velocity of serve increased after training in both groups ($F_{3,25} = 15.890$; $P = 0.001$). The practice in variable conditions seems to be effective in improving the performance of the tennis serve.	adaptation; learning; radial error
5	Masters, R., Poolton, J., Maxwell, J., & Raab, M. Implicit motor learning and complex decision making in time-constrained environments. <i>Journal of Motor Behavior</i> . 2008;40(1):71–9.	The cost-effectiveness of the implicit (procedural) knowledge that supports motor expertise enables surprisingly efficient performance when a decision and an action must occur in close temporal proximity. The authors argue that if novices learn the motor component of performance implicitly rather than explicitly, then they will also be efficient when they make a decision and execute an action in close temporal proximity. Participants ($N = 35$) learned a table tennis shot implicitly or explicitly. The authors assessed participants' motor performance and movement kinematics under conditions that required a concurrent low-complexity decision or a concurrent high-complexity decision about where to direct each shot. Performance was disrupted only for participants who learned explicitly when they made high-complexity decisions but not when they made low-complexity decisions. The authors conclude that implicit motor learning encourages cognitively efficient motor control more than does explicit motor learning, which allows performance to remain stable when time constraints call for a complex decision in tandem with a motor action.	analogy learning, cognitive load, expertise, explicit instructions, movement kinematics, procedural knowledge
6	Mazyn, L., Lenoir, M., Montagne, G., & Savelsbergh, G. Spatial and temporal adaptations that accompany increasing catching performance during learning. <i>Journal of Motor Behaviour</i> . 2007;39(6):491–502.	The authors studied changes in performance and kinematics during the acquisition of a 1-handed catch. Participants were 8 women who took an intensive 2-week training program during which they evolved from poor catchers to subexpert catchers. An increased temporal consistency, shift in spatial location of ball-hand contact away from the body, and higher peak velocity of the transport of the hand toward the ball accompanied their improvement in catching performance. Moreover, novice catchers first adjusted spatial characteristics of the catch to the task constraints and fine-tuned temporal features only later during learning. A principal components analysis on a large set of kinematic variables indicated that a successful catch depends on (a) forward displacement of the hand and (b) the dynamics of the hand closure, thereby providing a kinematic underpinning for the traditional transport-manipulation dissociation in the grasping and catching literature.	catching, kinematics, motor learning, transfer
7	Moradi, J., Movahedi, A., & Salehi, H. Specificity of learning a sport skill to the visual condition of acquisition. <i>Journal of Motor Behavior</i> . 2014;46(1):17–23.	The authors' main purpose was to determine whether learning of a real-world sport skill (basketball free throws) is specific to the sources of afferent visual information available during practice. Twenty-eight male high school students (inexperienced in the experimental task) were randomly assigned to a full vision or target only vision group. Participants trained under full vision or target only condition for 15 sessions. Following training, in immediate tests, they were examined under full vision and then under target only conditions. Ten days later, in delayed tests, they performed the task under full vision and then under target only conditions. Results showed both groups performed the task similarly across the experimental period. Interestingly, it was found that	Basketball free throws; specificity of practice hypothesis; vision

<p>8 Raab, M., Masters, R.S.W., & Maxwell, J.P. (2005). Improving the 'how' and 'what' decisions of elite table tennis players. <i>Human Movement Science</i>: 326 - 344.</p>	<p>immediate and delayed retention performance is specific to the training visual context. The groups' performances dropped significantly when we tested them at a visual condition that differed from what they had experienced while learning the task. Performance of the task seemed to have integrated with the visual information available during the task acquisition. These findings provide evidence for the specificity of practice hypothesis in the field of motor learning and control.</p> <p>Training methods in sport usually focus on improving either technical or tactical aspects of performance, ignoring the fact that successful performance requires the athlete to simultaneously decide what movement to perform and how it should be executed. Young elite table tennis players were trained, in a first phase, to improve their forehand and backhand movements and, in a second phase, to make a tactical switch between forehand and backhand movements. Half of the players took part in behavioral training focusing on how to perform the required movements, whereas half received additional video feedback about their technical and tactical performance (decision training). The results indicate that improvements of how decisions (techniques) and what decisions (tactics) can occur as a consequence of combining technical and tactical training. These results were stable in delayed Post-test analyses of competitive matches. It was concluded that a combination of both technical and tactical training is beneficial to elite table tennis performers, particularly during early seasonal training programs.</p>	<p>Implicit learning; Decision making; Principal component analysis</p>
<p>9 Stretch, R., Nurick, G., & McKellar, D. Improving the accuracy and consistency of shot reproduction in cricket batting. <i>South African Journal for Research in Sport, Physical Education and Recreation</i>. 1998;21(2):77-88.</p>	<p>In order to assess whether practising using a narrow (25mm) version of the conventional cricket bat would improve the accuracy and consistency with which the cricket batsman is able to strike the ball, an experimental (n = 9) and a control group (n = 9) were jointly exposed to a five-week coaching programme. The experimental group supplemented their training with three training sessions per week using the narrow bat. An instrumented cricket bat measured the exact impact locations of 60 deliveries for the pre- and post tests for each player. The analysis of covariance (ANCOVA) indicated a non-significant difference between the experimental and control groups (F = 0.36; p = 0.56). However, the batsmen performed significantly better than the bowlers (F = 0.50; p = 0.012) in these groups. A normalised performance plot was drawn up, with a decrease in the horizontal spread of the impacts, a closer proximity of impact to the centre-line of the bat (offset), and preferably both, indicating an increase in performance. The findings showed a smaller spread, with a larger offset for the experimental and control groups, with more of the experimental group showing an improvement in both the spread and the offset.</p>	<p>Decision making, learning, ability</p>
<p>10 Turner, A., & Martinek, T. An investigation into teaching games for understanding: Effects on skill, knowledge, and game play. <i>Research Quarterly for Exercise and Sport</i>. 1999;70(3):286-296.</p>	<p>The purpose of this study was to test the validity of the games for understanding model by comparing it to a technique approach to instruction and a control group. The technique method focused primarily on skill instruction where the skill taught initially was incorporated into a game at the end of each lesson. The games for understanding approach emphasized developing tactical awareness and decision making in small game situations. Two physical education specialists taught field hockey using these approaches for 15 lessons (45 min each). The control group did not receive any field hockey instruction. Data were collected from 71 middle school children. Pretests and posttests were administered for hockey knowledge, skill, and game performance. Separate analyses of variance or analyses of covariance were conducted to examine group differences for cognitive and skill outcomes. The games for understanding group scored significantly higher on passing decision making than the technique and control groups during posttest game play and significantly higher than the control group for declarative and procedural knowledge. The games for understanding group scored significantly higher on control</p>	<p>Tactics, decision making, knowledge base, games instruction</p>

		and passing execution than the other groups during posttest game play. For hockey skill, there were no significant differences among the treatment groups for accuracy, but the technique group recorded faster times than the control group on the posttest.	
11	Vickers, J., Livingston, L., Umeris-Bohnert, S., & Holden, D. Decision training: The effects of complex instruction, variable practice and reduced delayed feedback on the acquisition and transfer of a motor skill Decision training: The effects of complex instruction, variable practice and reduced delayed feedback. <i>Journal of Sports Sciences</i> . 1999;17(5):357–367.	Novice, intermediate and advanced baseball hitters followed a 7-week training programme, in which they received either behavioural training or decision training. Participants in the behavioural training group received simple-to-complex instruction, variable practice and an abundance of feedback throughout the acquisition period; the decision training group received complex instruction, variable practice and reduced delayed feedback. As predicted, the intermediate and advanced hitters who received decision training hit at a lower level (%) during acquisition but at a higher level during a transfer test in week 7. Novices in the behavioural training group were better than novices in the decision training group over both acquisition and transfer trials.	Baseball, Coaching, Cognition, Decision Making, Expertise, Practice
12	Williams, M., Ward, P., Smeeton, N., & Allen, D. Developing anticipation skills in tennis using on-court instruction: perception versus perception and action. <i>Journal of Applied Sport Psychology</i> . 2004;16(4):350–360.	On-court instruction involving either Perception–action training or Perception-only training Was used to improve anticipation skill in novice tennis players. A technical instruction group acted as a control. Participants’ ability to anticipate an opponent’s serve was assessed pre- and posttest using established on-court measures involving frame-by-frame video analysis. The perception–action and perception-only groups significantly improved their anticipatory performance from pretest to posttest. No pretest-to-posttest differences in anticipation skill were reported for the technical instruction group. The ability to anticipate an opponent’s serve can be improved through on-court instruction where the relationship between key postural cues and subsequent performance is highlighted, and both practice and feedback are provided. No significant differences were observed between the perception–action and perception-only training groups, implying that either mode of training may be effective in enhancing perceptual skill in sport.	No key words in the article
13	Williams, M., Weigelt, C., Harris, M., & Scott, M. Age-related differences in vision and proprioception in a lower limb interceptive task: The effects of skill level and practice. <i>Research Quarterly for Exercise and Sport</i> . 2002;73(4):386–395.	This study examined age-related differences in the role of visual proprioception during a lower limb interceptive action and how this varies as a function of skill and practice. In Experiment 1, skilled and less-skilled 8-, 10-, and 12-year-old boys controlled a soccer ball using their preferred foot under full vision and when sight of the effector was occluded. With the exception of the high-skilled 12-year-olds and low-skilled 8-year-olds, participants showed a decrement in performance when denied access to visual proprioception. In Experiment 2, the effect of practicing under different informational constraints was examined for 12 year-old boys. Children performed varying amounts of practice under full vision, or in a condition where sight of the foot was occluded, before being transferred to the alternative viewing condition. Participants who practiced under occluded viewing conditions showed greater relative improvement in performance over practice and transfer sessions compared with a full vision control group. Some support is provided for the manipulation of visual informational constraints as an effective pedagogical approach to motor learning.	ball control, learning, pedagogy, soccer

- 14 Ryu, D., Kim, S., Abernethy, B., & Mann, D. L. Guiding attention aids the acquisition of anticipatory skill in novice soccer goalkeepers. *Research Quarterly for Exercise and Sport*. 2013;84(2):252–62.
- The ability to anticipate the actions of opponents can be enhanced through perceptual-skill training, though there is doubt regarding the most effective form of doing so. We sought to evaluate whether perceptual-skill learning would be enhanced when supplemented with guiding visual information. Twenty-eight participants without soccer-playing experience were assigned to a guided perceptual-training group (n = 9), an unguided perceptual-training group (n = 10), or a control group (n = 9). The guided perceptual-training group received half of their trials with color cueing that highlighted either the key kinematic changes in the kicker's action or the known visual search strategy of expert goalkeepers. The unguided perceptual-training group undertook an equal number of trials of practice, but all trials were without guidance. The control group undertook no training intervention. All participants completed an anticipation test immediately before and after the 7-day training intervention, as well as a 24-hr retention test. The guided perceptual-training group significantly improved their response accuracy for anticipating the direction of soccer penalty kicks from preintervention to postintervention, whereas no change in performance was evident at posttest for either the unguided perceptual-training group or the control group. The superior performance of the guided perceptual-training group was preserved in the retention test and was confirmed when relative changes in response time were controlled using a covariate analysis. Perceptual training supplemented with guiding information provides a level of improvement in perceptual anticipatory skill that is not seen without guidance.
- anticipation, penalty kick, perceptual-skill training, sport
- 15 Buszard, T., Farrow, D., Reid, M., and Masters, R.S. Modifying equipment in early skill development: A tennis perspective. *Research Quarterly for Exercise and Sport*. 2014; 85(2):218-25.
- PURPOSE: The International Tennis Federation recently launched a worldwide campaign advocating the use of equipment scaling for children learning to play tennis. The aim of this study was to investigate the influence that varying racquet sizes and ball compressions had on children's ability to play a forehand groundstroke. METHOD This was a quantitative repeated-measures design experiment. Children were required to perform a forehand hitting task using each of 9 combinations of tennis racquets and balls (i.e., 3 racquet sizes x 3 ball compressions). Children's hitting performance was measured using a points system. The aim for the children was to score as many points as possible. Hitting technique was measured via video replay. RESULTS: Hitting performance was best when the smallest racquet combined with the ball with the least compression was used. The ball with the least compression also promoted 2 technique benefits: swinging the racquet from low to high and striking the ball in front and to the side of the body. CONCLUSIONS: This study demonstrated the benefits for young children playing with scaled racquets and low-compression balls. The findings are discussed with regards to their relevance to theories of skill acquisition.
- children's sport, complex skill acquisition, physical education, talent development
- 16 Kachel, K., Buszard, T., & Reid, M. The effect of ball compression on the match-play characteristics of elite junior tennis players. *Journal of Sports Sciences*. 2014; 33:320–326.
- The purpose of this article was to examine the effect of equipment scaling, through the modification of tennis ball compression, on elite junior tennis players (aged 10 years) within a match-play context. The two types of ball compressions that were compared were the standard compression (the normal ball) and 75% compression (termed the modified ball). Ten boys and 10 girls participated in the study. Participants were stratified into pairs based on their Australian Age Ranking and gender. Each pair played two two-set matches: one match with standard compression balls and one match with modified balls. The characteristics of each match were analysed and compared. The results showed that the use of the modified ball increased rally speed, allowed players to strike the ball at a lower (more comfortable) height on their groundstrokes and increased the number of balls played at the net. Ball compression had no effect on the relative number of winners, forehands, backhands, first serves in and double faults. The results are discussed in relation to skill acquisition for skilled junior tennis players
- skill acquisition, tennis, child, modified equipment, talent development

17	Oppici, L., Panchuk, D., Serpiello, F.R., & Farrow D. Long-term Practice with Domain-Specific Task Constraints Influences Perceptual Skills. <i>Front. Psychol.</i> 2017; 8:1387.	The long-term impact of practice with different task constraints on perceptual skill is relatively un-explored. This study examined the influence of extensive practice, i.e., more than a 1000 h of structured practice, with domain-specific task constraints on perceptual skill associated with the passing action. Despite performing the same passing skill, it is not known whether long-term exposure to specific soccer or futsal task constraints influences the players' attunement to environmental information. This study examined this issue by assessing the attention orientation of soccer (n = 24) and futsal players (n = 24) during modified games (6 vs. 6). Futsal players had higher scanning behavior during ball reception and control (40% more ball-player attention alternations) while soccer players mainly scanned the environment when not in ball possession (25% more attention alternations). We suggest that the behavioral differences found are elicited by the extensive domain-specific practice. That is, the higher number of players in soccer, and by a more intense game and easier to control ball in futsal. This study provides new insights into the long-term effects of practicing with specific task constraints.	attention orientation, performance, passing skill, soccer, futsal, football
18	Timmerman, E., de Water, J., Kachel, K., Reid, M., Farrow, D., & Savelsbergh, G. The effect of equipment scaling on children's sport performance: The case for tennis. <i>Journal of Sports Sciences.</i> 2014; 33:1093–1100.	The influence of scaling court-size and net height on children's tennis performance was examined. Sixteen boys (9.7 ± 0.5 years) had to perform a 30-min match in four different conditions, where court-size and/or net height were scaled by using a scaling ratio based on the differences in temporal demands between the children and the adult game. These 30-min matches were analysed using Tennis Analyst (FairPlay Ltd., Jindalee, QLD, Australia) software to determine typical tennis match performance characteristics. Children hit more winners, more forced errors, played more volleys, struck more shots from a comfortable height and played in a more forward court position when the net was scaled. Scaling both the court and net lead to a faster children's game, more closely approximating what is typical of the adult game. The differences between the typical tennis performance variables recorded suggested that scaling the net led to a more aggressive way of playing. Further, children enjoyed playing on the standard court-scaled net condition more than standard adult conditions. It is suggested that optimising the scaling of net height may be as critical as other task constraints, such as racquet length or court-size, as it leads to a more engaging learning environment for experienced children.	scaling; skill acquisition; talent development; tennis

Manipulation of interacting constraints in an intervention or manipulation of independent variables in an experiment?

What does this initial statistical/methodological criticism imply practically? The implication is that the high risk of bias with regards to assessing study methodology in the systematic review by Clark, McEwan and Christie might have led to the de-selection of articles that did not investigate 'technical development' from a CLA embedded in the theoretical framework of ecological dynamics. Essential to the evaluation of studies purporting to adopt the CLA is ensuring that each study assessed is not merely manipulating experimental variables but rather that the key principles of CLA underpin intervention design. For proper assessment with regards to a relevant theoretical rationale in ecological dynamics, the term 'constraints' needs to be used in a theoretically specific way to refer to the boundaries which shape the emergence of coordinated behaviours [7] or to refer to information that drives the spontaneous self-organisation tendencies in system dynamics [8,9,10].

A constraints-led approach is a well-promoted framework for understanding how humans acquire and organise the necessary actions to successfully engage with sport and exercise contexts [6,11,12,13]. The CLA articulates that, through the interaction of different constraints - task, environment, and organism -, individuals will self-organise actions, perception and cognitions in an attempt to generate functional movement solutions [11]. Ecological dynamics is a theoretical framework that has evolved by interlacing the theories of dynamical systems and ecological psychology, which inform principles of a nonlinear pedagogy, in which the methodological nuances of a CLA are captured in learning design [14]. The fundamental relationship between theory and practice is not a trivial issue for philosophical reflection only, as James Gibson (the founder of ecological psychology) pointed out in drawing inspiration from the words of the Gestaltist, Kurt Lewin: "There is nothing so practical as a good theory" [15, p. 135]. The ecological dynamics framework illuminates the essential relationship between the learner and the environment as a key

foundation of practice design and a theoretical tenet on which to consider skill acquisition processes. Adopting an ecological dynamics approach drives practitioners to conceptualise learners as complex, adaptive dynamical systems, co-adapting with events, objects and significant others in an ever-changing performance environment. Through the practical articulation of key theoretical ideas of ecological dynamics, guiding principles for the design of learning environments have been inferred, with relevant research still required to 'frame' the design of constraints-led practices. Philosophical and theoretical clarity has been provided by the extensive literature in the area of nonlinear pedagogy [cf. 6,13,14,16]. Without a comprehensive assessment of the methodological quality of studies in adhering to a CLA, the conclusion remains that Clark, McEwan and Christie's systematic review is at high risk of bias. In practice, we are arguing that research should focus on the principled manipulation of candidate control parameters [17] (i.e., carefully chosen variables that drive changes in system order parameters), that will enhance understanding of interactive constraints in real world interventions. We argue that for high impact research and changes in competitive sport performance we must seek to develop and establish research methodologies that are true to the underpinning theoretical framework, such as representative design.

Comparison of effects of traditional pedagogies and constraints-led training approaches

Clark, McEwan and Christie proposed that a significant reason for their systematic review was, that "Currently, there is a lack of sufficient evidence to advocate whether the manipulation of specific task constraints benefit individuals more so than traditional training regimes." Yet in their review, this comparison was not undertaken with respect to carrying out a separate systematic review of what could be defined as studies investigating the efficacy of traditional pedagogies. Indeed, in their review, no attempts were made to provide rigorous definitions of traditional skill learning practices, nor to compare these characteristics with constraints based learning designs. This is an important challenge for future researchers in skill acquisition and sport pedagogy. First, clear definitions are needed to characterise different

approaches and only then can rigorous assessment methodologies be undertaken to compare effectiveness of studies in different categories. For example, consider the work by Lee *et al*, [18] whose study comparing nonlinear and linear pedagogic approaches to motor skill acquisition provides a useful template for considering traditional vs. constraints-led approaches. The inherent intricacies in ‘measuring’ complex, emergent, adaptive, behaviours in skill performance should not serve as rationale for rejecting appropriate research methodologies, or indeed, serve as a rationale for rejecting an approach altogether. That we currently cannot effectively measure something, speaks more to the issue of methodological design and appropriate frameworks for representing a theoretical approach rather than it does for rejecting that approach as inappropriate for a field of study.

Representative Learning Design

Regardless of constraints manipulation, a major omission in the systematic review was the lack of evidence that studies were high in what Egon Brunswik [2] termed *representative design*. This is a major principle of ecological dynamics for ensuring that task designs for learning and experiments contain relevant informational constraints to elicit the emergence of functional behaviours, as performers are drawn to exploit affordances available [19]. Representative task design [2] advocates the need to maintain action-fidelity [20]. Brunswik’s [2] work has been adopted by ecological dynamicists [e.g.21,22], especially his request to sample performance contexts in the same way as researchers have traditionally considered the sampling of participants. Consequently, researchers and practitioners need to sample practice and experimental environments to ensure they have similar information flows to a performance environment, making them more representative and maintaining greater action-fidelity. The concept of representative learning design (RLD) calls into question the value of practice task designs that are decontextualized through artificiality and reductionism (potentially breaking the coupling of perception and action systems) in a performance environment. To exemplify, in practical learning interventions, it is important not to design an environment that requires learners to dribble around cones or manikins – with the aim of creating

realism. Without information from movements and locations of opposing defenders, spatial (line markings) or temporal (tempo of a ball feed) informational constraints (to exemplify) there will be little strengthening of the functional perception-action couplings required in skilled performance. Whilst it is clear that further work is needed in developing clarity for practitioners in representative learning design, it is a key theoretical construct that should not be overlooked when considering criteria for reviewing effectiveness of interventions in research. The transfer of skill learning from training to performance environments is central to any coaching endeavour. We argue that RLD embedded in a CLA allows practitioners to develop experiences during practice that are more likely to positively influence learning (and therefore performance). This involves moving the emphasis away from the memorisation of technique through isolated drills and onto the skilful execution of functionally-relevant actions in a performance context.

Choice of Interceptive Actions Only

An interesting question concerns the choice of interceptive actions by Clark and Christie as the specific research domain for their systematic review, rather than sports in general such as sprinting, weightlifting, rowing and climbing. Key to this question is our assertion that this approach (choosing interceptive actions only) assumes that domain-specific actions can be studied in isolation, which is incompatible with the CLA. The issue of assessing the effectiveness of specific approaches to learning is important for the study of skill acquisition more generally, not just in interceptive actions, and not just when using constraints based methodologies. The framing of the systematic review around studies of interceptive actions needs a comprehensive rationale for its selection. Additionally, interceptive actions include a much wider range of activities than those covered in the systematic review to include all sporting activities, as highlighted by the large number of studies (not intervention studies) that have ecological dynamics as the underpinning theoretical model (e.g. athletics hurdling - [23]; cricket bowling - [24, 25]; diving - [26]; rock climbing - [27]; swimming - [28]. Perhaps, Clark and Christie have confused the CLA with other Games Based pedagogies – which is a point we addressed in another paper,

as a result of an uninformed reviewer's comment [See, 29]. It is important to reiterate our argument that studies purporting to use a CLA need verification of methodology by assessing that the theoretical principles of ecological dynamics underpin the rationale in a study. Although the sample of only 18 papers in this systematic review is not a methodological issue, it does draw attention to the lack of literature available on interventions and it is, therefore, surprising that Clark and Christie chose not to widen their range of analysis beyond interceptive actions. Regardless, it is worth reiterating a key finding of this paper that future research is required to determine the effectiveness of constraint-led training to include all areas of skill learning in a range of different sports and not just on performance of a limited range of interceptive actions. Significantly, this is not just of relevance for a CLA but is a major issue for developing our understanding of traditional approaches to learning sport skills, as well as frameworks like TGfU, schema theory, closed-loop control, variability of practice, contextual interference and the specificity of learning hypotheses, for which there have been no recent systematic or quantitative reviews conducted.

Further, it is not clear that quantitative reviews of experimental studies are the most appropriate way to engage with evidence on effectiveness of learning interventions, which is a major assumption behind the paper by Clark and Christie. The inherent belief seems to be that a classical experimental design is best for examining skill acquisition in sport using constraints based methodologies. We believe it is worth challenging this ideology. A positivist approach to experimental design is employed by all of the studies reviewed in their systematic review. With the aim of establishing reliable results, a reductionist approach to the control of methodological research design is common, but not necessarily appropriate in all instances. By removing the inherent representative variability required in studies from the measurement of key dependent variables, researchers attempt to ensure that the experimental conditions are similar between the pre- and post- intervention trials. The key driver behind employing a constraints-based methodology is to create training environments that are representative of a specific performance environment in order to enhance the transfer of skill learning between practice simulations and performance. The enhanced 'chaos' and variability of a performance setting is

important to replicate in practice design in order to enhance fidelity between training and performing contexts. This foundational idea in ecological dynamics raises questions on measuring the impact of a constraints-led intervention in an environment designed for experimental control, and may not be representative of a performance environment. The stable and predictable nature of such experimental designs (for the purposes of control) is a significant issue for practitioners as removing key affordances might diminish the purposefulness of the training intervention itself. In order to truly respond to the intrinsic variability of most sports performance environments, and conduct real world, messy research, there is a need for a paradigm shift towards the use of methods that capture more qualitative information, in combination with quantitative methods [30]. Such a mixed methods design might best serve the purposes of methodological evaluation in sport pedagogy.

Future studies should explore the use of rich and varied research methodologies such as single case study analysis [31], longitudinal designs and the analysis of action research interventions [32]. A mixed method approach may be best suited for capturing skill acquisition processes over different timescales and the challenging issue of transfer fidelity from a range of learning environments to a competitive performance context. A good example here is the basketball study of Oudejans [33] who adopted a group and single case study design to study sports performers over a complete season.

Sample Size and Participants

Clark, McEwan and Christie questioned the low sample size in the studies in the systematic review with more than half of the studies having relatively small sample sizes of six to ten participants per group and suggested that this may have had an impact on the reliability of the results. Sample size is a key challenge, especially if we want to work in messy, noisy, real-world, competitive sporting environments. However, when traditional experimental designs are seen as the gold-standard for research, there is an over emphasis on use of laboratory conditions for experiments and undergraduate students as participants. Research studies with elite athletes or developing experts, by

virtue of their talent in adapting to challenging performance environments, are few and far between. Of course they are worthy of study, despite obvious challenges in access to, or recruitment of this population.

The good news for skill acquisition scientists is that advances in technology, and also greater acceptance of evaluating differing types of knowledge, means we have moved beyond traditional research designs. We are now able to collect data in environments that best replicate settings that people normally learn, practice, perform, compete, act or participate in. The key concern then becomes what information to collect from the vast plethora of information that *can* be collected [34]. Collecting data in complex sporting environments often requires a *distinct* approach to traditional hypothesis-based, experimental design and the utilisation of mixed methods may be entirely warranted [30]. This does not, however, mean that research of this type can abdicate itself from principled research design to test ideas. Instead, we argue that the approaches we are advocating must still be accountable to acceptable levels of scientific rigour. Rather, the paradigmatic assumptions of positivistic research methods are simply one way of developing knowledge and there is a need for valid and reliable methods to access rich and varied forms of information available on pedagogical methodologies implemented in learning design.

Intervention Length

The length of the training interventions employed in some of the reviewed studies is also questionable, but for some time this has been recognised as an inherent problem with the ubiquitous ‘6-week training study’ prevalent across all of the sport science disciplines [35]. Within skill acquisition research, intervention studies rarely use training periods longer than nine weeks [33]. In the sample of the systematic review, the studies by Masters [36], Hagemann [37] and Williams [38] consisted of only a single session, while the longest study reviewed consisted of 45 sessions over a nine-week period in table tennis [39]. Such short periods of training are unlikely to produce a change in performance, let alone a measurable one. Previous research within the ecological dynamics realm has highlighted that learning can take place over different time scales.

For example, attunement to a key informational constraint can lead to almost immediate improvements in performance (e.g. the cricket batter who is suddenly able to identify the wrist spin bowler's *googly* from the changes in his or her bowling action [40]). Alternately, changes can be more medium or long-term, with varied learning trajectories [41]. In fact, the way athletes react to any intervention is likely to be specific to each individual and their developmental history. This point also highlights the limitations of traditional group designs where individual responses can be masked and emphasises the need to move to research methodologies more in tune with the key ideas of ecological dynamics and complex systems in general (see [34] for an extended discussion of how to capture expertise in real world settings).

The role of Experiential Knowledge in assessing effectiveness of learning designs

Elsewhere it has been argued that many coaches and sport pedagogues implement a version of a constraints-based approach in their practice task design, which might be enhanced by a greater understanding of the theoretical concepts of ecological dynamics [42, 43]. These studies have revealed the potential value of elite coaches' experiential knowledge in understanding how to design training interventions, an often-overlooked source of knowledge. We have made the call for the experiential knowledge of coaches to be acknowledged, emphasising the need for coaches and sport scientists to work together [44]. The value and role of experiential knowledge of coaches has often been neglected largely because of the inability to 'collect' data through classical experimental designs because of the inherent complexity of expertise or knowledge in coaching. A number of programmes of work are emerging that have meshed qualitative and quantitative research findings to enhance our understanding of expertise in sport. Pluijms [44] in sailing and the PhD programmes of Sarah-Kate Millar [45] in rowing and Dan Greenwood [46] in sport run-ups. These innovative approaches need to be continued in further work. Future quantitative reviews need to also consider a range of different data sources, rather than simply sample experimental studies in the scientific literature. To exemplify, a blog by Brendan Nel [47] recently highlighted how the

coach (Swys de Bruin) of the South African Super 16s franchise, the Lions, encouraged his players to enhance their adaptive variability and seek affordances from the opposition ('what they offer') to decide emergent game strategies.

Furthermore, what are we to make of the post on the blog, Connected Coaches, by Blake Richardson [48] outlining evidence behind Coach of the Year, Danny Kerry's, success at the 2016 Olympic Games in leading Team GB to an unexpected gold medal in field hockey? Important 'watch words' in the successful pedagogical practice included a constraints-led approach. Perhaps questions about understanding the efficacy of a constraints-led approach to skill acquisition need to also consider opinions in a football coaching blog by Richard Allen [49] asking: Do we really know how to utilise the constraints-led approach?

This criticism of Clark, McEwan and Christie's restricted approach in focusing on evidence of the CLA from scientific experiments only, and ignoring the voices of practitioners as stakeholders who regularly use the CLA in practice task design, does raise an interesting challenge for future research: How to assess the value of information from blogs, podcasts and media articles expounding the effectiveness of constraints-based coaching approaches used at an elite level of performance? Here we have argued that sport science can no longer simply ignore this body of information because it has not been generated in controlled laboratory experiments.

Conclusion and Recommendations for future learning studies utilising a CLA

Clark, McEwan and Christie rightly, in our view, highlighted the need for more research examining the efficacy of constraints-based interventions in sport training and practice. However, this is an issue challenging skill acquisition theories and sport pedagogical frameworks across the board, and is not just of relevance to practitioners and scientists interested in the CLA. A systematic

review will only provide an analysis of the quality of findings from experimental studies of skill learning, some of which may contain reductionist methods less suited to providing the quality of evidence needed on intervention efficacy from a range of different sources. These include, but are not limited to, experiential knowledge of elite practitioners and athletes, as well as information from action-based research in which researchers are embedded in sports training environments. A particular challenge here is to also ascertain the quality of information evident in digital media such as blogs, websites and podcasts – a constant source of coaching information. With regards to the specific systematic review undertaken by Clark, McEwan and Christie, there are a number of factors addressed in this commentary that highlight some of the potential limitations of the studies and the conclusions of their review. Key for us was the need to ensure that studies reviewed should evidence the theoretical framework of ecological dynamics as the rationale underpinning the research.

Key principles for researchers interested in adopting CLA to inform future directions of research and practice, include the following:

- CLA is applicable to all sports and physical activities, not just those that contain interceptive actions.
- As CLA is based on an ecological dynamics theoretical rationale, the methodologies of the reviewed studies also need to be consistent with that specific framework.
- Longitudinal Studies: Future research designs on the CLA need to track skill learning, not only over days, weeks or months, but also to include research questions that capture competitive cycles over seasons and years.
- Use of Individual or Multiple Baseline Methodologies: Traditional group based designs with control groups is not necessarily the most appropriate when implementing a CLA in terms of the theoretical concepts or the ethics of impacting athlete's careers. This is especially the case when it comes to assessing impact of CLA interventions on elite

and developing expert athletes. It is simply not feasible to undertake experimental manipulations with such groups.

- Representative 'Testing': Appropriate measurement of interventions should be developed that utilises the knowledge of practitioners and scientists
- Participants and Sample Sizes: By definition, if we want to move away from 'student' populations and test the effectiveness of CLA in sports performance settings, interventions need to take place in the messy, noisy world of competitive sports performance.
- Robust Environment Design: frameworks are required to bridge the gap between the theoretical understanding and its practical application. These will acts as a guidance tool for practitioners and researchers to ensure they are designing environments consistent with the underpinning principles of Ecological Dynamics.

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