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# Evolving the Control-Chaos Continuum: Part 1 – Translating Knowledge to Enhance On-Pitch Rehabilitation

Successfully supporting an elite soccer player to return to sport following injury is a complex process requiring knowledge integration across disciplines, clinical expertise, and effective communication among stakeholders.[29,30,61,64,65,67,68] To facilitate effective communication between stakeholders, a player's pathway back to sport should be viewed on a progressive continuum aligning their recovery and rehabilitation.[5,16] On-pitch rehabilitation is a critical component of this pathway, preparing the player for the demands of team training and the specific requirements of their position, while accounting for the context of their injury.[58,60] While return to sport progressions can be highly complex, frameworks can guide practitioners to systematically design on-pitch rehabilitation.

**BACKGROUND:** On-pitch rehabilitation is a crucial part of returning to sport after injury in elite soccer. The *control-chaos continuum* (*CCC*) initially offered a framework for practitioners to plan on-pitch rehabilitation, focusing on physical preparation and sport specificity. However, our experiences with the CCC, combined with recent research in injury neurophysiology, point to a need for an updated model that integrates practice design and physical-cognitive interactions.

**CLINICAL QUESTION:** What are the insights from injury neurophysiology, soccer performance, and coaching science needed to update the CCC and improve the planning, delivery, and progression of on-pitch rehabilitation in elite soccer?

**KEY RESULTS:** Drawing on extensive experience in elite sport, we explain how recent research on neurophysiological recovery from injury, game models, and practice design has been applied to update the CCC and evolve the existing framework.

**CLINICAL APPLICATION:** The evolution of the CCC expands on the original model to enhance planning, delivery, and progression of on-pitch rehabilitation. The updated framework incorporates elements of visual cognition, attentional challenges, decision-making, and progressive representation of the game model to enhance sport-specific preparation for returning to sport. *J Orthop Sports Phys Ther 2025;55(2):78-88. Epub 3 January 2025. doi:10.2519/jospt.2025.13158*

**KEY WORDS:** *control-chaos continuum, elite soccer, injury, rehabilitation, return to sport*

The *control-chaos continuum* (*CCC*) was developed using a conceptual framework analysis[28] aiming to improve on-pitch rehabilitation by reflecting on the realities of elite soccer, integrating scientific literature and practitioner experience in the English Premier League.[58] Conceived through an ecological lens, the *CCC* progresses from *High Control* to *High Chaos* using a constraints-led approach to prescribe on-pitch training guided by preinjury running load targets to develop sport-specific training capacities while considering the injured structure/tissues and estimated status of healing.[3,23,58] The *CCC* also considers the perceptual and attentional demands of sport as critical components of training design which can play a role in the progression from controlled rehabilitation to a chaotic sporting environment.[58–61,64–68]

## LOOKING BEYOND DEVELOPING PHYSICAL QUALITIES IN REHABILITATION

The development of physical qualities and sports-specific training capacity is well recognized as a crucial factor in return to sport.[56,62] However, on-pitch rehabilitation provides an opportunity for holistic player development. While models designed for coaching *healthy* athletes are informative, planning practice and redeveloping skills in the injured player adds a layer of additional variables to consider.[27,74] Alongside

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healing physiology, increasing evidence now suggests that the visual-cognitive demands of sport such as anticipating and responding to opposition movement at game speed should be integrated into return to sport progressions.[11,12,22] An over-emphasis on physical preparation may limit the integration of advanced practice design, attention challenges, and decision-making aspects into pitch-based rehabilitation.

The associations between the recovery of isolated physical outcomes, such as isokinetic eccentric knee flexor strength, relative quadriceps/hamstring strength, and strength symmetry, and future injury are inconsistent, suggesting that key elements are missing in training prescription and return to sport assessments.[8,20,21,55] Furthermore, as elite soccer continues to evolve, it will likely require higher speed decision-making and more efficient environmental scanning, placing greater demand on a player's neurophysiological capacity, underscoring the importance of training physical-cognitive abilities in concert with physical qualities.[2,24,32] Restoring physical-cognitive capabilities while incorporating components of the game model (ie, replicating positional roles within key game moments) also increases ecological validity and transfer of training in preparation for return to sport.[46–48,50]

## PRACTICAL OBJECTIVE

The *CCC* provided an initial framework to help guide practitioners with planning on-pitch rehabilitation in elite soccer. However, the final stage of a conceptual framework analysis encourages revision based on new insights and literature.[28] We propose revising the *CCC* to integrate insights from other disciplines, and further experience in elite settings to better support practitioners in planning on-pitch rehabilitation. In part 1 of this 2-part clinical commentary, we aim to provide an overview of insights from injury neurophysiology, soccer performance, and coaching science, and explain their role in evolving the *CCC* to improve the design, delivery, and progression of on-pitch rehabilitation.

## INCORPORATING VISUAL-COGNITION INTO SPORTS-SPECIFIC REHABILITATION

While traumatic brain injury induces apparent neuroplasticity, musculoskeletal injury also leads to neuroplastic changes that impact return-to-pitch performance.[38,70,77] In the case of ligament injury, the neuroplasticity may occur secondary to changes in sensory feedback, specifically affecting cross-modal sensory integration, an important neurological phenomenon that informs both the temporal and spatial congruency of sensory stimuli (allows one to map visual perception with proprioception to plan and coordination movements).[12,14,54]

While neuroplasticity may preserve motor control in isolated settings, in environments that demand intensive visual-cognitive decision making like soccer competition and training, motor coordination can become impaired due to the elevated cross-modal demands to both engage with the game and preserve joint stability.[22,26,76] Ineffective neural compensation after ligament injury is recognized through the dual-task literature for injured individuals, as additional attentional or rapid decision-making challenge results in reduced physical performance.[11,39,40,52,57] We anticipate that returning to the increasingly *chaotic* sport environment will present an even more demanding visual-cognitive dual-task challenge, increasing the likelihood of movement errors or a decline in movement quality for unprepared athletes. Thus, players recovering from injury may be at a greater risk for deficits in on-pitch perceptual-motor skills secondary to compensatory neuroplasticity after injury.

The original *CCC* emphasized the significance of progressively integrating the qualitative aspects of movement in competition, but it did not specifically address the inclusion of visual-cognitive dual-task challenges. Diverging from the original framework, the *Visual-Cognitive CCC* (*VC-CCC*) was recently developed to progressively integrate visual-cognitive dual-tasks progressing from high stability to increasing levels of complexity.[12] The *VC-CCC* progressively layers divided attention and visual selective attentional constructs to challenge aspects of neurophysiological affected by injury, yet essential in sport.

Divided attention dual tasks challenge a player's ability to simultaneously provide or switch attention between 2 or more stimuli.[45] During a drill, a player may be required to simultaneously scan the environment and decipher a stimulus such as a hand signal to initiate an action, ie, pass to a mini goal during a pass and move drill (Limited Resource Theory; single pool of attentional resource).[45] Alternatively, divided attention dual tasks could challenge a player's ability to switch cognitive priority between auditory stimuli (ie, call from coach) while scanning the environment to decipher whether an appropriate pass is available based on the cues provided. For example, during a pattern-of-play drill, dependent on the provided stimuli, a central midfield player may play the pass or instead turn out and recycle possession to start another attack (Multiple Resource Theory; not all competing stimuli require the same attentional resource).[71]

Selective visual attention dual tasks challenge a player's ability to select pertinent and/or ignore irrelevant sensory stimuli for goal-directed action.[41] Selective visual attention challenges can be further broken down into *top-down* voluntary attention that a player may allocate to a given task for identifying task-relevant stimuli, and *bottom-up* stimulus derived attention that a player may allocate unintentionally and is modulated by the stimulus intensity.[33] During a drill, *top-down* selective visual attention could challenge a defending player's decision making to either move toward the ball from an incoming cross, or an attacking player's movement to attack the cross during a crossing and finishing drill based on the defenders selected choice before all sensory information is available. On the other hand, *bottom-up* selective visual attention could require a defender to intercept the through-ball or drop and track a forward during a counterattacking 1v1 situation following a game-based situation. Requiring a decision based on the defender's interpretation of which action to take in the 1v1, which occurs in an unanticipated area of pitch and moment within the game. When integrating visual-cognitive dual-task challenges, practitioners must consider the nuances of how the player will use attention in game situations with relevance to the game model, ie, in defensive organization, and approximate that as they progress through on-pitch rehabilitation.

While the *VC-CCC* was intended to inform rehabilitation from anterior cruciate ligament reconstruction, the concepts may be extrapolated to recovery from other musculoskeletal and brain injuries such as concussion, increasingly recognized due to enhanced screening and diagnoses.[12,15,44] The updated *CCC* transfers the concepts of divided and selective visual attention introduced in the *VC-CCC* to on-pitch sport-specific rehabilitation, while considering ecological dynamics (**FIGURE 1**).[49] Practitioners should progress visual-cognitive challenges in drills, aligning with practice design while assessing both physical and cognitive performance (please see "Monitoring" subsection).[12] In addition, beyond the *High Control* phase, practitioners may alter the level of visual-cognitive challenge in a manner analogous to that of an equalizer on a stereo system—boosting or cutting visual-cognitive constructs within a phase to assist with phase transition. For example, at the start of the *Control-to-Chaos* phase, a pass and move drill may challenge 2-step processing and congruent decision-making, whereas toward the end of the phase, multistep processing and response inhibition elements such as no-go challenge, can be added to the same drill to increase the cognitive challenge (**FIGURE 1**).[12]

## INTEGRATING THE GAME MODEL INTO DRILL DESIGN

A GAME MODEL IS A FRAMEWORK USED by a head coach to establish a team's system of play, encompassing tactical patterns, defensive and offensive principles, and player-specific roles. (**FIGURES 2**, **3**, and **4**).[42,47,50] It arises from the interplay of a coach's cultural background in soccer, their ideology, the capabilities of their playing squad, the club's ecosystem, and its financial limitations.[47,48] Proactive coaches will consistently seek to adapt their game model in response to the evolving tactics of the game.[19,35] Gaining insight into the coach's game model is crucial for practitioners to design engaging on-pitch sessions and drills that reflect the physical, technical, and tactical demands of competition. Integrating elements of the game model into drill design fosters collaboration between rehabilitation practitioners and coaches, improving return to sport

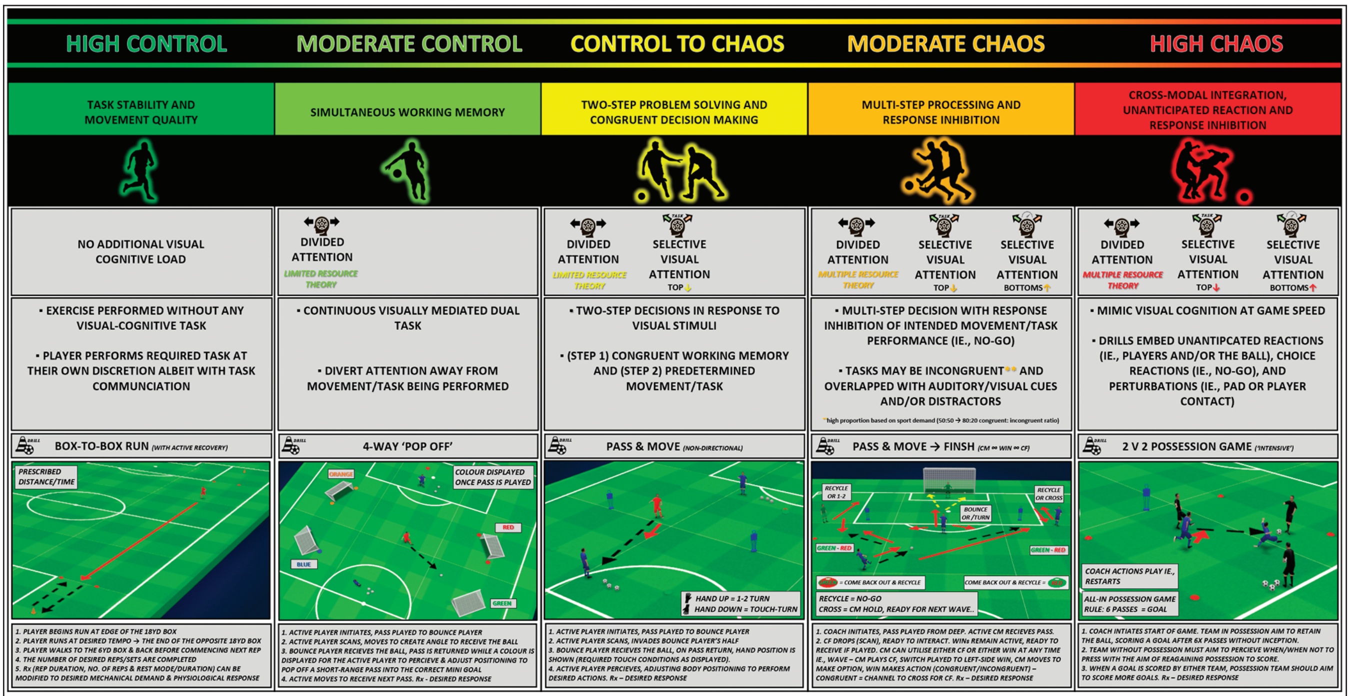


**FIGURE 1.** The Visual Cognitive Control-Chaos Continuum (*VC-CCC*) applied to on-pitch rehabilitation. Phase goals and targeted attentional mechanisms with on-pitch example drills. Progression of visual-cognitive dual-task interventions from *High Control* to *High Chaos*. Beyond *High Control*, practitioners may blend *VC-CCC* concepts like an equalizer on stereo system in transition to the next phase of the CCC.

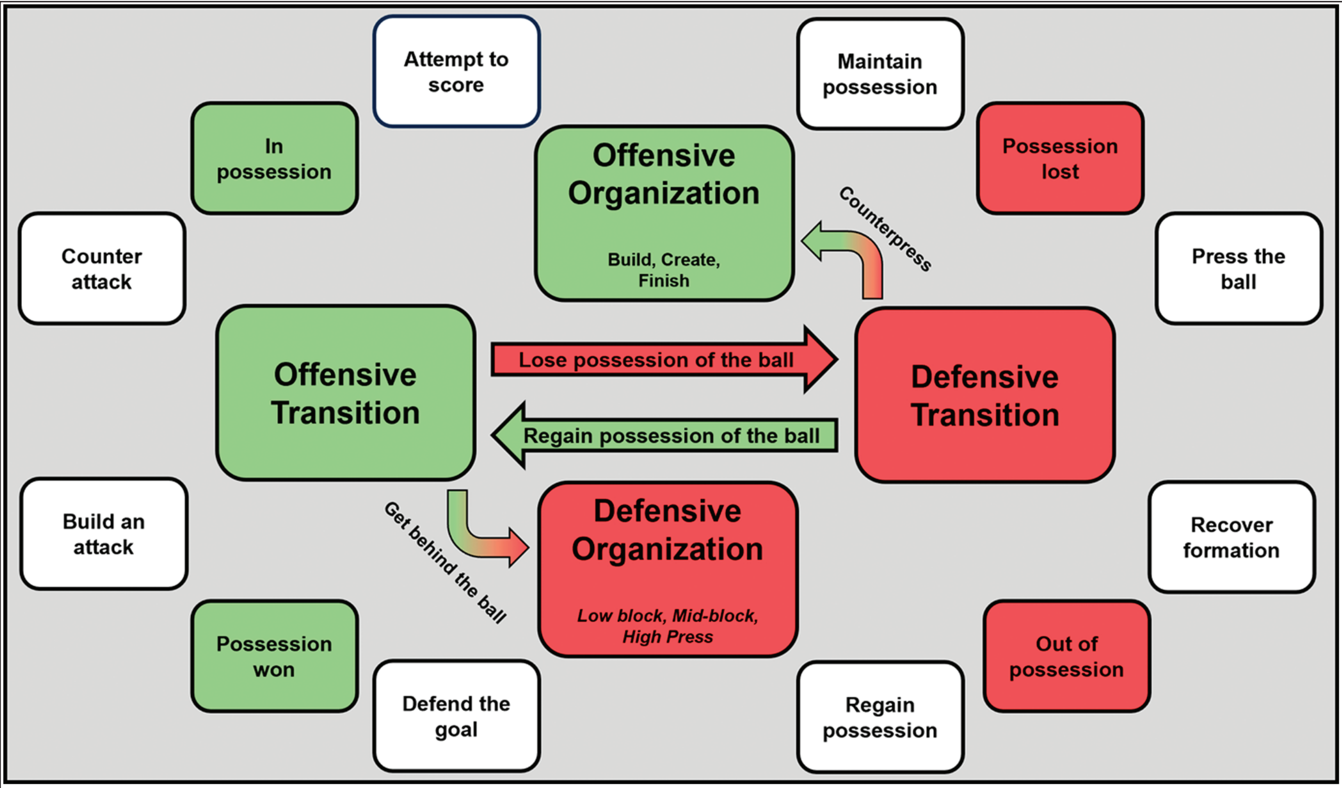


**FIGURE 2.** Key moments of the game model to consider for on-pitch rehabilitation practice and drill design. Phases of play can be subcategorized into organizational and transitional elements.

readiness.[9,63] Additionally, integrating input from coaches enhances game theory application and can accelerate a player's transition to full team training. This integration becomes essential when the manager changes, as it allows the returning player to gradually adapt to a new model rather than facing a sudden increase in cognitive demands upon returning to full team training.[60,64] The game model also exerts an important influence on the periodization structure, particularly during the latter stages of rehabilitation. Elements to consider include session themes and content, frequency and density of training days, and total duration.[60] The value of the game model during early rehabilitation should also not be underestimated. Injured player involvement in tactical team meetings (reviewing the game model against opposition constraints and individual performance analysis) are vital for player support and learning.[34,63]

Incorporating player roles during specific phases of play (ie, defensive organization) during on-pitch rehabilitation enhances ecological validity and boosts player confidence. (**FIGURES 3** and **4**).[46,60] For example, a winger in a uniform 4-4-2 formation will have individual responsibilities during both defensive and offensive organization. In the *create* subphase of offensive play, a winger may be required to shift into a wider position on the pitch, moving close to the touchline to (1) create space between defensive lines or (2) provide an option to receive a pass from a teammate before progressing into the final third of the pitch (**FIGURE 3**). In the defensive phase, with a *mid-block* strategy employed, the player may *drop-off* from play when inactive, waiting for an appropriate trigger to initiate a press (ie, alterations in an opponent's body shape), to attempt to regain possession and force a counterattack (**FIGURE 4**). Drill design can also incorporate positional units and/or the interconnection of these units (ie, a back three; 3 defensive players) co-interacting to initiate an attack before interlinking with a holding central midfielder who has to scan and perceive before deciding upon the appropriate secondary action (ie, turning out to play a forward pass).[3,32,60]

## STRUCTURING PRACTICE DESIGN FOR ON-PITCH REHABILITATION

During team training, players are routinely required to problem solve within unpredictable situations, providing both affordances and challenges.[74,75] Practice design in rehabilitation should closely mirror the team environment, with adjustments only made for specific task limitations related to physiological healing and progress. For example, a player returning following anterior cruciate ligament

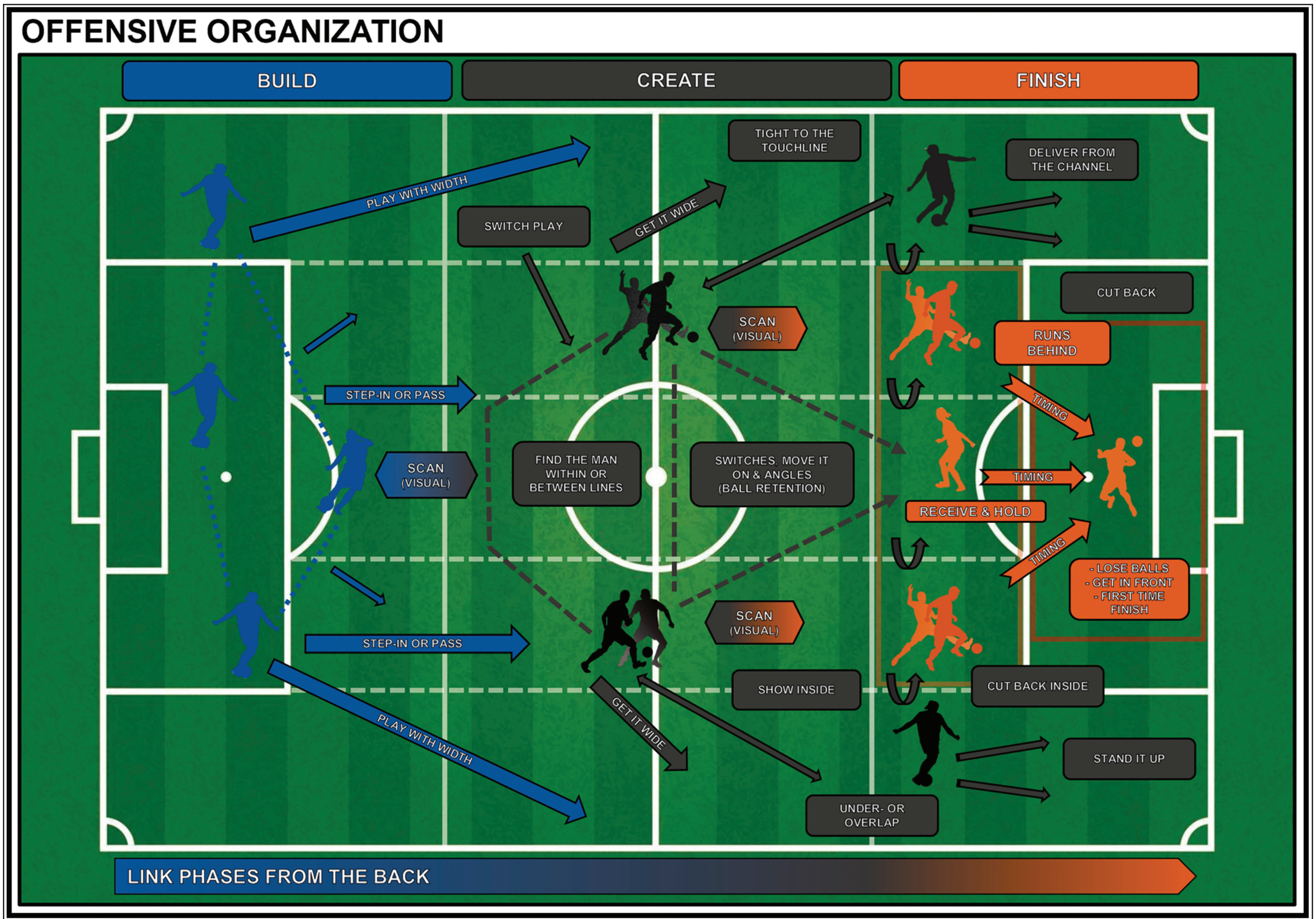


**FIGURE 3.** Offensive organization separated into 3 subphases: (1) build, (2) create, and (3) finish and key elements relative to each phase/position. Key offensive principles for consideration in drill design may include (1) dispersal, (2) penetration, (3) movement, (4) support, and (5) creativity. Refer to the club's game model to provide the most ecological challenge.

reconstruction may be limited in their initial capability to decelerate, representing avoidance of decelerative loads on the involved limb.[13,36,59,67] Session content and complexity (open vs closed), and specific task and environmental constraints are applied based on the player's limitations. In elite soccer, there is often limited or no, pitch-based interaction between players and coaches until the players return to team training. However, other team sports integrate coaches earlier in the return to sport pathway, fostering skill development during recovery.[66] By working alongside coaches, practitioners should strive to gradually incorporate game-related constraints to maximize the transfer of training.

On-pitch rehabilitation that mirrors game constraints was the main focus of the original *CCC*, emphasizing progressive drill difficulty and game specificity. The updated *CCC* adds the extended-challenge model, in which practice design provides highly *controlled* situations to maintain performance, moving toward highly *chaotic* challenges that transfer to competition (**FIGURE 5**).[27] Updates to the *CCC* incorporate practice to maintain, learn, and transfer considerations:

*Practice to Maintain* (redefined as *Practice to Reinforce* in rehabilitation) aims to reinforce desirable skills/actions, critical for engaging and motivating players to promote confidence returning to on-pitch activities.[27] As rehabilitation progresses, raising the degree of task difficulty and sport-specificity provides opportunities for learning and skill (re) development.

*Practice to Learn* (redefined as *Practice to (Re)develop* in rehabilitation) describes the phenomenon in which increased training challenge potentially requires a short-term decrease in performance to progress skill learning.[27] New challenges may not reflect greater physical requirements of the task but may include perceptual-cognitive skills in conjunction with technical skills (ie, challenging a player's passing under situations requiring decision-making), reflecting

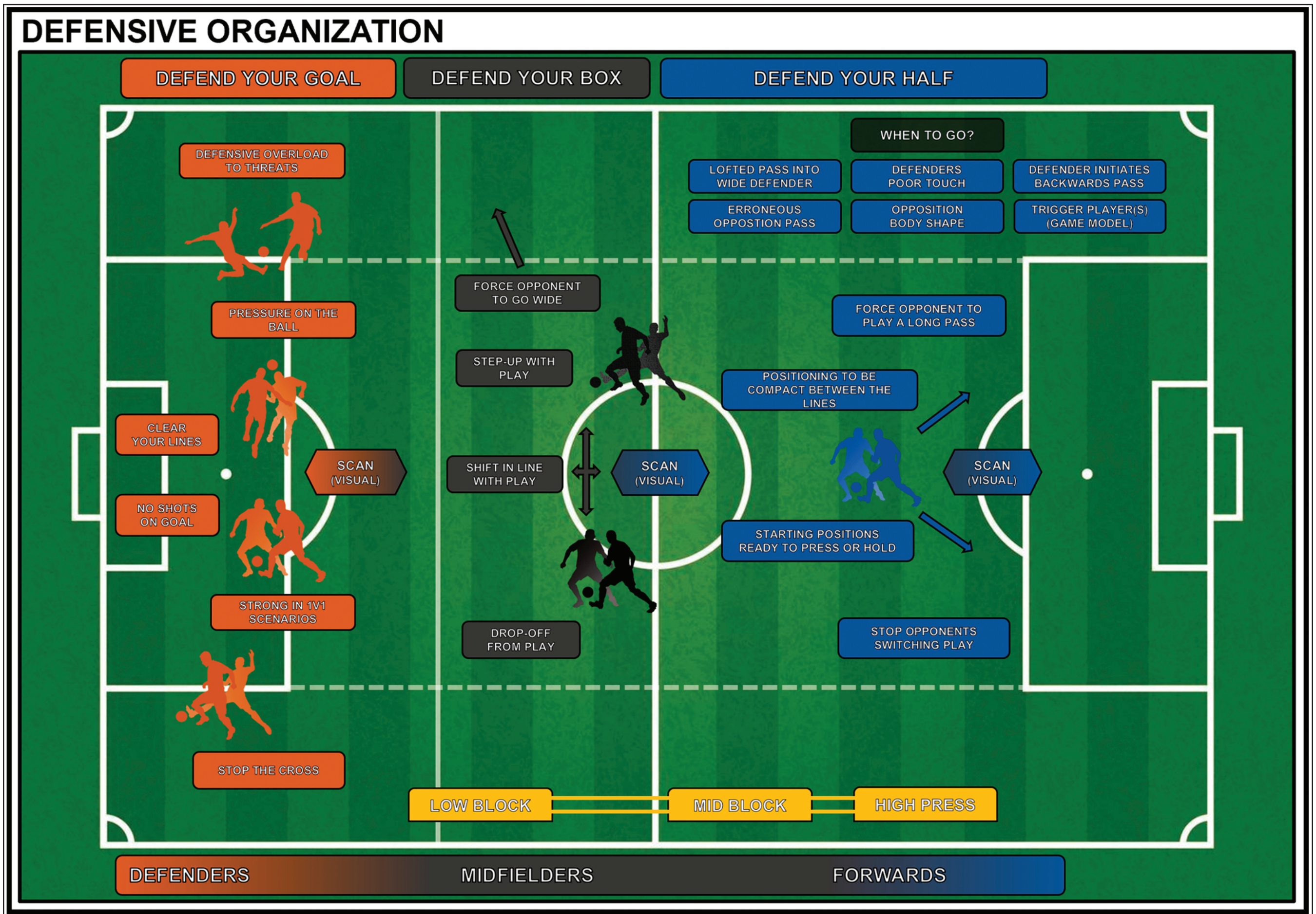


**FIGURE 4.** Defensive organization separated into 3 subphases: (1) defend your goal, (2) defend your box and (3) defend your half and key elements relative to each phase/position. Key defensive principles for consideration in drill design may include (1) delay, (2) compactness, (3) depth, (4) balance, and (5) discipline. Refer to the club's game model to provide the most ecological challenge.

game scenarios. Random practice conditions such as switching between skills and applying opposition constraints (ie, defenders) increases variability and perceptual-cognitive load.[27,31,73] Challenges that increase perceptual-cognitive demands have been shown to promote better retention and transfer into competition.[18] The degree of challenge should however be considered in lieu of the injury timeline and proximity of return-to-competition to balance player confidence with ability.[63]

In drills where the goal is to *Practice to Transfer* (redefined as *Practice to Perform* in rehabilitation), the aim is to maximize transfer to competition.[27] Drills should mimic the stresses and challenges of team training and the player's positional role within the team. Practitioners and coaches should create *live* situations where players are faced with opportunities to problem solve.[74] Such drills create time-related constraints, require rapid decision-making, and elevate attentional demands.[74] An additional consideration may be training in a state of physical and mental *fatigue*, if applicable to the injury case.

Within a training session (*CCC* phase dependent), practitioners may use part practice, where a session is broken down where drills have different objectives based on the extended-challenge model (**FIGURE 5**),[27] and progressive manipulation of task (and environmental) constraints to alter the level of challenge and the practice objective.[3] For example, a drill may transition from reinforcing midrange passing under *controlled* conditions to one with player being pressed having to play a midrange pass into the path of a player making a forward run.

## AN INTEGRATED APPROACH TO MONITORING PHYSICAL-COGNITIVE "LOAD"

Given the emphasis on the physical-cognitive interactions within the revised *CCC*, we propose that practitioners use a simplified version of the

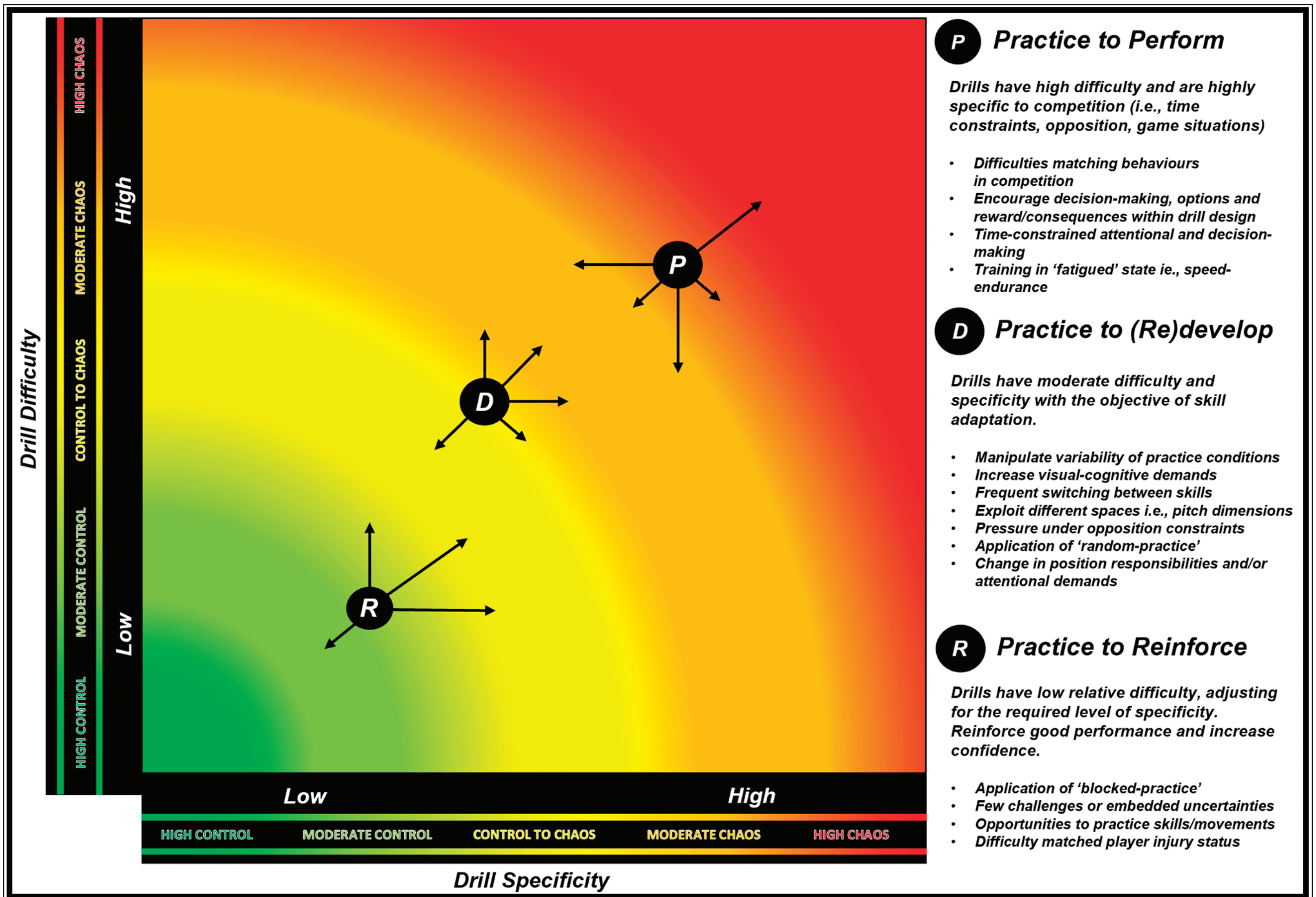


**FIGURE 5.** Adapted extended-challenge model for practice design using the *control-chaos continuum.* This adapted model shows different types of practice when the relative difficulty is considered as a function of the specificity. Multidirectional arrows indicate individual variation in challenge points (+/– difficulty and +/– specificity).

NASA task load index (NASA TLX) to discriminate between mental and physical demands placed on the player during on-pitch sessions (**FIGURE 6**).[18,25,46,57] Typically used in aviation and surgical settings,[1,7] the NASA TLX provides a validated multidimensional subjective evaluation of 6 dimensions: mental demand, physical demand, temporal demand, personal performance, effort, and frustration.[25] We recommend practitioners use 2 dimensions: mental and physical, collecting player evaluations within 15 minutes following on-pitch training (**FIGURE 6**). Tracking these subjective measures enable the practitioner to reflect upon session design to determine the level of challenge and progress in each dimension.

The long absence from the intensive visual-cognitive demands of on-pitch training after injury likely compounds the neural compensations for motor control.[6,13,36,59] We have observed this effect following ACL injury, with higher perceived mental demands and elevated internal cardiovascular responses, particularly from the *Control-to-Chaos* phase onwards, likely due to the higher level of drill complexity and representative design.[4,51,59,63,67,69] This is in contrast to concussion injury cases, where within dual-task drills elevated perceived mental demands and *perception delays* are recognized, but without elevated internal cardiovascular responses relative to imposed physical demand.[10,43,53] This reinforces the value of tracking the mental demand dimension of the NASA-TLX in brain-related injuries particularly as current Football Association concussion return to sport guidelines (on-pitch stages 3-4) only encompass physical-orientated objectives.[17]

Frustration may also be tracked using the NASA-TLX, allowing practitioners and coaches to evaluate proposed practice design outcomes, relative to the aims/objectives of session content. Moderate-high frustration may indicate that the learning point was beyond the player's boundaries (difficulty level outside of the player's current skill parameters), requiring future session modification.[27] Planned visual-cognitive challenges imposed by manipulating task (and environmental) constraints may also be evaluated in relation to perceived mental demand during

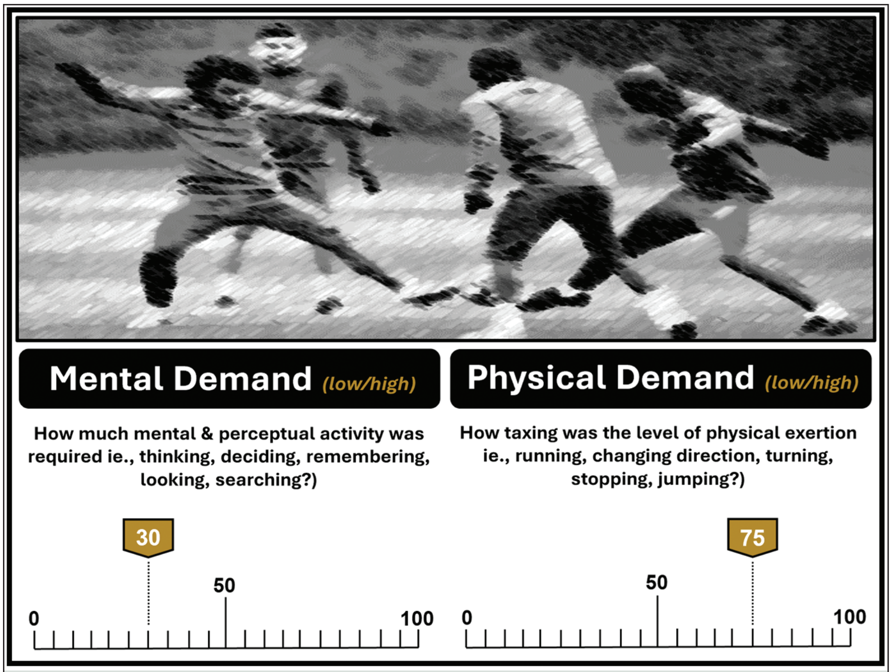


**FIGURE 6.** Visual representation of a simplified version of the NASA Task Load Index (TLX) to monitor physical-cognitive load demands. Two dimensions highlighted: (1) mental demand and (2) physical demand (0-100 arbitrary units, 0 = Low and 100 = High). Frustration may also be tracked from the TLX dimensions. Frustration may help establish a player's challenge point to further progress or regress practice design for skill development during rehabilitation.

postdrill rest period communication with players and used in collaboration with success rate.[12]

We encourage a ~70% success rate in drill-related outcomes, inducing moderate challenge while leaving space for error-based learning.[37,52] For example, referring to the *Control-to-Chaos* phase nondirectional pass and move drill (**FIGURE 1**), if the drill is performed for a duration of 1 minute, the total number of successful actions can be extracted from unsuccessful actions (ie, target player missed, mannequin hit, mini goal missed). We also recommend practitioners perform subjective evaluations (ie, observing potential *perception delays* in lieu of success rate) to understand the imposed mental demand and refine drill design and progression.[72]

## SUMMARY

ON-PITCH REHABILITATION IS A CRITIcal component of return to sport following injury. The original *CCC* served was a framework to guide practitioners in designing and delivering on-pitch rehabilitation. Insights from other disciplines and increased implementation experience in elite settings highlighted the need for an updated model. We present a comprehensive overview of knowledge drawn from injury neurophysiology, soccer performance, and coaching science, highlighting its importance to on-pitch rehabilitation and the evolution of the *CCC*. ◉

## KEY POINTS

**FINDINGS:** We synthesized insights from injury neurophysiology, soccer performance, coaching science, and further experience in elite settings to provide an update of the control-chaos continuum (*CCC*) for elite soccer. The updated *CCC* retains key features of the original model with an enhanced emphasis on the physical-cognitive aspects of rehabilitation. The *CCC* now integrates practice design principles, visual-cognitive and attentional challenge, decision-making, and progression representation of the game model, providing a more holistic framework for player development under the constraints of injury.

**IMPLICATIONS:** While the development of physical qualities is a vital component of returning to sport, the evolution of on-pitch rehabilitation should look beyond physical performance. Practitioners should place greater emphasis on progressively challenging a player's neurophysiological capabilities, fostering skill redevelopment and reducing cognitive demands on return to sport by embedding tactical principles and positional responsibilities of the game model earlier in the rehabilitation process.

**CAUTION:** Return to sport after injury in elite soccer is complex. The knowledge used to update the CCC is intended to support planning, delivering, and progressing on-pitch rehabilitation alongside physical preparation and sports-specificity.

## STUDY DETAILS


**AUTHOR CONTRIBUTIONS:** M.T. created the original *CCC* concept, updated the *CCC*, and wrote the initial draft. T.A., J.O.K., M.C., D.G., and D.D.C. provided feedback throughout an ongoing process until a final version was agreed by all authors. M.T., M.C., and D.G. designed **FIGURE 1**; M.T. designed **FIGURES 2** to **6**.

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