

Progressing rehabilitation after injury: consider the ‘control-chaos continuum’

Matt Taberner,^{1,2} Tom Allen,³ Daniel Dylan Cohen⁴

INTRODUCTION

Early reintegration to training and match play following injury increases the risk of reinjury. However, having key players available benefits the team.¹ Practitioners must balance these two components of the return to sport (RTS) process, combining evidence and clinical experience to estimate this risk, then plan

and adapt RTS accordingly.¹ Quantifying and monitoring training load is key in guiding this process while managing reinjury risk,^{2–4} and global positioning systems (GPS) provide a valid measure of external running loads.⁵ However, as practitioners, we should focus on both quantitative aspects of running load progression and qualitative characteristics of movement in competition. This includes highly variable, spontaneous and unanticipated movements (the conditions of ‘chaos’) reflecting the unpredictable nature of the sport.

In this editorial, we present the ‘control-chaos continuum’ (CCC) (figure 1), interlinking GPS variables, while progressively incorporating greater perceptual and reactive neurocognitive challenges.^{6,7} This framework moves from high control to high chaos,

and is based on more than a decade of rehabilitation and RTS in the demanding setting of English Premier League football.

THE CONTROL-CHAOS CONTINUUM

Using retrospective player chronic running loads (GPS) in conjunction with estimated tissue healing times, we propose a five-phase framework. We give the example of a central defender with a hamstring injury; estimated return to training after 6 weeks of rehabilitation, with a sample chronic load progression (figure 2). However, the model applies to both short-term and long-term injuries using shorter or longer phases—particularly as progression is criteria based, not time dependent. We also share examples of strength and power diagnostics that we use to accompany GPS data to inform phase progression decisions (table 1).

High control

Aims: Return to running with high control over running speeds/loads (figures 1 and 3), low musculoskeletal impact forces, building player confidence.

¹Performance Department, Everton Football Club, Liverpool, UK

²School of Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, Merseyside, UK

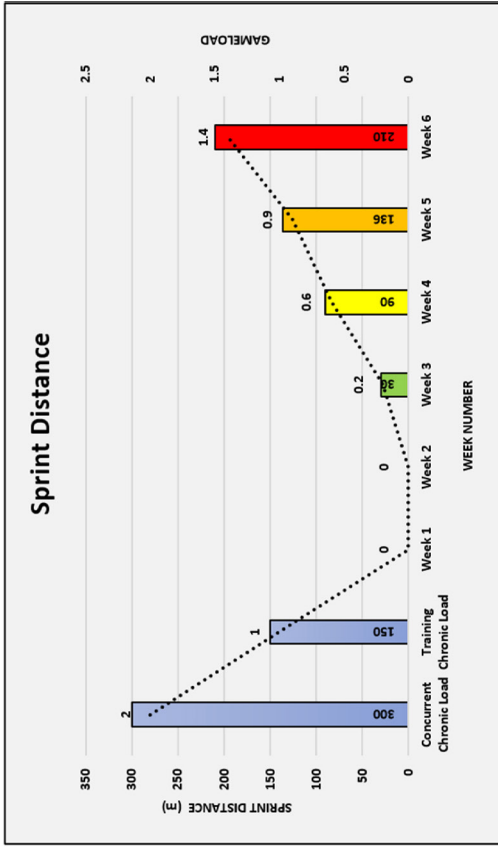
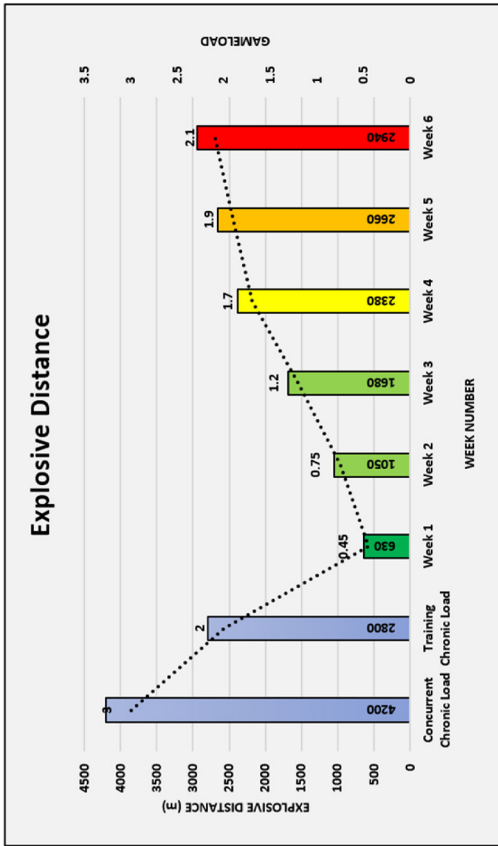
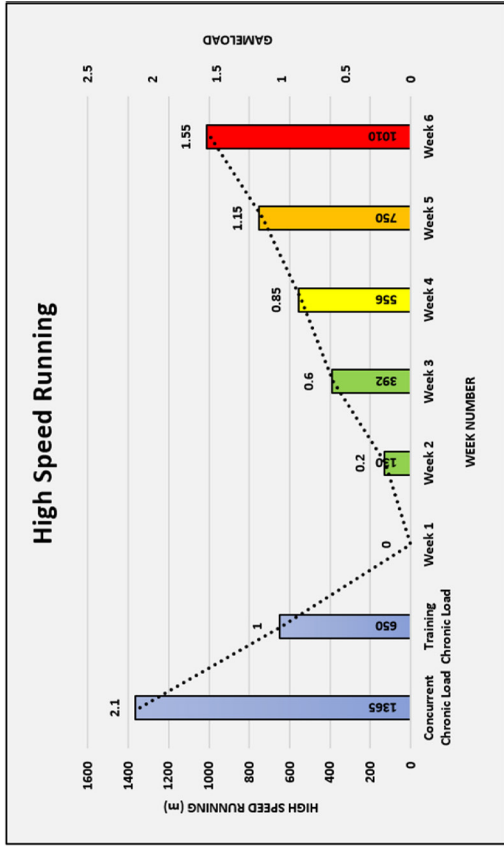
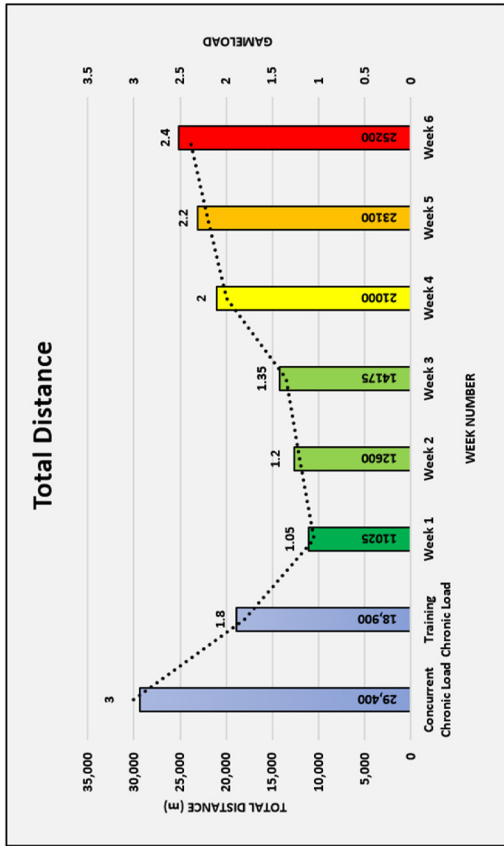
³Performance and Research Department, Arsenal Football Club, London, UK

⁴Faculty of Health Sciences, University of Santander, Bucaramanga, Colombia

Correspondence to Matt Taberner, Performance Department, Everton Football Club, Liverpool L26 3UE, UK; matt.taberner@evertonfc.com

HIGH CONTROL		MODERATE CONTROL		CONTROL>CHAOS		MODERATE CHAOS		HIGH CHAOS	
SESSIONS	<0.35GAME LOAD**	SESSIONS	<0.35-0.55 GAME LOAD**	SESSIONS	<0.40-0.60 GAME LOAD**	SESSIONS	*0.55-0.70 GAME LOAD**	SESSIONS	>0.70 GAME LOAD**
TYPE	RETURN TO RUNNING PHASE 1 (RTR1)	TYPE	RETURN TO RUNNING: CONTROLLED CHANGE OF DIRECTION PHASE 2 (RTR2)	TYPE	INTENSIVE	TYPE	INTENSIVE	TYPE	INTENSIVE
CONDITIONING EMPHASIS	THRESHOLD ENDURANCE (80-85% MAX**) INTENSIVE ENDURANCE (70-80% MAX**)	CONDITIONING EMPHASIS	THRESHOLD ENDURANCE (80-85% MAX**) INTENSIVE ENDURANCE (70-80% MAX**)	CONDITIONING EMPHASIS	EXTENSIVE TEMPO LEVEL 1 (**55-70% MS) VPMAX DEVELOPMENT (7-85% MAX**) THRESHOLD ENDURANCE (80-85% MAX**) INTENSIVE ENDURANCE (70-80% MAX**)	CONDITIONING EMPHASIS	EXTENSIVE TEMPO LEVEL 2 (**65-85% MS) VPMAX DEVELOPMENT (7-55-65% MS) THRESHOLD ENDURANCE (80-85% MAX**) INTENSIVE ENDURANCE (70-80% MAX**)	CONDITIONING EMPHASIS	SPEED (>85% MS) EXTENSIVE TEMPO LEVEL 2 (**65-75% MS) VPMAX DEVELOPMENT (7-85% MAX**) THRESHOLD ENDURANCE (80-85% MAX**) INTENSIVE ENDURANCE (70-80% MAX**)
DESCRIPTION	LINEAR RUNNING (> FROM ALTER-G - 90% BW) LOW MAGNITUDE ACC/DEC LOW VOLUME EXPOSURE LOW MUSCULOSKELETAL IMPACT FORCES END OF STAGE INTRODUCTION TO HSR (INJURY SPECIFIC) EXAMPLES: 306.AIG (3-4XMIN) 3X8, 4X8 (8-4XMIN) (1-2MIN PR)	DESCRIPTION	INTRODUCE COD WITH/WITHOUT BALL (ALL TURNS) (45-180° TURNING) >LINEAR RUNNING SPEEDS (FARTLEK) >MUSCULOSKELETAL IMPACT FORCES/Joint DEMANDS INTRO SHORT-RANGE TECHNICAL E.G. PASSING EXAMPLES: 3.5X2-4MIN (1-2MIN PR)	DESCRIPTION	COD ONLY / WITHOUT BALL (ALL TURNS) RUNNING SPEEDS (**60-70% MS - HSR) LOW VOLUME/INTENSITY P+M/POP >MUSCULOSKELETAL IMPACT FORCES/Joint DEMANDS >ACC/INTENSIFICATION PROGRESSION OF TECHNICAL SKILLS INTENSIVE: 4-6X1-2MIN (1-2MIN PR) EXTENSIVE: 4-6X4-5MIN (2-3MIN PR) TEMPO/HEROIC POWER INTERVAL RUNNING (1:1.5/1:2.5) <small>**WITH BALL WILL INCREASE HEART RATE RESPONSE AND PLAYER INTENSIFICATION TO PROGRESSIVE LEVEL</small>	DESCRIPTION	>RUNNING SPEEDS (**75% MS) >ACC/INTENSIFICATION POSITIONAL P+M/POP (INCLUDING TECHNICAL SKILLS) >ACC/DEC DEMANDS (POSITIONAL) >MUSCULOSKELETAL IMPACT/Joint DEMANDS >VOLUME/INTENSITY SPEED: 5-10S (1.5-1.10) SPEED ENDURANCE: PRODUCTION/MAINTENANCE INTENSIVE: 20-45/1-3MIN (1-2MIN PR) EXTENSIVE: 4-8MIN (2-3MIN PR)	DESCRIPTION	>RUNNING SPEEDS (>90% MS) >HSR/SRR ACCUMULATED RTT >ACC/INTENSIFICATION >ACC/DEC DEMANDS (POSITIONAL) >MUSCULOSKELETAL IMPACT/Joint DEMANDS >MATCH-DAY TYPE PREPARATION SPECIFIC P+M/POP (POSITIONAL - TECHNICAL SKILLS) SPEED: 5-10S (1.5-1.10) SPEED ENDURANCE: PRODUCTION/MAINTENANCE INTENSIVE: 20-45/1-3MIN (1-2MIN PR) EXTENSIVE: 4-8MIN (2-3MIN PR)
LOAD EMPHASIS (INJURY SPECIFIC)	TD	LOAD EMPHASIS (INJURY SPECIFIC)	TD	LOAD EMPHASIS (INJURY SPECIFIC)	TD	LOAD EMPHASIS (INJURY SPECIFIC)	TD	LOAD EMPHASIS (INJURY SPECIFIC)	TD
	<EXP/ <HSR		>EXP/ <HSR		>EXP/ <HSR		>EXP/ <HSR		<EXP/ <HSR (SFR)
	<ACC		>ACC		>ACC		>ACC		>ACC
	<DEC		>DEC		>DEC		>DEC		<DEC
NO. OF SESSIONS	2-4	NO. OF SESSIONS	3-4	NO. OF SESSIONS	3-4	NO. OF SESSIONS	3-5	NO. OF SESSIONS	3-5
							(DEPENDANT UPON TRAINING METHOD)		(DEPENDANT UPON TRAINING METHOD)

Figure 1 Return to sport framework - the control-chaos continuum. Control=high level of structure on behaviour/actions/movement, that is, controlled situation. Chaos=unpredictable behaviour/actions/movement, as to appear random/reactive, that is, chaotic situation. Green represents high control (low intensity) moving towards high chaos (high intensity). Model can be adjusted according to specific injury diagnosis, estimated tissue healing times and expected return to training. Acc/Dec Magnitude =rate of change in velocity, for example, 3 ms^{-2} . ** Game load adjustable dependent on injury type/severity. ACC, accelerations; BW, bodyweight; COD, change of direction; DEC, decelerations; Exp-D, explosive distance (accelerating/decelerating from 2 to $4 \text{ ms}^{-1} < 1 \text{ s}$); HSR, high-speed running ($>5.5 \text{ ms}^{-1}$); MS, maximal speed; MAXHR, maximal heart rate; PR, passive recovery; SFR, sprint distance ($>7 \text{ ms}^{-1}$); TD, total distance.



Player Game Load			
Total Distance	High Speed Running	Explosive Distance	Sprint Distance
10,500m	650m	1,400m	150m

Player Weekly Chronic Training Load (Concurrent Chronic Load)			
Total Distance	High Speed Running	Explosive Distance	Sprint Distance
1.8x (2.8x)	1.0x (2.1)	2x (3x)	1x (2x)
18,900 (29,400m)	650m (1,365m)	2,800 (4,200m)	150m (300m)

Figure 2 Sample return to chronic running loads using the control-chaos continuum. Data representative of central defender game load, that is, physical demands of game (mean) and respective training and concurrent (including game) in both absolute and relative (game load, ie, 2x=2 games). Control-chaos continuum: control=high level of structure onbehaviour/actions/movement, that is, controlled situation. Chaos=unpredictable behaviour/actions/movement, as to appear random/reactive, that is, chaotic situation. Green represents high control (low intensity) moving towards high chaos (high intensity). High-speed running, >5.5 ms⁻¹; Sprint distance, >7 ms⁻¹; Explosive distance (accelerating/decelerating from 2 to 4 ms⁻¹<1 s).

Table 1 Injury-specific load planning considerations and strength/power diagnostics for phase progression during return to sport (RTS)

Injury	Considerations for RTS load planning	Strength/power diagnostics
Hamstring injuries	Progression of running speeds (>70% maximal speed) Progression of acceleration/deceleration magnitudes (intensity) Appropriate stage to combine sprint distance and chaos	Iso posterior chain/hamstring PF, RFD, SE (FP) Ecc hamstring PF (NHE) Con/ecc hamstring PT (IKD)
Quadriceps injuries	Progression of acceleration frequency and magnitudes (explosive distance) Progression of running speeds (>70% maximal speed) Progression of change of direction angles (45°–180°) Progression of technical actions—passing, shooting, jumping/landing actions	Iso squat PF, RFD (FP) Iso quadriceps PF (HHD) Dyn split squat force/impulse asymmetries (FP) Con/ecc quadriceps PT (IKD)
Calf injuries	Progression of running volumes (total distance, HSR, sprint distance) Progression of running speeds (>70% maximal speed) Progression of acceleration/deceleration frequency and magnitudes (explosive distance)	Iso soleus/gastrocnemius PF, RFD (FP) SL/DL CMJ jump height, force/power/impulse and asymmetries (FP) 10–5 hop test RSI, force/impulse asymmetries (FP)
Adductor injuries	Progression of acceleration/deceleration frequency and magnitudes (explosive distance) Progression of change of direction (45°–180°) Progression of technical actions—passing, crossing, shooting, tackling Appropriate stage to combine change of direction, at speed, under chaotic conditions	Iso hip abductor/adductor; PF (GroinBar)
Ankle injuries	Progression of running volumes (total distance, HSR, sprint distance) Progression of change of direction (45°–180°) Progression of acceleration/deceleration frequency and magnitudes (explosive distance) Appropriate stage to combine change of direction, at speed, under chaotic conditions Progression of technical actions—jumping/landing actions	Iso soleus/gastrocnemius PF, RFD, SE (FP) DL CMJ ecc, con, landing force/impulse asymmetries (FP) 10–5 hop test RSI, force/impulse asymmetries (FP) Hop+hold dynamic stability (FP)
ACL injuries	Progression of running volumes (total distance, HSR, sprint distance) Appropriate weekly planning between sessions in early stages Progression of acceleration/deceleration frequency and magnitudes Appropriate stage to add chaotic conditions to HSR and change of direction	DL CMJ ecc, con, landing force/impulse asymmetries (FP) SL CMJ jump height, power, impulse asymmetries DL/SL drop jump RSI (FP) Iso squat/mid-thigh pull PF, RFD (FP) Iso soleus/gastrocnemius PF, RFD (FP) Iso posterior chain PF, RFD, SE (FP) Ecc hamstring PF (NHE) 10–5 hop test (FP) Iso hip abductor/adductor PF (GroinBar)
Fractures (injury mechanism specific, ie, stress or trauma)	Progression of running volumes (total distance, HSR, sprint distance)—novel 'load' Appropriate weekly planning between sessions in early stages Progression of technical actions—passing, shooting, jump/landing actions Progression of tackling/volume of tackles (mid-shaft tibia/fibula)	CMJ ecc, con, landing force/impulse asymmetries (SL, DL) (FP) Iso squat/mid-thigh pull PF, RFD (FP) Iso soleus/gastrocnemius PF, RFD (FP) Iso posterior chain PF, RFD (FP) Ecc hamstring PF (NHE) 10–5 hop test (FP) DL/SL drop jump RSI (FP) Iso hip abductor/adductor PF (GroinBar)

Novel 'load', new/unusual load, providing a novel stimulus for bone remodelling.

ACL, anterior cruciate ligament; CMJ, countermovement jump; COD, change of direction; con, concentric; DL, double Leg; DJ, drop jump; Dyn, dynamic; ecc, eccentric; FP, force platform; HHD, hand-held dynamometer; HSR, high-speed running (>5.5 ms⁻¹); IKD, isokinetic dynamometer; iso, isometric; NHE, Nordic hamstring exercise; PF, peak force; PT, peak torque; RFD, rate of force development; RSI, Reactive Strength Index; SE, strength endurance; SL, single leg.

First, determine key considerations specific to the injury (eg, speed progression for hamstring injury or passing volume

for a groin injury) and the individual (eg, position or style of play) alongside potential risk factors for reinjury (table 1). The

goal during an early return to running is a gradual increase in the volume of running at lower speeds, thereby limiting high-speed running (HSR) exposure (<60% maximal speed (MS)) and musculoskeletal demands (online supplementary video 1). Linear running at lower speeds also minimises high acceleration/deceleration magnitudes (figure 1). Sport-specific tasks, that is, incorporating a ball, are minimised to reduce movement variability, and manipulation of work to rest ratios enables appropriate energy system development (figure 1).

Moderate control

Aims: Introduce change of direction (COD) with the ball, reduce control (somewhat controlled chaos) and HSR load progression (figure 2).

We progressively integrate COD to gradually reduce control, with acceleration/deceleration demands determined by the intensity and volume of directional

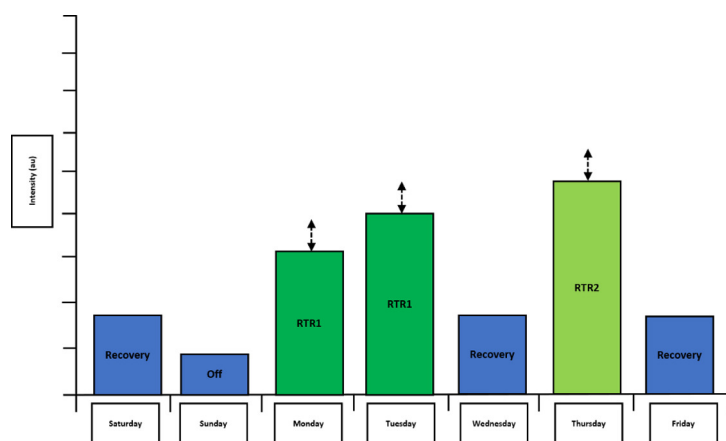


Figure 3 Example of a potential weekly planning template from high and moderate control. Arrows represent session load increments in week-to-week individual return to running sessions (increments represent increases in running loads individualised to the player and specifics of their injury). Intensity, arbitrary unit (au); Off, day off; Recovery, recovery day; RTR1, return to running 1; RTR2, return to running 2.

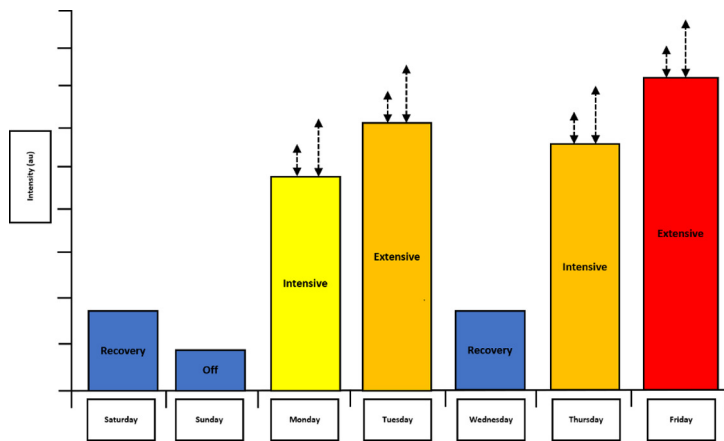


Figure 4 Example of a potential weekly planning template from control—>chaos to high chaos. Arrows represent load increments in week-to-week individual intensive and extension outdoor physical preparation sessions to build chronic load (increments represent increases in running loads individualised to player and specifics of their injury). Extensive, extensive football; Intensive, intensive football; Intensity; Intensity, arbitrary unit (au); Off, day off; Recovery, recovery day.

changes. The goal is to both reduce the degree of task constraint⁸ and to progressively increase explosive distance (distance covered accelerating/decelerating, i.e. from 2 to 4 ms⁻¹ <1s) relative to the player's preinjury training demands. We increase linear HSR (60%–70%MS) and COD activities with and without the ball to increase movement variability (online supplementary video 2), the relative proportion of these activities depends on both the player and the specific injury (table 1).

Control to chaos

Aims: Introduce football specific weekly structure (figure 4) to overload game-specific demands reflecting a transition from control to chaos (inclusion of limited volume of movements with unanticipated actions).

In our framework, fitness development has a football-specific focus that incorporates technical aspects, moving from control to increasing levels of chaos. The week is structured to overload game components using 'intensive' and 'extensive' football to increase training specificity.⁹ Intensive football overloads the musculoskeletal system and specific energy systems through acceleration, deceleration and COD components in restricted areas (online supplementary video 3).⁹ Drills include more reactive passing and movement (online supplementary video 4), as well as progressive, positional-specific acceleration/deceleration to replicate explosive movements (online supplementary video 5).⁹

Extensive football reflects typical match demands, using larger areas to produce higher speed and distance.⁹

Drill prescription progressively incorporates running at higher speeds (>65%–80%MS) using aerobic power interval runs to target the required energy systems (online supplementary video 6).

Moderate chaos

Aims: Increase HSR under moderate chaos (unpredicted movements, minimal limitations), with the addition of pass and move and specific pattern of play drills.

In this phase, HSR loads increase further under both control and chaotic conditions. Extensive sessions target HSR (>75%MS) including subtle directional changes (online supplementary video 7), and progressive increments in sprint distance based on the player's relative match demands, minimising 'spikes'—large/acute increments in load. Additionally, we include pass and move drills of increasing specificity alongside pattern of play drills to address technical skill progression (online supplementary video 8). Accumulated weekly total distance should now have reached typical training levels (figure 2).³

High chaos

Aims: Return the player to relative weekly training demands (figure 2) and include drills designed to test worst-case scenarios (high speed/high chaos).

Technical considerations: passing/crossing and shooting; graded in intensity from short/mid/long range while jumping/heading and tackling; graded in intensity as static/movement/in-context. The volume of technical actions should be

progressively increased and be player and injury specific.

In the final phase, we emphasise position-specific conditioning and reflect game intensity with volumes relative to weekly preinjury training outputs. Positional specific speed/speed-endurance drills (online supplementary videos 9 and 10) prepare players for game activity—where the speed/direction of the pass dictates how fast the player moves. Technical considerations specific to the injury in question (eg, ball striking activity for a groin injury) form part of our final criteria for return to training, alongside strength and power diagnostics (table 1).

CONCLUSION

In an elite environment, RTS is a dynamic process balancing the benefits and risks of RTS to the player and the team.² The CCC moves from high control to high chaos, prescribing running loads under progressively riskier conditions. The continuum is the product of scientific evidence blended with years of experience. This framework provides the practitioner with an individualised approach to RTS that integrates quantitative and qualitative progression criteria.

Twitter @MattTaberner

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