

FROM CONTROL TO CHAOS TO COMPETITION

BUILDING A PATHWAY FOR RETURN TO PERFORMANCE FOLLOWING ACL RECONSTRUCTION

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INTRODUCTION

Despite the enhanced knowledge around rehabilitation and large body of research defining return to sport (RTS) criteria following anterior cruciate ligament (ACL) injuries¹; RTS following ACL reconstruction (ACLR) is a complex process². No consensus exists regarding the optimal rehabilitation and re-injury risk remains high^{3,4}. Is it possible that current rehabilitation approaches fail to fully prepare athletes for the demands of their sport, hindering the success of a return to performance?

It is suggested that safe (i.e. with minimal risk of re-injury) RTS may require up to two years following ACLR⁵. However, risk management is key in the high-pressure environment of professional sport where team success is the goal but must be balanced with protecting the player's

health. The balance of risk [to player]: and benefit [to team of having player available to play] potentially represents competing interests which require shared decision-making between performance/medical team, player and coach/club. However, there are limits to the influence of the performance/medical team's objective data, clinical experience and literature evidence^{4,5}. Even if this suggests completely safe return requires approximately two years, would this be implemented in team sports?

Sports-specific physical preparation and return retrospective chronic loading (i.e. training loads that players have been used to performing pre-injury) are vital elements of the rehabilitation pathway but are suggested to be overlooked components of RTS criteria².

We recently proposed the 'control-chaos continuum' (CCC; Figure 1)⁶, an adaptable RTS pathway developed for on-pitch rehabilitation in football. The CCC progresses from high control to high chaos, underpinned by sports-specific conditioning and the concept of returning players to retrospective (pre-injury) chronic running loads. This process can be informed by global positioning systems⁷, combined with a gradual increase in qualitative characteristics of in-competition movement providing incremental perceptual and neurocognitive challenges⁸.

WHY WE THINK THE CONTROL-CHAOS CONTINUUM FITS END-STAGE REHABILITATION AFTER ACLR

We believe the CCC is an ideal model for on-pitch rehabilitation following ACLR,

HIGH CONTROL		MODERATE CONTROL		CONTROL>CHAOS		MODERATE CHAOS		HIGH CHAOS						
SESSIONS	<0.35GAME LOAD**	SESSIONS	<0.35-0.45 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 (RTL)	RETURN TO RUNNING: CONTINUOUS CHANGE OF DIRECTION PHASE 2 (IRT2)	RETURN TO RUNNING: CONTINUOUS CHANGE OF DIRECTION PHASE 2 (IRT2)	TYPE	INTENSIVE	INTENSIVE	INTENSIVE	TYPE	INTENSIVE					
CONDITIONING EMPHASIS	THRESHOLD ENDURANCE (80-85% MAX ^(m)) INTENSIVE ENDURANCE (70-80% MAX ^(m))	THRESHOLD ENDURANCE (80-85% MAX ^(m)) INTENSIVE ENDURANCE (70-80% MAX ^(m))	THRESHOLD ENDURANCE (80-85% MAX ^(m)) INTENSIVE ENDURANCE (70-80% MAX ^(m))	CONDITIONING EMPHASIS	EXTENSIVE TEMPO LEVEL 1 (~55-70% MS) VOPMAX DEVELOPMENT (>85% MAX ^(m)) THRESHOLD ENDURANCE (80-85% MAX ^(m)) INTENSIVE ENDURANCE (70-80% MAX ^(m))	CONDITIONING EMPHASIS	EXTENSIVE TEMPO LEVEL 1 (~65-85% MS) VOPMAX DEVELOPMENT (>85% MAX ^(m)) THRESHOLD ENDURANCE (80-85% MAX ^(m)) INTENSIVE ENDURANCE (70-80% MAX ^(m))	CONDITIONING EMPHASIS	EXTENSIVE TEMPO LEVEL 2 (~65-75% MS) VOPMAX DEVELOPMENT (>85% MAX ^(m)) THRESHOLD ENDURANCE (80-85% MAX ^(m)) INTENSIVE ENDURANCE (70-80% MAX ^(m))					
DESCRIPTION	LINEAR RUNNING (> FROM ALTER-G -90% BW) LOW MAGNITUDE ACC/DEC LOW VOLUME EXPLOSIVE DISTANCE LOW MUSCULOSKELETAL IMPACT FORCES END OF STIR-ORANGE PRODUCTION TO HSR (INJURY SPECIFIC) EXAMPLES: 3X6,4X6 (3-4X3MINS) 3X6, 4X8 (3-4X4MINS) (1-2MINS PR)	INTRODUCE COD WITH/ WITHOUT BALL (15-180° TURNING) >LINEAR RUNNING SPEEDS (FARTLEK) >MUSCULOSKELETAL IMPACT FORCES/JOINT DEMANDS INTRO SHORT-RANGE TECHNICAL E.G. PASSING EXAMPLE: 3,5X3,4MINS (1-2MINS PR)	INTRODUCE COD WITH/ WITHOUT BALL (ALL TURNS) RUNNING SPEEDS (~60-70% MS - HSR) (FARTLEK) LOW VOLUME IMPACT FORCES/JOINT DEMANDS >MUSCULOSKELETAL IMPACT FORCES/JOINT DEMANDS >ACC/DEC PREPARATION PROGRESSION OF TECHNICAL SKILLS INTENSIVE: 4-6X1-2MINS (1-2MINS PR) EXTENSIVE: 4-6X4-5MINS (2-3MINS PR) TEMPO/AEROBIC POWER INTERVAL RUNNING (17:13/13:13) *WITH BALL WILL INCREASE HEART-RATE RESPONSE, AND PLAYER MOTIVATION TO PERFORM DRILLS*	DESCRIPTION	>RUNNING SPEEDS (~75% MS) >HSR ACCUMULATED POSITIONAL P-HM/POP (INCLUDING TECHNICAL SKILLS) >MUSCULOSKELETAL IMPACT/JOINT DEMANDS >VOLUME/INTENSITY SPEED:5-10S (1.5-1.10) SPEED ENDURANCE: PRODUCTION/MAINTENANCE INTENSIVE: 20-45S/1-3MIN (1-2MINS PR) EXTENSIVE: 4-8MINS (2-3MINS PR)	DESCRIPTION	>RUNNING SPEEDS (~90% MS) >HSR ACCUMULATED RTT POSITIONAL SPECIFIC DEMANDS ACC/DEC DEMANDS POSITIONAL >MUSCULOSKELETAL IMPACT/JOINT DEMANDS >MATCH-DAY TYPE PREPARATION SPECIFIC P-HM/POP (POSITIONAL - TECHNICAL SKILLS) SPEED:5-10S (1.5-1.10) SPEED ENDURANCE: PRODUCTION/MAINTENANCE INTENSIVE: 20-45S/1-3MIN (1-2MINS PR) EXTENSIVE: 4-8MINS (2-3MINS PR)	LOAD EMPHASIS (INJURY SPECIFIC)	LOAD EMPHASIS (INJURY SPECIFIC)	LOAD EMPHASIS (INJURY SPECIFIC)				
NO. OF SESSIONS	2-4	3-4	3-4	LOAD EMPHASIS (INJURY SPECIFIC)	>EXPD / <HSR	>EXPD / <HSR	>EXPD / <HSR	LOAD EMPHASIS (INJURY SPECIFIC)	TD	>EXPD / <HSR	>ACC	>DEC	NO. OF SESSIONS	3-5 (DEPENDANT UPON TRAINING METHOD)
				NO. OF SESSIONS	3-4	3-4	3-4	NO. OF SESSIONS	3-5 (DEPENDANT UPON TRAINING METHOD)	TD	>ACC	>DEC	NO. OF SESSIONS	3-5 (DEPENDANT UPON TRAINING METHOD)

Figure 1: Return to Sport model: Control-Chaos Continuum. Model adjusted to specific injury diagnosis, estimated healing times, and expected return to training. TD = Total Distance, HSR = High Speed Running (>5.5ms⁻¹), SPR = Sprint Distance (>7ms⁻¹), Exp-D = Explosive Distance (Accelerating/Decelerating from 2-4ms⁻¹ <1s, Acc = Accelerations, Dec = Decelerations, Magnitude (Acc/Dec) = rate of change in velocity e.g. 3ms⁻², PR = Passive Recovery, COD = Change of direction, BW = bodyweight, MS = maximal speed, MAXHR = maximal heart-rate, ** = game-load adjusted according to injury specificity/severity.

targeting potential modifiable risk factors for re-injury whilst building running loads and performance to pre-injury levels (or beyond).

Epidemiological evidence in elite football is highly suggestive of an association between fatigue and injury. In relation to acute fatigue, time dependent increases in incidence are evident during match-play⁹. Similarly, accumulation of residual fatigue increases incidence during congested match periods¹⁰. Acute fatigue is associated with temporary alterations in neuromuscular function including decrements in peak force, rate of force development (RFD), and decision-making ability^{11,12}. Notably, soccer-specific activity is associated with a selective reduction in the eccentric strength of the hamstrings¹³ – potentially reducing their effectiveness as ACL agonists. Moreover, soccer-specific fatigue in parallel with the decline in hamstring strength, leads to unfavourable changes in knee biomechanics which may heighten injury risk¹⁴. Therefore, attempting to limit the adverse effects of fatigue is logical from both a performance and injury risk perspective; despite this, recent meta-analyses concluded that there is a lack of evidence demonstrating an association between fatigue and ACL injury risk^{15,16}.

One of the key objectives of the CCC is to progressively provide adequate energy system conditioning throughout the different phases of rehabilitation. The manipulation of exercise : rest ratios, ensures the required stimulus is placed on the cardiovascular system to improve both general work capacity and target energy system conditioning for the sport inclusive of positional demands, aiding the player to return to pre-injury levels of performance (or beyond). Furthermore, the CCC aims to reduce soft tissue injury risk during ACL rehabilitation through careful player management, taking into consideration retrospective running loads and neuromuscular measures to define players response to loading. Appropriate progression is also applied, ensuring increments are not too rapid (i.e. running speeds/volumes), to avoid exceeding the capacity of the musculoskeletal system to adapt.

ACL injuries have recently been suggested to be neurophysiological injuries¹⁷, with apparent neurocognitive deficits following ACLR. Rehabilitation should therefore integrate training of the neurocognitive system in a sport relevant format, to facilitate transfer of training. The construct of the CCC is based upon a

constraints-led approach, with task and environmental constraints manipulated to influence movement variability⁸. In the high control phase, we maintain constraints to limit movement variability and cognitive demands to reduce re-injury risk or setbacks associated with excessive high-speed running (HSR) or unexpected changes of direction⁶. This phase provides a safely delivered base of metabolic and tissue/neuromuscular (NM) conditioning for progression of conditioning/running loads. As these constraints are reduced, we gradually increase situational awareness, sensory integration, motor control, co-ordination and NM demands. They are also required to perceive and respond to increasingly complex, unpredictable situations including movement of other players, opponents and interaction with the ball. Technical actions are also progressively incorporated including passing/crossing, shooting, jump/landing and tackling to ensure adequate training of sport-specific skills (Figure 2).

Once the player enters the sport-specific phases, we emphasise periodisation to condition in a format resembling the NM and physiological demands of team training. Fitness development is structured to provide overload in game components

PHASE	PASSING/CROSSING		SHOOTING		JUMP/HEADING		TACKLING	
HIGH CONTROL	N/A: ALLOWANCE OF SMALL TECHNICAL SKILLS INCLUDING "KEEP-UPS" AND TOUCHES BETWEEN 'FEET'							
MODERATE CONTROL	SHORT RANGE	LOW	N/A		STATIC	LOW	STATIC	LOW
CONTROL>CHAOS	SHORT/ MID RANGE	MODERATE-LOW (SESSION SPECIFIC)	SHORT RANGE	LOW	STATIC/ MOVEMENT	LOW-LOW	STATIC/ MOVEMENT	LOW-LOW
MODERATE CHAOS	SHORT/MID/ LONG RANGE	MODERATE- MODERATE-LOW (SESSION SPECIFIC)	SHORT/MID RANGE	MODERATE-LOW (POSITIONAL SPECIFIC)	MOVEMENT/ CONTEXT	MODERATE-LOW (POSITIONAL SPECIFIC)	STATIC/ MOVEMENT	MODERATE-LOW
HIGH CHAOS	SHORT/MID/ LONG RANGE	HIGH/ MODERATE (SESSION SPECIFIC)	SHORT/MID/ LONG RANGE	MODERATE-HIGH (POSITIONAL SPECIFIC)	CONTEXT	MODERATE-HIGH (POSITIONAL SPECIFIC)	MOVEMENT	MODERATE-HIGH (POSITIONAL SPECIFIC)
RETURN TO TRAIN (NON-CONTACT AND CONTACT)	SHORT/MID/ LONG RANGE	HIGH/ MODERATE (SESSION + POSITION SPECIFIC)	SHORT/MID/ LONG RANGE	MODERATE-HIGH (SESSION + POSITION SPECIFIC)	CONTEXT	MODERATE-HIGH (SESSION + POSITION SPECIFIC)	CONTEXT	MODERATE-HIGH (SESSION + POSITION SPECIFIC)
RETURN TO TRAIN (FULL INTEGRATION)	SHORT/MID/ LONG RANGE	SESSION SPECIFIC	SHORT/MID/ LONG RANGE	SESSION + POSITION SPECIFIC	CONTEXT	SESSION + POSITION SPECIFIC	CONTEXT	SESSION + POSITION SPECIFIC

Figure 2: Pathway for progression of technical actions during rehabilitation (control-chaos continuum) and transition back to the team training environment (return to training phases). Model adjusted to specific injury diagnosis, estimated tissue healing times, and expected rehabilitation and return to training durations. Intensity of passing/crossing/shooting - Short = 5-10m, Mid = 10-15m, Long = 15m+, Low, Moderate, High = no of efforts; refers to number of technical actions performed, relative to the number performed by the individual in the normal / current team training model and their game traits/position i.e. number of passing efforts different to number of tackles. Static = in-place e.g. block tackle, Movement = technical action preceded by movement e.g. running take-off for a header, Context = how these actions would be performed in training/match-play e.g. centre forward attacking a cross for a header at goal.

TABLE 1

Injury	Considerations for RTS Load Planning	Neuromuscular Strength/Power Diagnostics
ACL Graft type emphasis/ considerations *patella tendon #hamstring tendon	Appropriate weekly planning between sessions in early stages Progression of running volumes (total distance, explosive distance, HSR, sprint distance) Progression of running speeds (>70% Maximal Speed) and running speed with chaos# Progression of acceleration/deceleration efforts (no. of efforts)* Progression of acceleration/deceleration magnitudes (e.g. 3 to 5ms ⁻²)* Progression of acceleration/deceleration density i.e. maximal intensity periods* (e.g. max no. of decelerations efforts (>3ms ⁻²) in 2-minute period) Progression of technical actions – passing/crossing, shooting, jump/landing actions, tackling (type/volume) Session/drill modification during RTT (NC and C phases) Appropriate integration of ‘recovery’ during RTT (NC and C phases) Appropriate monitoring/progression of external/internal load during RTT-RTC-RTPerf phases Appropriate progression of competitive match minutes during RTC-RTPerf phases	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) Dynamic split squat force/impulse asymmetries (FP) Iso, con/ecc* quadriceps: PT, RFD, SE (IKD) Iso soleus/gastrocnemius: PF, RFD (FP) Iso posterior chain PF, RFD, SE (FP)# Ecc hamstring: PF (NHE)# 10-5 hop test: RSI, CT (FP) Triple hop test: distance (asymmetry) Iso hip abductor/adductor: PF (GroinBar™)

Table 1: ACL injury-specific load planning considerations and neuromuscular strength/power diagnostics for phase progression during return to sport (RTS). HSR = High-speed running (>5.5ms⁻¹), COD = Change of direction, ACL = Anterior Cruciate Ligament, iso = isometric, ecc = eccentric, con = concentric, PT = peak torque, PF = peak force, RFD = rate of force development, IKD = isokinetic dynamometry, RSI = reactive strength index, DL = double Leg, SL = single leg, DJ = drop jump, NHE = nordic hamstring exercise, SE = strength-endurance, FP = force platform, CT = contact time, RTT = return to train, NC = non-contact, C = contact, RTC = return to competition, RTPerf = return to performance, no. of = number of.

using ‘intensive’ and ‘extensive’ football practice environments⁹. Intensive football aims to overload the musculoskeletal system and specific energy systems through accelerations, decelerations, and changes of direction within restricted areas (e.g. 10x15m). Extensive football reflects typical positional match demands using larger areas to allow higher speeds and distances.

Periodising the rehabilitation model to mirror the demands of the training model is a key aspect of the CCC model and as the methodology and training approach of each coach varies, it is important to quantify and monitor team training indicators under a new coaching regime.

If the player’s chronic retrospective running load data was under a previous management (more likely in long-term injuries such as an ACLR), there may be

changes in intensity, volume and duration under the new regime which must be accommodated for. The player may also be expected to play in a different position, leading to different competitive load demands. This may necessitate adjustments to the rehabilitation plan to ensure appropriate conditioning, potentially above pre-injury chronic training load and/or different style of training loads to ensure adequate preparation for new and varying demands.

PLANNING END-STAGE REHABILITATION; FROM CONTROL, CHAOS AND BEYOND

Formulating a rehabilitation plan involves communication with the inter-disciplinary sports performance and medical team and the coaching staff to obtain as much information as possible regarding the individual player, whilst keeping the player informed and involved in the process. The

players retrospective chronic training and concurrent (training plus match) running load should be obtained, alongside training indicators and expectations under the coaching team (number of training days, sequence of training days, training duration, training type, etc.). Additionally, previous injury history, details of his/her current injury, positional demands (and playing style), objective neuromuscular profile (strength and power diagnostics) and trends in this data prior to and since injury, nutritional status, and potential healing times i.e. graft maturation should also be considered. This information, alongside the training considerations (including gym-based strength and conditioning) should inform decision making, estimates of the required duration of pitch-based rehabilitation, and the required level of running load that the player needs to return to. In our experience, outdoor physical

preparation for an ACLR injury should be around 10-14 weeks. However, this is entirely dependent upon each individual case, considering that progression is based principally on objective criteria and informed by strength and power diagnostics (Table 1) to support clinical reasoning and aid decision-making⁶.

Simple clinical tests such as the triple hop (for distance) may serve value²⁰, whilst persistent post-ACLR kinetic and kinematic asymmetries in female athletes have been highlighted using the drop jump²¹. However, the dual force platform bilateral CMJ is a core diagnostic tool, as it is more common for players to have historical (benchmark) CMJ data. Increased lower limb kinetic asymmetries in specific eccentric and concentric variables and in the landing phase are reported in this test after return to competition (RTC) following lower limb injuries in elite players²², and post-ACL in other populations²³. These involved limb deficits may lead to potential compensatory movement strategies and unusually asymmetrical loading patterns.

CONTROL-CHAOS CONTINUUM

High Control

Aims: Return to running with high control over running speeds/loads indicative of low musculoskeletal impact forces and build player confidence.

The goal during this phase is to gradually increase linear running volume at lower speeds, with limited HSR (<60% Maximal speed (MS)). Task constraints can be maintained using speed = distance/time as indicator of the target speed, albeit with speed changes implicit in accelerating and decelerating at the start/end of each effort. By integrating different periods of active recovery between running bouts the development of the required energy system is emphasised. During this phase sports-specific tasks and ball based technical actions are limited (Figures 1 and 2). We suggest running volumes <0.35 game load with minimal HSR. HSR threshold is determined by individuals maximal speed (MS) i.e. high MS >10ms⁻¹ or low MS ~7ms⁻¹ (possibly in the case of some female athletes), then adjustment is made to apply

relative rather than absolute speed zones. Minimal knee swelling and pain (<2/10 numerical rating scale (NRS)) indicates that the involved limb is coping with imposed demands. As a foundation for the next phase we suggest that controlled acceleration/deceleration drills (Table 2) are incorporated to prepare the player for the increased force production and acceptance demands to build upon physical qualities developed in gym-based conditioning.

Moderate Control

Aims: Introduce change of direction (COD) with and without ball, reduce control (somewhat controlled chaos), progression of HSR load.

In this phase, we progressively integrate COD, reducing the level of control and restrictions on movement variability. Acceleration/deceleration demands increase with increments in the intensity and volume of directional changes; reducing task constraint and progressively increasing explosive distance. Progressively, we incorporate running mechanics,

TABLE 2

<i>Drill Focus</i>	<i>Drill progressions</i>
<i>Running Mechanics</i>	<i>Walking A's, A-skips, running A's Walking B's, B-Skips and running B's Straight-leg bounds, straight leg bounds into acceleration</i>
<i>Acceleration Preparation</i>	<i>Falling starts, partner falling starts, falling MB throw starts, split stance starts, split Kneeling starts Jump-back starts, sideways split stance starts, sideways kneeling starts, cross-over step NB. Additional resistance can be applied to certain drills if required</i>
<i>Deceleration Preparation</i>	<i>In-place deceleration: drop squat, drop squat 'catch', drop split squat, drop split squat 'catch' Acceleration to: squat stance deceleration, sideways deceleration, split stance deceleration, staggered stance deceleration</i>
<i>Movement Transition</i>	<i>Back-pedal into acceleration, diagonal back-pedal into acceleration, acceleration > backways 'jockey' Directional changes: 0-45°, 45-60°, 60-180°, sequence of directional changes Cutting: speed cuts, power cuts, sequence of speed/power cuts Combination of acceleration/deceleration preparation drills i.e. Falling start into 10m acceleration into split stance deceleration Addition of auditory/spatial/reactive cues to movement transition, directional changes, cutting drills Sports-specific context: passing speed/direction dictates athlete movement strategy (positional acceleration/speed conditioning)</i>

Table 2: Drill focus and sample drill progressions to be used within pre-training preparation to link gym-based and on-pitch conditioning and promote the development of sports-specific starting-strength (rate of force development), movement quality and control. NB. Emphasis should be made to overload involved limb as appropriate on split stance/split kneeling drills i.e. 2sets/1set, MB = medicine ball, 45° = 45-degree directional change.



The ‘control chaos continuum’ is an adaptable pathway, progressing from high control to high chaos, underpinned by sports-specific conditioning and the concept of returning players to retrospective (pre-injury) chronic running loads characteristic of in-competition movement providing incremental perceptual and neurocognitive challenges.



acceleration/deceleration and COD drills into warm-ups prior to the conditioning element of the session (Table 2). We progress these drills by controlling speed, acceleration/deceleration magnitudes, acceleration start (e.g. falling, split stance, split kneeling) and deceleration end positions (e.g. squat stance, split stance) to help address starting-strength (RFD) and force reduction deficits. Drills are designed to provide specific progressive overload of deceleration capabilities on the involved limb under controlled conditions. Within the conditioning element of the session, most directional changes involve the ball, progressively increasing explosive distance alongside linear HSR (60-70% MS). We progress running load relative to game load (~0.35-0.45) according to the individual rehabilitation plan. Routine physiotherapy communication is essential to ensure the knee is coping with the imposed load; minimal knee swelling, and lack of pain are criteria for progression.

Control to chaos

Aims: Introduce a sport-specific weekly training structure to overload game-specific demands reflecting a transition from control to chaos (inclusion of a limited number of movements with unanticipated actions).

The periodisation of the weekly rehabilitation plan now switches to a football-specific training weekly structure. We continue to use the warm-up to progress development of athletic qualities (Table 2), with emphasis on the specific demands of the session i.e. extensive; preparation for running at higher speeds and increased

magnitude of accelerations/decelerations. Within intensive sessions, drills include more reactive passing and movement alongside position-specific acceleration/decelerations to replicate explosive movements. Drill prescription within extensive football sessions progressively incorporates running at higher speeds (>65-85% MS) with work: rest ratios manipulated to target the required energy systems, where the emphasis is towards aerobic qualities i.e. VO_2max development (time >85% Max^{HR}).

Moderate chaos

Aims: Increase HSR, sports-specific COD and reactive movements under moderate chaos.

In this phase, HSR loads increase progressively under both controlled and chaotic conditions. Extensive sessions target HSR (>75% MS) including directional changes, with progressive increments in sprint distance, relative to game load (~0.55-0.70; according to planned sessional load progression). Increasingly position-specific pass and move and pattern of play drills are used to progress technical skills. For example, short/mid-range passing and crossing, whilst interaction with other individuals challenge visual perception and spatial awareness. Other technical skills are also incorporated, such as position-specific jump-land activities. Adding reactive elements to positional speed drills aims to challenge the player by increasing movement variability and exposure to conditions of higher risk within restricted areas i.e. reaching to an unexpected, mis-directed or bad pass. Conditioning continues to emphasise aerobic qualities, and HSR

load progression (tolerance of intensity driven increases in ground reaction forces) allows introduction of speed-endurance conditioning.

High chaos

Aims: Return the player to, or just above chronic retrospective weekly training indicators using drills designed to challenge the player in worst-case (high-risk) scenarios.

In the final phase before return to training, we emphasise position-specific conditioning and retrospective weekly volumes. We integrate position-specific speed/speed-endurance drills – whereby player movement speed is dictated by the speed/direction of pass, achieving peak speed (>90% MS) relative to retrospective volumes (number of efforts). Conditioning of both speed and speed-endurance qualities now become the focus as well as integration of technical actions in position-specific contexts i.e. tackling in 1 vs 1 situations or drills ending with a shooting opportunity in position-specific areas. Training duration should also be considered, and dependent upon the training methodology i.e. long technical sessions or physical drills combined with decision-making at the end of a session. Alongside achieving target chronic training loads and number of/volume of technical actions, strength and power diagnostics form the final part of RTS criteria to ensure the player is physically prepared whilst communication with the player helps keep them involved in the shared decision-making process and ensures all parties

are confident that the player is ready for progression.

BEYOND RETURN TO SPORT: MAKING STRIDES TOWARDS RETURN TO PERFORMANCE

While successful rehabilitation includes achieving both planned chronic running loads and passing RTS criteria, the journey may not be fully complete. As we mentioned earlier, the decision when to return to competition is a risk management exercise and sometimes players can return before attaining pre-injury levels. Additionally, reaching target pre-injury chronic running loads and strength/power criteria etc. are clearly different to being back to pre-injury levels of competitive match-play (e.g. technical, tactical, physical, mental performance). The return to performance transition process is a continuum of pitch-based rehabilitation, safe resumption of team training and gradual introduction to competitive match-play². However, due to the long duration of absence from training and an inability to truly replicate the training (and match) environment in the rehabilitation scenario, we propose an adjunct to the CCC; The Return to Performance (RTPerf) pathway (Figure 3). This framework fits within the RTS continuum²⁴ and is specifically for players returning to training/competition following ACLR due to the persistent deficits in explosive and decelerative neuromuscular (RFD) and neurocognitive performance^{25,26} and biomechanical control²⁷. The RTPerf framework separates the return to training (RTT) phase into three subphases; non-contact, contact, full integration, followed by a transition back to competition.

Players often experience a 'trafficking' effect when reintegrated to training with a high cognitive load and 'little space and time' to manoeuvre. This phenomenon is likely due to the long period of absence of intense player interaction. neurocognitive readaptation is required to become re-accustomed to player interaction, especially under game-based training conditions.

RETURN TO TRAINING; NON-CONTACT

Aims: Re-introduction to team training (non-contact), use of 'modified' acquisition days (training to overload game formats; intensive/extensive football incorporating technical/tactical elements) to minimise



player trafficking, monitor running load progression.

In this phase the player is re-integrated into non-contact team training. On the main team acquisition days¹⁹ (Figure 4), training is modified to reduce the experience of 'trafficking' but ensure player interaction to promote neurocognitive system conditioning under game-specific conditions. The unpredictable team environment is the only real-life stimulus with match level demands of rapid information processing and responding to the situation-specific visual-spatial cues and is crucial to the RTPerf pathway. The emergence of virtual reality technology in elite sport rehabilitation reflects the interest in replicating these situational-specific demands while maintaining neuromuscular control and recognition that brain dynamics is an important, but untapped area⁸. Specific session modification is implemented primarily in game-based session elements where 'trafficking' is highest. For example, the player may act as link on the outside of

the small sided games and then progress to a 'floater' in small sided games (e.g. 4v4+1). A similar format is followed in medium to large sided games where the 'floater' option is the most effective way to integrate with minimal contact. In such conditions, it is essential to monitor HSR loads, as required outputs may not be achieved with football-specific activity/sessions only. Maintenance or required progression in HSR can be achieved through additional aerobic power i.e. 15:15s intervals or speed-endurance conditioning (preferably position-specific drills). Importantly, during this phase the internal response (time >85% maximal heart-rate and heart-rate exertion) is comparable to running loads achieved during the CCC-high chaos phase. An elevated internal response is expected due to interaction with players in the team training environment. If subjective fatigue increases after two modified acquisition days, a recovery day is advised before rejoining the team match-day minus one session (MD-1; reactivity). On match-day, the player can either join

players not involved in the match-day squad alongside additional top-up conditioning or have an individualised session related to achieving performance targets required for running load progression/stability.

RETURN TO TRAINING; CONTACT

Aims: Continue re-integration to team training under contact conditions, modified acquisition days to minimise trafficking, monitor running load progression.

In this phase the player is progressively integrated into team training and exposed to contact. The previous phase weekly training structure applies, with modification on acquisition days (Figure 4). Within game-based conditions, the player may alternate between a 'floater' to becoming fully integrated into games e.g. 4v4+2 to 5v5. This allows gradual exposure to full training in controlled doses, allowing the player to become accustomed to player interaction in restricted areas, training fast reactive abilities, true sport-specific agility and high-level decision making. Communication with the coaching staff is also key to help ensure that technical skills requiring practice can be refined in-session i.e. pass and move drill with increasing passing distance and touch number restrictions. Internal response to running loads is still monitored; time >85% Max^{HR} and HRE relative to running load metrics ratio in comparison to the high chaos and RTT – non-contact phases. Recovery can be scheduled if appropriate, or a reduced match-day minus two type session such as team warm-up, boxes, pass and move (moderate sized area) and finish – restricting session intensity/volume. As in the previous phase, the player should join with the team on MD-1 and be involved with the players not selected on match-day and on a match-day minus 5 (non-starters training; Figure 4).

RETURN TO TRAINING; FULL INTEGRATION

Aims: Resume full team training, implement a minimum of two acquisition days and two taper days. Monitor running loads i.e. changes in intensive/extensive session loads, internal response, and week to week changes. Introduction to behind closed doors/development squad match minutes.

In this final RTT phase the player is fully integrated into team training. The team's specific training structure will apply here, where two acquisition days are followed by two tapering days leading into match-day

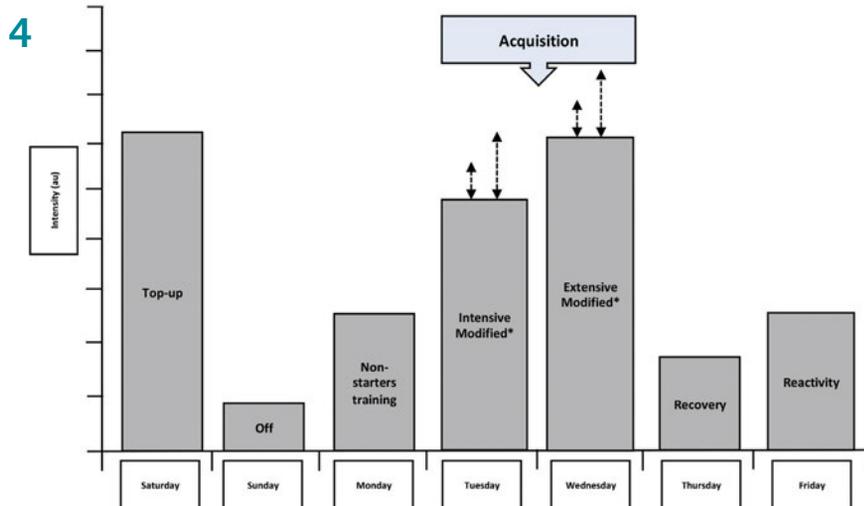


Figure 4: Potential Weekly Planning Template (Return to Training; non-contact and contact). Arrows represent load increments in week to week individual intensive and extension training sessions to build chronic running loads (Increments are increases in running loads; magnitude of increment dependent on 1) player's chronic (pre-injury) loads 2) current injury. Intensive = Intensive Football, Extensive = Extensive Football, Off = Day off, Intensity = arbitrary unit (au), Modified* = modified session/drills.

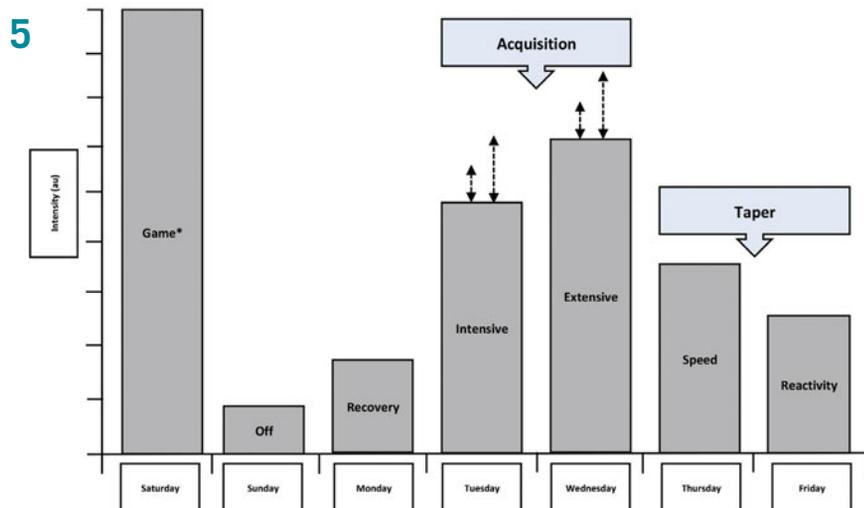


Figure 5: Sample Planning Template (Return to Training – Full Integration, Return to Competition and Return to Performance phases). Arrows represent load increments in week to week individual intensive and extensive sessions to build chronic running loads. Increments are increases in running loads; magnitude of increment dependent on 1) player's chronic (pre-injury) loads 2) current injury. Intensive = Intensive Football, Extensive = Extensive Football, Off = Day off, Recovery = Recovery day, Intensity = arbitrary unit (au), Game* = progression of competitive match minutes, Recovery or Non-starters training* = recovery or training determined by number of competitive match minutes/match minutes running load output and response to load (subjective, selected S&C diagnostics, medical assessments).

(Figure 5). Within the two acquisition days, the continued progression of energy system development in game-based elements of session can be manipulated through alterations in work: rest periods whilst set and repetition parameters of specific drills can be progressed to provide a new

training stimulus (e.g. standard sets, wave loading, descending/ascending pyramids or mixed game formats). These parameters are influenced by technical/tactical coaching alongside the competitive playing schedule. If the sports medical, performance, and coaching team as well as the player him/

herself feels they are ready, a behind closed doors game could be arranged or, commonly the player follows the development squad training schedule in the two days leading into match-day. Match minutes are normally limited to less than thirty as part of a step-wise progression for RTC. If the shared-decision is not in favour of competitive match minutes, then the same format as the two previous phases is repeated.

RETURN TO COMPETITION; MATCH EXPOSURE

Aims: Continue integration to full team training, progression of competitive match minutes (as appropriate), monitoring of running loads/response, regular inter-disciplinary discussion and shared-decision making on competitive involvement.

In this subphase, the player is integrated with the team and preparation is now focused on a progressive increase in competitive match minutes (Figure 5). This phase represents a substantial marker for the player as they are now faced with their biggest psychological challenge; coping with the intense physical and mental demands of professional football. A considered progression of match minutes is implemented, dependent on any development squad minutes accumulated in the previous phase. We suggest starting off with ~20-30 minutes as a substitute or starting the first 45 minutes.

Training load information should form a starting point for discussion with sports medical/performance team to create a planned match minutes strategy for the forthcoming games schedule in collaboration with the coaching staff and the player. We have presented an idealised scenario in which player care is paramount and in which the medical and fitness/performance staff communicate with each other and the coach which does not always align with the reality of the elite environment²⁸. Coaches may be willing to take a higher risk than the support staff. The player's voice may be critical in such circumstances, as experienced professionals know their bodies, and the last thing they want is return to play and get another injury²⁹; hence shared decision-making is critical. Availability of other players in the same position, management opinions, tactical decisions and/or in-game circumstances such as injuries to other players can result in the player not

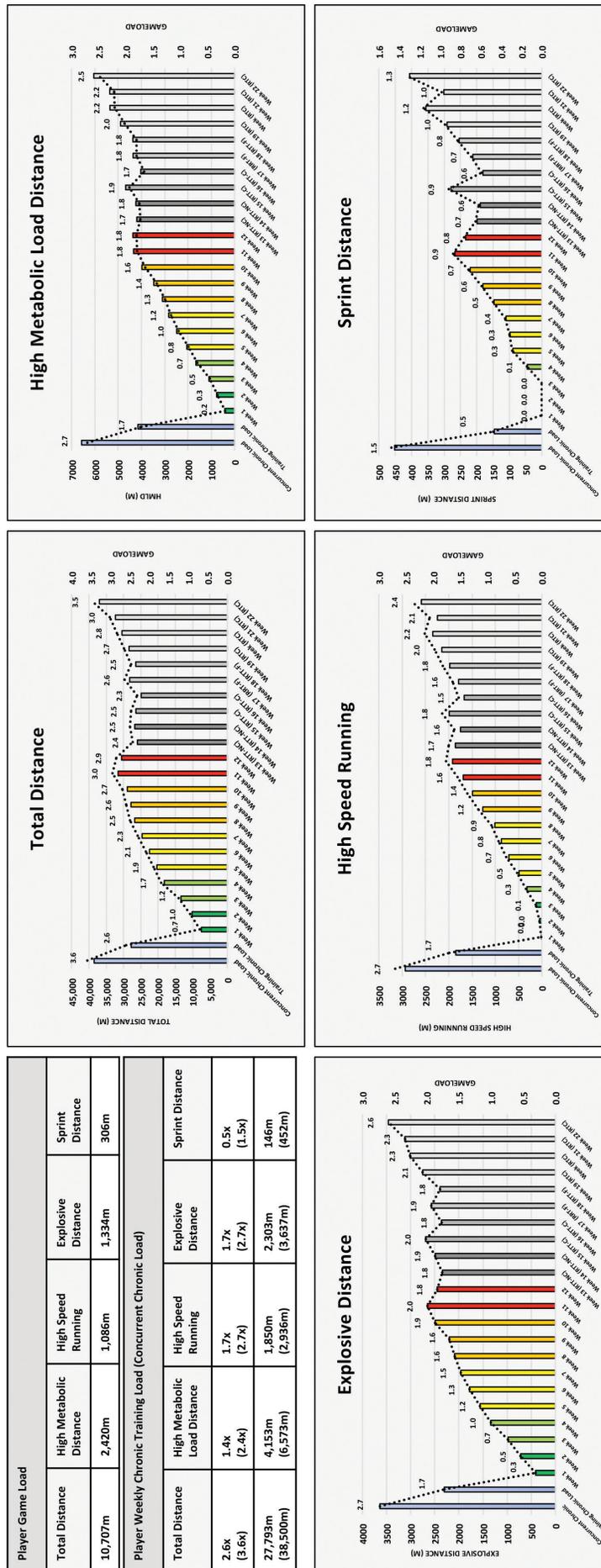


Figure 6: Example of progression in Return to Chronic Running loads following ACLR using the Control-Chaos Continuum and Return to Performance (RTPerf) pathway. Data representative of full-back game load i.e. physical demands of game (mean) and respective training and concurrent (training + match) absolute and relative load (game-load i.e. 2x = 2 games). TD = Total Distance, HSR = High Speed Running (>5.5ms⁻¹), Exp-D = Explosive Distance (>7ms⁻¹), SPR = Sprint Distance (>7ms⁻¹), Exp-D = Explosive Distance (Accelerating/Decelerating from 2-4ms⁻¹ <1s). Green = High control (low intensity) moving towards High Chaos (high intensity). Grey shades = Return to Performance Continuum; Darkest grey = Return to Training: non-contact (RTT-NC), dark grey = Return to Training: contact (RTT-C), Mid-grey = Return to Competition: match exposure (RTC), Light Grey = Return to Training: match exposure (RTC) – the phase leading into a RTPe.

achieving match minutes targets or playing more minutes than planned. One must plan for a worst-case scenario and adapt plans accordingly to changing circumstances. If the player does not play, appropriate post-match top-up conditioning planned in line with running load targets and the upcoming training/fixture schedule is an option. If the player plays more minutes than expected, medical checks in the acute post-match/proceeding days followed by appropriate player management i.e. extra recovery (off-loaded), or modified training is recommended. Although early reintegration increases risk of re-injury, having key players available benefits the team³⁰. Information (i.e. subjective, running loads and response) should therefore be collated in order to estimate risk associated with full return.

Running loads are monitored to try and ensure planned progression and avoid unnecessary 'spikes' (increments or decrements in load). If responses (i.e. perceived exertion, subjective ratings, neuromuscular profile) to load compared to the individual's norms suggest an abnormality, then a reduction in load may be required, albeit while attempting to somewhat maintain load 'stability' (i.e. minor week-to-week fluctuations). At this stage, concurrent running loads should now be approaching pre-injury outputs, dependent upon match involvement and training indicators, as demonstrated in our example of a full-back (Figure 6). If a key player is returning with the possibility of more rapid RTC (immediately playing >60mins), during the RTT subphases we recommend practitioners provide a more aggressive (albeit safe) overload stimulus to specific running loads metrics i.e. exposing the player to HSR demands rather than the typical progression of match minutes to achieve concurrent running load.

RETURN TO PERFORMANCE

Aims: The player is meeting required training demands, regularly involved in competitive match minutes, confident in their level of performance, monitoring concurrent running loads/response, continue development of physical qualities.

Judgement on whether RTPe status has been achieved is made after the RTC phase and depends upon match exposure and the period of adaptation to the imposed

competition load. No definitive length of time is suggested for this period due to variable responses and likely disruption of medical/performance staff plans (described above). During this phase, the player is becoming accustomed to the normal training/competition routine and accumulating full matches, during which time we recommend close attention to concurrent running loads and load response through NM performance monitoring. Off-pitch conditioning/pre-training preparation should be maintained, as an on-going part of development of physical qualities.

Player management around fixture schedules i.e. multiple fixtures in the same week, may represent a challenge. A reduction in training load (number of sessions/intensity of sessions) can assist with management alongside building up to these periods where game load is high, ensuring the training stimulus (volume/intensity) is adequate to condition to meet these expected physical outputs. Factors to consider in defining progress towards RTPe include; equal or exceeding pre-injury typical match outputs, typical performance traits (i.e. physical, technical, tactical qualities) visible to coaching staff and frequent team selection. Load-response monitoring of selected strength and power diagnostics such as CMJs is performed on a standard day of week leading into match-day, both bilateral "fatigue-markers" and in a returning player, attention to individual limb responses and trends, particularly if abnormally high interlimb deficits remain at RTC.

SUMMARY

Sports-specific preparation and return to chronic loading is suggested to be overlooked in RTS criteria in the complex process of rehabilitation from ACLR². The CCC is an adaptable pathway with which to formulate an on-pitch rehabilitation plan, returning the player to the required running loads whilst integrating sport-specific conditioning and technical skills.⁶ Due to the long duration of absence from training and inability to truly replicate the training (and match) environment in the rehabilitation scenario following ACLR we propose an adjunct to the CCC. The RTPe pathway fits within the RTS continuum²⁴ to ensure a logical return to the team training environment, competitive matches and setting a pathway towards a RTPe.

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