Part IV: SKILL ACQUISITION AND TRAINING

Skill change in elite-level kickers: Interdisciplinary considerations of an applied framework

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1. INTRODUCTION

In coaching practice, technical preparation plays an important role. Therefore, interdisciplinary models which provide concrete starting-points for the improvement of technique are substantial for practical work. Coaches . . . would like to know how to stimulate stable modes of coordination in the athlete, how to stabilize proper techniques, and how to change previously acquired, inefficient movement patterns during training. All these questions cannot be answered merely through biomechanical analyses or through detailed movement observations. In this context, relevant methods are rather those which comprehend and illuminate the cognitive–coordinative background of technique execution. (Schack & Bar-Eli, 2007, p. 63)

This quotation which spans a number of characteristics and elements of optimum high-performance environments, stresses the need for a cross and interdisciplinary approach to support practice. Central to the pursuit of this ideal are two important considerations. Firstly, and in contrast to evidence-based guidance on stimulating (i.e., acquiring) and stabilising (i.e., performing) skills, there is a relative dearth when addressing how to *change* an athlete's already acquired and well-established movement (Carson & Collins, 2016; Fitts & Posner, 1967). Specifically, we refer here to such change as making a small tweak, or refinement, to technique in a way that is new to the athlete, although not of sufficient scope so as to constitute the complete acquisition of an entire new skill (cf. Carson & Collins, 2011). This scarcity of advice is unfortunate, since sporting domains present many situations when a technical refinement can generate significant performance improvements (e.g., Carson, Collins & Jones, 2014; Hanin, Korjus, Jouste & Baxter, 2002). For example, when executing on new playing surfaces or with different equipment, responding to new playing styles of competitors, following the different challenges and styles posed by a new manager, or returning from injury. Crucially, coaches need to know how to implement refinement in a way that (1) changes remain permanent in the long-term and (2) ensures that the new version is robust against negative anxiety effects. These outcomes, or a lack thereof, are most clearly evident during closed and self-paced skills, when immense pressure during execution is loaded onto a single individual. As such, this chapter will directly focus on refining skills of this nature (e.g., penalty kicking). Indeed, anecdotal evidence has shown that considerable difficulty is experienced when attempting to realise these outcomes within professional team sports, such as penalty taking in rugby, soccer or hockey; perhaps as a consequence of employing coaching knowledge and techniques intended for different outcomes (i.e., acquisition versus present performance)? Either way, there is a clear and current need within both academic and applied communities to understand why theory to explain skill acquisition and performance cannot be directly applied to athletes seeking long-term permanent and pressure resistant refinement.

Secondly, we welcome Schack and Bar-Eli's (2007) consideration towards the oversight of not coaching both cognitive and co-ordinative aspects of skill execution. Indeed, while it should be obvious to readers that execution outcome is a direct result of kinematic and kinetic processes, a wealth of evidence has also demonstrated the perils of maladaptive conscious processing over these factors during highly stressful situations (e.g., Collins, Trower & Randall, 2002; Hill & Shaw, 2013); a factor that must be proactively addressed if the skill is to be suitably 'pressure proof'. Equally important, however, is the athlete's attitude and intention to bring about change (Ajzen, 1991); therefore highlighting a breadth of cognitive factors that must also be catered for. Finally, and extending this interdisciplinary perspective, social factors can also be seen to significantly impact on a diverse range of outcomes during technical refinement, from programme adherence to the presentation/interpretation of feedback provided. Accordingly, it is insufficient and, in fact, misleading, to conceptualise optimum applied coaching solutions as being anything but biopsychosocial in approach (Bailey *et al.*, 2010; Collins *et al.*, 2012).

Taken together, this chapter presents a change in emphasis from solely addressing mechanical aspects of football movements (an important but inherently limited consideration), to understanding how the biomechanist can usefully support and act within an interdisciplinary coaching team to bring about effective refinement of closed and self-paced skills. Accordingly, we begin by addressing such team dynamics and the important underpinnings for successful co-operation across support practitioners. Following this, we outline and provide exemplification of a five stage process, the Five-A Model (Carson & Collins, 2011), that is designed to facilitate the dual outcomes of long-term permanent and pressure proofed refinement. Finally, and highlighting the most significant contribution offered by the biomechanist, measures will be presented for both assessing and tracking athlete progress.

2. **THE IMPORTANCE OF SHARED MENTAL MODELS**

In supporting an athlete to undertake the difficult challenge of skill refinement, notable benefit may be found through various contributions from a range of support practitioners; namely, a coach, biomechanist, sport psychologist and skill development specialist, with these roles provided through either different specialists or multiple expertise individuals. Although one most typically considers the athlete–coach relationship as paramount (and there is no doubt that this is important), we propose that, in the present context, positive collaboration and input between practitioners is worth equal consideration (Burwitz, Moore & Wilkinson, 1994). Indeed, the impact of support team interaction has already been documented in other aspects of coaching practice; for example, in elite team culture change and talent selection panels. Underpinning such efficacy is the presence of a Shared Mental Model (SMM), or representation, of the task as a reference for coherent and reliable decision making (Collins & Hill, in press). In this regard, the construction of a SMM should be derived from a Professional Judgement and Decision Making (PJDM) approach (Abraham & Collins, 2011; Collins, Burke, Martindale & Cruickshank, 2015; Martindale & Collins, 2005), whereby multiple courses of action are generated and evaluated against planned outcomes and expected lines of consequence.

The application of a SMM has several important implications for the professional preparation, accreditation and practice of biomechanists. Indeed, many of these considerations are pan-domain, carrying similar consequences for other disciplines as for the constrained world of this (arguably) most objective of sport science disciplines. For the present discussion, however, we will focus on two: role clarity and the team dynamic. Firstly, the need for all concerned to understand and adhere to their role within the support process.

With multidisciplinary support teams increasingly the norm across high performance sport, and certainly a consistent feature of sports institutes worldwide, it is increasingly important to know exactly 'who does what, with whom and when'. This challenge was highlighted by Collins and Collins (2011) in considering the various roles, and potential for conflict, between the sports physician, physiotherapist, Strength and Conditioning (S and C) provider and coach. In simple terms, which specialist is responsible for communicating with the athlete? If all, then the risk for mixed messages, confusion, angst and obfuscation is significant. Furthermore, how do the team communicate internally, to conduct the essential internal debate on how data are weighted and what actions are optimum? This situation is further complicated by the various phases through which support may be provided; for example, through the passage of an injury–diagnosis–rehabilitation–return to play cycle. The solution developed by the interdisciplinary team at UK Athletics (with full acknowledgement to Dr. Bruce Hamilton and then Lead Physiotherapist Neil Black) was to phase support through these contexts, with each phase 'led' by the most appropriate disciplinary specialist. Thus, diagnosis was down to the doctor, early and mid-stage rehabilitation to the physiotherapist, later stage rehabilitation to the S and C provider, then return to play to the physiotherapist, S and C provider and coach. One of the most important principles here was that only the lead for that phase would communicate results and actions to the athlete–client. All others involved would feed data and actions through him/her, or at the very least ensure that everything was approved before they spoke one-on-one with the client! As a consequence, although debate behind the scenes/under the surface might be rigorous and vigorous, so far as the athlete–client was concerned, all was certainty, consistency and clarity (see Collins & Collins, 2011, for a more complete treatment of this approach).

Now consider the parallel situation for a biomechanist, hired to examine and evaluate the kicking performance of a senior player in a professional setup. Who is the client in this situation and, therefore, the target for feedback? The player or the coach? Then, in terms of action, who will now decide on, then direct, the actions taken as a result of the evaluation? Who will decide on the timing of this? Does the coach fully understand the time and resource implications of the refinement process which might be implicated (cf. the next section)? In short, who does the biomechanist tell, what, when and with what implications? Hopefully, this series of questions, both common and complex in our experience, offers a grounding in reality for the challenge of providing effective performance support.

The second, and related issue here is based around the team dynamic, and the 'rules' applied to their role execution by the different members of the support team (cf. Collins *et al*., 2002). Returning to the rehabilitation example cited above, our original motivation for implementing the role clarity structure was because of obvious differences between specialists being aired to the athlete and coach, with predictably messy results! So, when physiotherapists and S and C providers would suggest diagnostic tests and checks, doctors suggest exercises, S and C providers suggest electro-treatment modalities and all offer differing views on the prognosis and pathway of return; the fans were clogged to say the least! In our skill refinement example, does the biomechanist 'merely' report the data and retire immediately? Does s/he offer implications of the data, together with various options? Indeed, is s/he trained to design interventions for such refinement? And even if they are, does this training extend to acknowledging and catering for the psycho-emotional implications and ensuring that the eventual execution is sufficiently pressure proof to withstand a clutch competition? In short, there is a lot to this.

Thus, the bottom line of all these concerns is that the team must 'enjoy' a dynamic through which differences can be aired and solved, with no negative implications for the client, be it athlete or coach. This is reflected in our statement made elsewhere, that high performING environments are characterised, or even classified, by the quality of disagreement. As Burke (2011) points out, high-performing teams must be comfortable with, even committed to, living life in the ZOUD…the Zone of Uncomfortable Debate.

In summary, the structure, role and dynamic between staff of every persuasion must be addressed and catered for, in an optimised, high-performing environment. That these considerations apply to even the most objective of disciplines represents an important realisation for the aspirant professional analyst. Consequently, the informed and aware biomechanist must avoid the simple trap of "I can measure it, so it's important and so is my advice" (cf. Collins, Carson & Cruickshank, 2015).

3. IMPLEMENTING TECHNICAL REFINEMENT

As established in the previous section, it is important that all members of the support team understand their role as part of a synergetic group. To assist in the development of a SMM, we now present the Five-A Model (Carson & Collins, 2011). Specifically, this five-stage process is designed to deliver long-term permanent and pressure proof technical refinement through a variety of biomechanical, psychological and coaching 'tools'. In contrast to the mechanisms of acquiring (i.e., establishing technique and levels of automaticity) or prompting optimal performance of a skill (i.e., exploiting the already acquired technique and associated levels of automaticity), the Five-A Model explains refinement as requiring conscious deautomation of the aspect in need of modification (hereafter termed target variable), adjustment to a desired new version, reautomation of the new kinematics within the entire skill and finally, pressure proofing the skill to be 'competition ready'. Notably, due to our current emphasis on support practitioners operating in concert with others, the biomechanist (from this chapter's perspective) must appreciate and incorporate at least some elements of other disciplinary practice as a complimentary aspect; in short, knowing only about biomechanics is insufficient when seeking application within the coaching context.

3.1 Stage 1: Analysis

Before deciding to refine technique, a detailed analysis must be undertaken by the interdisciplinary team. Indeed, for advanced athletes technical refinement is an inevitably risky transition, unless it is known that technical refinement is necessary, what needs refining, how to refine and that a time has been identified for when refinement is appropriate. What the team must avoid is an athlete becoming trapped in a prolonged cyclical process of relapse and recycling through the refinement stages (typically observed during cessation of smoking habits; cf. Schachter, 1982). Accordingly, a PJDM approach to assessing the many factors required to answer these questions offers a sound starting point.

In determining the likelihood of successful refinement, considering the athlete's commitment and capability to achieve the course of action decided upon is paramount. To boost commitment levels, ideas and procedures may need to be 'sold' which, depending on the athlete's previous experience, intention (Ajzen, 1991) and reason for changing, could take up to several months, resulting in a decision to defer any potential refinement. Reflecting our earlier discussion of team dynamics, who does the selling must be carefully calculated based on the level of trust with the athlete. Of course, good coaching practice will have already equipped athletes with essential skills required to overcome such challenges/transitions. As our previous work has identified, exposure or (better still) mastery of several psycho-behavioural characteristics during skill acquisition, can facilitate progress through what is an inevitably 'rocky road' (e.g., imagery, goal setting, motivation, vision of what it takes to succeed, social skills; MacNamara, Button & Collins, 2010; MacNamara, Holmes & Collins, 2008). For the biomechanist, similar 'pre-exposure' may require the athlete to feel confident in their ability to understand basic kinematic feedback (not so detailed as to cajole the athlete, or coach for that matter!) for use when evaluating training goals and a degree of familiarity with motion capture procedures and equipment; those too will have to be determined by the biomechanist as most appropriate. For instance, consider an athlete's willingness and ability to resist distraction from such equipment. Contrasting attitudes between an enthusiastic "I can really see that this is going to help me develop my skills" athlete and another “this is obtrusive and I’m not getting any better already” sceptical athlete, can seriously impact on the team’s decision to even commence with the refinement intervention until this is rectified. That is not to say it is entirely the athlete’s responsibility to adapt to the situation, however. Simplifying the process as much as it can be, may mean sacrificing some kinematic data and only recording the most essential elements of the skill. For example, our previous research (e.g., Carson & Collins, 2015) limited the analysis of golfers to upper body segments (pelvis upwards). From a pragmatic perspective, we employed mobile inertial measurement units over and above the ‘reference standard’ optoelectronic camera systems (e.g., Qualisys); our rationale being to ensure improved anatomical meaning (i.e., 3D data using local co-ordinate systems) versus the more usual video (i.e., 2D data from global co-ordinate systems) recording by a coach and, ecological validity when compared to indoor laboratory constraints. As such, it is important to recognise the various trade-off decisions that might need to be made when it comes to deviating from most typical anatomical modelling techniques and sampling rates, for example, to ensure all-important athlete ‘buy-in’.

When assessing the case either for or against refinement, the necessity for, and technical aspect in need of, change must be on an individual basis; that is, avoiding the trap of Hume’s Law (e.g., “Jonnie Wilkinson does that, so therefore Athlete ‘X’ ought to as well”). Once a skill has been learnt it is clear, simply from behavioural observation, that kickers demonstrate their own style of kicking (some technical aspects being more, others less, similar across individuals). What must be determined is whether these technical idiosyncrasies are ‘errors’ or in fact causative of successful executions? If the biomechanist is not well acquainted with the particular athlete’s playing style, team role and technical capabilities, coach-guidance will be essential in translating what would ideally be a six degrees-of-freedom analysis into technical principles that are widely used by athletes and coaches. Failure to establish even a general qualitative idea about potential target variables from those working closest to the athlete can, with tremendous frustration, lead to the situation of “trying to find a needle in a haystack”. In summary, cross team consensus, developed through triangulation across practitioners, is an important if sometimes illusive precursor for effective progress.

3.2 Awareness

Having decided to implement technical refinement, the support team must now encourage increased conscious control over the flawed target variable. Indeed, it is widely argued that permanent change to an automated movement requires, at least temporarily, deautomation of the motor memory trace (Beilock, Carr, MacMahon & Starkes, 2002; Carson, Collins & Richards, 2016; Oudejans, Koedijker & Beek, 2007). In our previous research (Carson & Collins, 2015; Carson, Collins & Jones, 2014; Collins, Morriss & Trower, 1999), and that of others (Hanin *et al*., 2002; Hanin, Malvela & Hanina, 2004), contrast drills have shown to be an effective coaching technique to help direct an athlete's attention narrowly inward (cf. Wulf, 2013). Specifically, these contrast drills require the athlete to perform alternate 'versions' of the skill, one that is 'correct/new' and one 'incorrect/old'. For example, Hanin *et al*. (2004) asked an Olympic swimmer to contrast the diving start position, height of jump and hand position involved during deep (old/incorrect technique) versus shallow (new/correct) water entries. In addition to this more conventional contrast, Collins *et al*. (1999) showed good effect when asking an Olympic javelin thrower to execute both left- and right-handed throws, simply to force greater concentration within the athlete. Undoubtedly, the ability of an athlete to forfeit subconscious control requires a good mental imagery ability, both in terms of visualisation and kinaesthetic acuity, to know how these two versions should be performed. Direct questioning (e.g., "tell me how it was different?") with the athlete to generate verbal 'cues' can help to clarify the motoric differences, since verbal and sensory memories are stored in parallel (i.e., one may activate the other; Paivio, 1986).

As expected, regaining conscious awareness can be very disorientating for the athlete and frustration can easily mount as performance drops in response to a regression in automaticity. Accordingly, manipulating the training environment can facilitate a most productive change in focus. Godbout and Boyd (2010) used a slower and more upright skating stride to allow an athlete to better sense the contrast in their ankle extension pattern during the cross-over skill. Collins *et al*. (1999) employed a shortened run-up during javelin throwing and Carson *et al*. (2016) a net for golfers to execute their shots into. All of these less than 'representative' environments/tasks (cf. Pinder, Davids, Renshaw & Araújo, 2011) are intended to assist in initiating the awareness process by reducing influence from additional distractions. Therefore, optimum procedure includes highlighting skill refinement as a complex nonlinear process and stressing the need for careful decision making, sometimes resulting in contradictory practices, in relation to both short- and long-term goals.

Finally, the support team must also consider the instruction offered against the athlete's perceptions about what is happening during the execution. Typically, athletes do not understand their movement in quantitative terms (e.g., instructing the athlete to "increase/decrease your knee flexion by 10%"; Giblin, Farrow, Reid, Ball & Abernethy, 2015), but rather through sensory representation (e.g., feeling the body lean, sound of the foot making contact with the ball, etc.) and the perceived effort required. Indeed, understanding these cues from the athlete and feeding them back (e.g., "now do that again but ramp up the 'volume' on it"), a process akin to imagery response training (Lang, Kozak, Miller, Levin & McLean Jr, 1980), will require consistency across the support team's language and/or only a limited number of individuals offering instruction. Notably, however, these cues may offer quality guidance in locating the general area of focus and then serve to reduce the number of tracking target variables down to a single kinematic measure; as opposed to tracking all components within the kinematic chain. Assessing that the contrast versions are at least being executed in the correct direction is a positive sign, one that should be much welcomed by both athlete and coach!

3.3 Adjustment

Despite regaining high consciousness, success at achieving the desired kinematics is often infrequent, with the athlete normally generating an approximation (cf. Tallet, Kostrubiec & Zanone, 2008) of the desired target variable. Accordingly, the Adjustment stage attempts to gradually increase the accuracy of executions and heighten the athlete's acceptance and comfort towards the new technique. Carson, Collins and Jones (2014) describe this process as "shaping" (p. 69), whereby the motoric representation, in the form of kinaesthetic, visual and verbal stimuli, undergo progressive revisions/updates as the athlete becomes more familiar with, and better at, the targeted movement goal; that is, going beyond the initial sense of "this feels strange". Indeed, demonstrating technical improvements can be very motivational and provide an increasingly vivid perception of 'what' and 'how' to execute. As such, the biomechanist can play a crucial role here in assessing for any changes to drive the modification intervention.

As an exemplar practice of the shaping intervention, Carson, Collins and Jones (2014) employed self-modelling, but only against the athlete's best attempt. In simple terms, as the athlete got closer to the targeted technique, video footage was replaced in order to stimulate an ever-improving mental imagery prime (Holmes & Collins, 2001; Lang, 1979). It was crucial that the athlete did not get stuck part way through the change and automate an incomplete version or regress back toward the original version. In doing so, we highlight two important factors (1) the viewing angle and (2) the level of mental engagement during observation. To maximise an observational effect, the athlete must be able to see their progress being made, after all, the behaviour is the intention of future attempts. As such, the modelling video might not necessarily be the same as used in conventional technique analysis (e.g., sagittal or frontal plane). Also, these images must relate to what the movement felt like during execution. Watching and recalling the cues attended to increases the vividness of the skill; therefore providing a greater number of retrieval cues for subsequent attempts (Paivio, 1986).

At the same time, the support team must intervene to ensure that the athlete departs from their previously erroneous technique; otherwise the risk of regression becomes increasingly likely. We recommend a tapering strategy for both physical and mental practice. As utilised within javelin throwing (Collins *et al*., 1999), weightlifting (Carson, Collins & Jones, 2014) and golf (Carson & Collins, 2015), this requires the gradual removal of incorrect attempts within the contrast training regime, therefore increasing the pressure to execute with, and establishment of, the desirable kinematics.

3.4 (Re)Automation

Once the athlete can consistently achieve the desired new technique, the skill must return to being executed under largely subconscious control. Indeed, MacPherson, Collins and Obhi (2009) explain the effects of focussing on part-skill 'cues' as detrimental under conditions of competitive pressure due to the movement being fragmented, which disrupts the necessary flow and timing of the entire movement. Therefore, it is suggested that athletes focus on holistic patterns of thought which emphasise the whole action and do not overly tax attentional recourses; meaning that athletes can still utilise task-relevant environmental information (e.g., assessing the strength and direction of wind). Often these cognitions relate to the timing, or rhythm, of the movement and intensity/emotion contained within it (cf. Holmes & Collins, 2001). For instance, Collins *et al*. (1999) overlaid a sequence of bleeps onto real-time video footage for a javelin thrower when reautomating their technique. Bleeps occurred at every foot–ground contact; the volume, pitch and timing emphasised to reflect changes in the technical phases (i.e., straight run, sideways turn, planting the 'block' leg and throw) and how the athlete perceived these to be represented. Importantly, the stimulus was a fluid and continuous stream of information. Clearly there are similarities here to the skill of penalty kicking, where rhythm and timing appear to be distinctly emphasised (at least behaviourally) within the professional game (e.g., Neil Jenkins; see Jackson & Baker, 2001). Likewise, mood words (e.g., thump, swish, clip) can also provide the athlete with a beneficial motoric 'aide memoire' of the skill (Rushall, 1979), so long as it reflects pertinent movement capacities such as the required strength, speed, power, agility, balance or endurance. In either case, such thoughts are described as "sources of information" (MacPherson, Collins & Morriss, 2008, p. 289), providing a "prophylactic against potentially disruptive cognitions and emotional states that inhibit fluid movement" (MacPherson, *et al.*, 2009, p. S58) and as creating a most direct route to retrieval of the entire skill from memory (see Winter, MacPherson & Collins, 2014). As such, and in contrast to experimentally-derived guidance to avoid thinking about one's body movements (Masters, 1992; Wulf, 2013), we encourage practitioners to consider the role that a positive self-focus (see Carson & Collins, 2016) can have in promoting better performance outcomes (Bortoli, Bertollo, Hanin & Robazza, 2012).

Notably, regaining automaticity should be gradual, in contrast to the more catastrophic nature of the Awareness stage. Primarily, this is because technical components that were not targeted for refinement must 'settle' in with this new version. In preventing too quick a return to automaticity, the support team should taper out the intensity and frequency of their input by adopting a more hands-off approach within more representative, on-field and game-like contexts. That is not to say the movement will be fully established and always consistent from day-to-day, there will be some inevitable bumpiness, but that constant harassment from the biomechanist and/or coach regarding technical instruction will not help the matter. In fact, consultation and evaluation of skill progression would most probably be well suited to the sport psychologist's less threatening and emotionally-attuned role.

3.5 Assurance

Competition at any level brings with it an expected degree of anxiety and, therefore, potential to influence an athlete's execution. Within the football context, anxiety is likely to manifest both physiologically (e.g., breathlessness, high heart rate, muscular tension and fatigue) and psychologically (e.g., worry, self-consciousness, negative self-focus). Indeed, anxiety has long been understood to be an essential component of optimum performance (Yerkes & Dodson, 1908), but also a significant debilitating source which can cause regression in motor control (e.g., Collins, Jones, Fairweather, Doolan & Priestley, 2001; Pijpers, Oudejans, Holsheimer & Bakker, 2003). For elite-level or professional athletes, the consequences of succumbing to these latter effects are often far more severe than within recreational or amateur contexts (i.e., potential to be dropped by the manager, social ridicule and personal embarrassment). Accordingly, the support team must proactively work to ensure that the athlete not only possesses a high degree of automaticity, but also confidence in this process (Carson & Collins, 2016). When these factors are high, the skill can almost certainly be pressure proofed against negative anxiety effects (Cheng, Hardy & Markland, 2009), leading to improved performance consistency and proficiency. A significant challenge confronting the athlete is, therefore, being able to achieve complete and fluid activation of the newly refined skill when distracted from multiple streams. While it is often recommended that the athlete try to clear their mind and think of nothing, this reality is normally impossible in these situations and akin to trying to consciously make oneself fall asleep (Montero, 2015). Instead, confidence in knowing how to 'make it happen' and, that one can make it happen, offers a much more realistic solution to preventing such an uncomfortable scenario occurring in the first place. Of course, this search for greater assurance in performance does not develop without practice.

From a practical perspective, a method that we find to be successful in securing skills at this stage, is to simulate anxiety and face the symptoms head on, alongside the provision of quality evaluation of both performance outcome and process consistency. We call this intervention combination training; that is, combining physical fatigue symptoms with a difficult level of technical challenge. Exemplar implementation has included sprints prior to executing challenging shot strategy in golf (Carson & Collins, 2015) and fully committed javelin throws (Collins *et al*., 1999), introducing higher social pressure by the presence of peers (Carson, Collins & Jones, 2014) and, in our professional consultancy experience within rugby union, incorporating upper body weight lifting exercises alongside 150 m sprints prior to each line-out throw. Within the kicking context, manipulation of task difficulty may utilise acute kicking angles, longer distances and perceived social pressure from the presence of coaching and/or managerial staff (or at least video recording that the player believes will be shown to these individuals). In fact, it is not uncommon in our experience that, when athletes have established their skills to such a high degree, they perform better during this type of training when compared to unpressurised conditions. Crucially, an ability to offer objective—either three-dimensional and/or video—feedback to demonstrate the skill's security is a very powerful tool to assure the athlete just how consistent their performances really are. Additionally, verification of this kind is of equal importance in preventing the coach from implementing further intervention!

4. ASSESSING AND TRACKING ATHLETE PERFORMANCE

In light of our previous assertion that there is a lot to manage during the refinement process, biomechanists are well equipped to bring several valuable pieces of information to assist in tracking progress through the Five-A Model. Indeed, demonstration of accurate and meaningful data can present essential monitoring for other support disciplines and drive the necessary stages involved. Since many chapters within this book provide ample guidance towards the measurement of football movements, here we will introduce a related concept that has shown to bridge the cognitive–co-ordinative relationship explained by Schack and Bar-Eli (2007); inter-trial movement variability.

Firstly from a co-ordination perspective, a most fundamental investigation of this domain addresses how successful outcomes are consistently achieved by a redundant motor system (i.e., the degrees-of-freedom problem; Bernstein, 1967). In other words, how does the central nervous system (CNS) solve a movement problem, such as organising the limbs to kick a ball, when there are so many different whole body joint configurations available to it? Importantly in this regard, it is accepted that no two movements are ever executed in exactly the same way, even at the elite-level where athletes and coaches train to ensure a high degree of establishment (e.g., Carson & Collins, 2016; MacPherson *et al*., 2008). During skill acquisition, however, inter-trial movement variability can be seen to reduce as movements become both more efficient and proficient, due at least to reductions in stochastic noise (Bobrownicki, MacPherson, Coleman, Collins & Sproule, 2015; MacPherson *et al*., 2008; Müller & Sternad, 2004). For closed and self-paced skills, individually preferred movement patterns are stabilised with practice to exploit each individual's physical characteristics (hence why every kicker will have their own recognisable 'style') to complete the task requirements. Therefore, such variability can be considered as 'functional' (Davids, Glazier, Araújo & Bartlett, 2003) and catering for the inevitably different task requirements such as kicking from different distances, angles and ground conditions.

How this variability is structured across all of the different movement components is more complex and dependent on the motor system apparatus (e.g., limb length and joint flexibility) involved. Recent interpretations have viewed motor redundancy not as problematic to the CNS (Bernstein, 1967), but instead as a luxury (Gelfand & Latash, 1998). According to the UnControlled Manifold (UCM) concept (Scholz & Schöner, 1999; Schöner, 1995), the CNS preferentially stabilises (i.e., reduces the variability) aspects of the movement that are essential to task success and frees up (i.e., increases the variability) less essential movement components to accommodate/support changes imposed by dynamic task constraints (e.g., kicking on wet vs. dry grass). The UCM concept therefore satisfies concerns that the CNS cannot control every movement component and that it is an adaptable system within a dynamic environment. Crucially for sports biomechanists, this perspective carries with it a number of implications. Firstly, variability is not simply 'noise' within the system that should be ignored.

Secondly, movement invariance does not reflect representative executions that should be sought after; in fact, too low variation could be a hallmark of dysfunctional movement control. Thirdly, and finally, the variability of specific movement components (e.g., pelvis–torso lateral flexion at foot–ball contact) may not be comparable between individuals.

Now to the cognitive element of this tracking tool. Recently, we suggested that the co-variation principle explained by the UCM concept might apply also when movement components are subjected to different requirements of conscious intervention (Carson, Collins & Richards, 2014). Specifically, when an athlete decides to consciously emphasise the control of a movement component, they assign greater importance to it and, therefore, inter-trial variability would predictably decrease below that of normal functional levels. Concurrently, less associated aspects of that component would predictably increase in inter-trial variability due to a reduction in emphasis. Overall, resulting in an imbalance of control across the entire skill; that is, 'dysfunctional' movement variability and a dip in performance (Carson & Collins, 2016). It is important to realise at this stage that the extent of this disparity cannot be quantitatively known in advance, only that measurement will never reach zero. We suggest that a plateau across several sessions following a noticeable decrease should be aimed for. Taking the skill refinement process in its entirety, therefore, initial inter-trial variability across different movement components would be predictably different (cf. Scholz & Schöner, 1999) but relatively consistent from session-to-session (i.e., a well-established movement pattern; Carson & Collins, 2016). Once applying a narrow internal focus of attention, overall control will be unbalanced (with the target variable reducing and some other increasing in inter-trial variability), until a time when the technique is modified and conscious attention is applied more holistically. Indeed, this disruption to the overall movement control once again highlights a risk involved and therefore need for careful planning to decide when the right time is to start refining. If all is going to plan however, pre-change variability levels offer a valuable reference guide to know when the athlete no longer needs to attend to the target variable and the new version has been internalised. Here, variability levels should return to normal functional amounts, with the new kinematics of course! Crucially at this stage, functional movement variability must also be demonstrated under pressure testing conditions for the refinement to be considered complete. As such, it is most beneficial for biomechanical instrumentation to be well suited to applied testing conditions, therefore offering a desirable alternative to self-reported measures of conscious control during the latter stages.

To exemplify this application, we have explored the practical utility of movement variability in the comparable closed and self-paced skill of golf. Specifically, our most recent research has assessed co-variation trends across several training designs and both short- and long-term timescales, with promising effect. For example, Carson, Collins and Richards (2014) showed high-level golfers to demonstrate greater consistency for target variables when intentionally executing non-preferred shot trajectories versus a more natural, less effortful and preferred type (fades or draws; i.e., left-to-right or right-to-left ball flights), whilst variability for contralateral non-target variables increased (see MacPherson *et al.*, 2008, for similar effects when employing a part-skill vs. holistic focus in javelin throwing). In another study evaluating the efficacy of different training environments when initiating refinement in the Awareness stage, variability of target variables reduced more when golfers executed shots in front of a net versus on a driving range with 100% outcome feedback (Carson *et al*., 2016). These data suggesting that better use of attentional control towards narrow internal cues was apparent in the absence of environmental distractions. Finally, Carson and Collins (2015) report longitudinal case studies showing different outcomes for high-level golfers attempting permanent and pressure-resistant refinements. Notably, the level of agreement with expected co-variation trends corresponded to the extent of intervention success. One participant was able to complete their intended refinement and co-variation trends were largely as we have discussed. For another participant the kinematics were modified as planned, however there was a 'double-dip' in the target variable's variability; signalling a reduction in conscious attention following the change and then a return to increased attention shortly after. Self-report data indicated that they were not yet fully comfortable with the new movement, probably due in part to intervention adherence problems. In a final example, the refinement was abandoned with the golfer not able to complete the change due to confusion, a lack of intention and experience of using the mental skills required. Movement variability trends in this case showed no resemblance to that expected. Therefore, employing movement variability has the potential to inform about possible derailments as well as intended progress. Crucially, however, interpretation of data must consider biopsychosocial interactions to explain why training is/is not working. As such, we believe that there warrants much anticipation towards what this 'psychomechanical' measure may offer football practitioners when designing and monitoring effective interventions.

5. SUMMARY

The ability to successfully refine an already learnt and well-established skill is essential at times during high-performance sport. Indeed, success in this task requires necessary consideration of biopsychosocial factors which underpin development and, therefore, an interdisciplinary model that recognises the unique and interactive contributions of different specialists at varying points in the process. This chapter has explained how the biomechanist can usefully support and act within such a team to bring about effective refinement of closed motor skills, such as the rugby penalty kick. Central to the successful operation of an interdisciplinary team is the generation of a SMM derived from a PJDM approach. Facilitated by an atmosphere of open and intensive debate, the SMM ensures role clarity and an effective team dynamic within the supporting personnel, while a clear and assured front is presented to the athlete–client. This chapter has also presented an overview of the Five-A Model (Carson & Collins, 2011), designed to facilitate the dual outcomes of long-term permanent and pressure proofed refinement. Beyond the traditional biomechanical focus on observation and diagnosis of errors, the Five-A Model first emphasises the need and methods to establish both cross team consensus and athlete "buy in" regarding whether a refinement should be attempted, what needs refining and, if the decision to proceed is reached, how and when to proceed. Subsequent stages present a rationale and methodology for returning the movement to conscious control, shaping the movement towards the desired pattern, automating the modified pattern and assuring the athlete and coach that the refinement has been successfully accomplished. As such, the Five-A Model may be considered as an integrated, practical framework to guide the performer, coach and support team. For the biomechanist in particular, the model aids in understanding the objectives and activities of other support team members, and raises important considerations regarding what, how and when measurements are appropriate. Finally, this chapter has explained how the biomechanist can employ inter-trial variability within several different training environments and simulations to evaluate athlete progress throughout the nonlinear refinement process. Indeed, the utilisation of this measure can facilitate a better understanding of the cognitive–coordinative relationship and, therefore, provide valuable data for both sport psychologist and coach in relation to the athlete's attentional focus and automaticity. In conclusion, we hope that this chapter has stimulated discussion and offered new suggestions on how a biomechanist can act most efficiently within an interdisciplinary team when implementing technical refinement.

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