Development of a Skill-Acquisition Periodisation Framework for High-Performance Sport

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Figure captions

Formal running head

Skill acquisition periodisation framework

Abstract:

Unlike physical training, skill acquisition does not currently utilise periodisation to plan, monitor and evaluate programs. Development of a skill acquisition periodisation framework would allow for the systematic investigation into the acute and longitudinal effectiveness of such interventions. Using the physical training literature as a reference point a skill training periodisation framework was developed for use in high-performance sport. Previous research undertaken in skill acquisition was used to provide support for the framework. The specificity, progression, overload, reversibility and tedium (SPORT) acronym was adopted. Each principle was then re-conceptualised so that it related to relevant skill acquisition principles. Methods for the measurement and analysis of each principle are provided and future directions for the longitudinal assessment of skill acquisition are discussed. The skill acquisition periodisation framework proposed in this study represents an opportunity for the principles relating to skill acquisition training to be measured in a systematic and holistic manner. This can also allow for a more sophisticated evaluation of the efficacy of longitudinal training programs and interventions designed for sustained skill enhancement.

Key points

- While skill acquisition literature provides a range of principles that may guide effective skill development, much research is required to ensure appropriate translation to the high performance sport setting.
- Skill acquisition research and practice can benefit from a periodisation framework to provide a structure for the longitudinal skill monitoring and development of athletes.
- Physical training literature provides a useful reference point for the development of a skill acquisition periodisation framework.

1. Introduction

In high performance sport, athletes are required to develop high levels of physical and skill proficiency. Despite the relative importance of both these contributors to overall sporting performance, elite performance has often been defined by the physical precocity or prowess of an athlete [1]. With respect to skill, it is well established that elite athletes display higher levels than their sub-elite counterparts. This expression of skill is evidenced in the elite athlete's superior technical execution and adaptability, perceptual-cognitive (i.e., tactical) proficiency, capacity to process multiple sources of information concurrently as well as more efficient muscular activation patterns (see Baker and Farrow [2] for a review). In the context of the current paper we considered skill (and its acquisition or refinement) in a holistic sense and consider both perceptual-cognitive and technical motor skill collectively given the reciprocal nature of the relationship between perception and action (see Davids et al. [3] for a review).

When the physical and skill training literatures are compared it is evident that systematic approaches to physical training prescription and monitoring are more prevalent and established comparative to offerings in the skill acquisition literature. While the relative importance placed on physical preparation is contributory, equally the field of skill acquisition, particularly as it relates to application in the high performance setting, has lagged behind other sub-disciplines of sports science [4]. This lag has been due to a number of factors. Most notably the predominant body of research to date has preferred to complete theoretically-driven examinations of skill acquisition in controlled laboratory settings. These experimental approaches have typically used simple movement tasks that can be learned by untrained participants in short intervention phases (i.e., 1-2 days) where high volumes of repetition are accrued [5-6]. Although such research has made a substantial contribution to the understanding of skill learning, its applicability to the context of high performance sport requires translation.

In a high performance setting, athletes' skills are obviously expected to be at a superior stage of development to the general population. However this does not preclude these individuals from requiring support to refine or remediate an existing skill (or in some cases learn a new skill). Yet, an underpinning framework to translate established skill acquisition principles to the longitudinal skill development needs of high performance athletes is not well established. One specific example of this knowledge gap is in the use of periodisation, whereby systematic variations to training are implemented at regular intervals with the aim of improving performance [7-8]. Although the evidence in support of periodisation as a concept is mixed [9] various forms are relatively common practice in not only elite [10] but also amateur and sub-elite sports [11-12]. Periodisation utilises short and long term planning to prescribe specific workloads and tasks, with adjustments made based on the athlete's biological response to training stimuli as well as their developmental status [8].

Although in skill acquisition a range of practice and instructional / feedback approaches have been detailed [13], research has generally been silent on how to systematically implement such concepts into a long term training plan. Further, load monitoring of physical training, the process by which external (i.e., global positioning satellite [GPS] derived metrics) and internal (i.e., rate of perceived exertion [RPE] or heart rate) measures are routinely collected, is also widespread (see [14-15] for respective examples). However analogous monitoring of skill training to date has largely centred on the outcome of a skilled performance (i.e., whether a kick resulted in a score) rather than the underpinning process measures of skilled performance (i.e., attentional capacity, kinematics etc.).

A contributing factor to the large body of research undertaken in the physical training domain has been the widespread use of various systematic periodisation and training load monitoring frameworks. Notable illustrations include the specificity, progression, overload, reversibility and tedium (SPORT) (see Grout and Long [16] for examples) and frequency, intensity, type and time (FITT) [17-18] models. These frameworks provide a means by which descriptors of training can be recorded, evaluated and reviewed in a systematic manner, thereby informing decision-making on future prescription. For instance using the SPORT example, the specificity of an athlete's physical training can be assessed with respect to the extent to which it reflects competition. Both the discrete and longitudinal athlete response to specific training stimuli can then be determined, with future planning refined in light of this observed reaction (dose-response).

Whilst specific skill training frameworks and models have been proposed in the literature [19-21] the concept of periodisation of the key underpinning skill learning principles has received little attention or development. For example, currently no specific periodisation framework exists (such as the SPORT or FITT model) to record similar types of information to that which is routinely collected in the physical training domain. Historically, there are logical explanations for this, namely, skill can be difficult to observe and objectively measure in comparison to physical fitness [5]. For example, whilst a physiological measure such as heart rate can be sampled in real-time and connected to physical training load [22], finding an analogous skill measure is often more challenging. Furthermore, separating the temporary from permanent effects of a skill learning intervention can be difficult due to the multi-factorial nature of skill [5-6]. This is particularly the case in high performance sport settings, where multiple development priorities are targeted in training concurrently.

However, in recent times the measurement of skill has been improved due to advancements in observational-facilitating technologies [23]. For example, it is now possible to record metrics such as the gaze behaviour of athletes in the performance setting. This can arguably provide an insight into the visual-attentional processes employed by a performer in different circumstances (e.g. visual scanning in different tactical situations). Similarly, movement kinematics are now being more readily collected in the performance setting and can be linked to match analysis variables representative of performance such as the effectiveness of skill execution. Furthermore, the continued growth of wearable technologies such as player tracking devices / inertial sensors means that metrics such as skill practice volume relative to physical workload variables such as movement speed or exertion can be recorded in situ. Consequently the development of a periodisation framework for skill acquisition needs in a high performance setting is possible and may provide similar benefits to those observed in the physical training domain.

In the following section existing models and concepts from the physical training literature are adapted as a basis for a skill training framework. For each training principle detailed, empirical support is provided from the skill acquisition literature and is followed by a practical application of the concept. This imported paradigm proposed as a ‘skill acquisition periodisation’ (SAP) framework is provided as an initial stimulus for researchers and practitioners alike. The framework has been developed with the aim of providing a system to assist in the measurement, monitoring and evaluation of skill training and resultant behaviour in high-performance sport. It is suggested that application of this new framework could assist in improving the efficacy of existing skill acquisition program prescription. Further, the framework could provide a model that can be empirically investigated using prospective longitudinal research design, a methodology largely absent from the extant skill acquisition literature [24].

2. Development and Application of the Skill Acquisition Periodisation (SAP) framework

Support from the literature for the direct application of the SPORT framework for use in skill acquisition is detailed below. Illustrations demonstrating application are provided under each component of the new framework, using the sport of football (soccer) as an example.

2.1 Specificity

In the context of skill training, specificity can be defined as the extent to which the practice (training) prescribed (or completed) reflects the demands typically experienced in competition [25-26]. A substantial portion of the literature investigating specificity in skill practice has often been considered in laboratory-based contexts. This work has typically focused on the presence or absence of specific sensory information in the practice setting, such as vision, and how this manipulation influences eventual skill performance [27]. The results of such work have not been conclusive in either supporting or rejecting a "specificity of learning" hypothesis [28].

More recently, the concept of 'representative learning design' [29-30] has been introduced providing an alternative theoretical perspective to the traditional views of specificity [25]. This refers to extent to which the practice prescribed reflects the behavioural demands of the task [29, 31]. In other words, "the constraints of training and practice need to adequately replicate the performance environment so that they allow learners to detect affordances for action and couple actions to key information sources within those specific settings" [29, p.151]. The "constraints" Pinder et al. [29] refers to can be typically allocated into one of three categories; individual, environmental and task [32]. Individual constraints can include physical and psychological characteristics of the athlete, such as their speed, endurance or attentional control. Environmental factors include considerations such as weather or pitch conditions, whereas task constraints relate to the type of skill being performed, the rules of the game and/or the equipment used.

A considerable body of work has investigated how the manipulation of constraints and in turn representative learning design can influence skilled performance [33-34]. Despite this, a systematic method by which a practitioner or scientist can assess the specificity (or representativeness) of skill training has not been proposed. For example, an increasing volume of research has investigated the task constraints relating to playing numbers (i.e., 2v2 vs 3v2 etc.) and in turn relative playing density in sports such as football [35]. However such work has not tackled how the constraints manipulated represent or transfer to actual match performance. A logical starting point for these investigations could centre on how individual/organismic constraints interact particularly with task constraints as a primary determinant in how specific training needs to be. Physical training prescription considers specificity in terms of qualities such as athlete capacity, joint action and movement speed. However, there is a need to determine the equivalents for skill prescription, for example attentional capacity or technical efficiency. Further, a method by which these comparisons can be systematically evaluated to inform practice prescription at different stages of an athlete's or team's development has also been largely absent.

A notable element of representativeness that needs to be considered in relation to some of the training principles that follow (particularly 'overload') is that it has been demonstrated that greater representativeness of the performance (competition) setting in training can lead to an increase in load. This load can manifest in many facets of performance. For example, more representative football training has been demonstrated to be more physically and cognitively demanding than matched low representative training conditions as measured by relative intensity, distance covered, ratings of perceived physical and cognitive exertion, and decision making complexity [36]. Similarly, psychological load has also been found to increase when representativeness is increased. For example, increased anxiety and narrowed attention (analogous to increased 'load') have been found in a wall (rock) climbing task situated higher from the ground than an identical task lower to the ground [37]. Developing a greater understanding of this relationship between load and task representativeness is critical when the longitudinal demands of high performance training are considered.

For the purpose of application, a hypothetical scenario whereby a footballer has performed a total of 200 passes over a training week (commonly referred to as a ‘microcycle’ in the physical training literature) is outlined in Figure 1. Three example skill constraints are presented (column A). First, the task constraint of the processing time the player is allowed prior to executing a pass is shown. This has been arbitrarily categorised into one second epochs for the purpose of the scenario. A second example of pass difficulty is represented by the player density in which the player is required to pass within. For instance, a pass to an unmarked player would be considered less difficult in comparison to a 3 vs 3 attacker/defender scenario. The third example, this time an environmental constraint, relates to the pitch size. In this instance, it is assumed that creating a reduction in space in which to execute a pass represents a more difficult environment than a full size pitch.

****** INSERT FIGURE I ABOUT HERE ******

Using the skill concept of representativeness and the three constraints discussed above, Figure 1 illustrates both the number and percentage breakdown of passes under each of the three constraint’s separate sub-categories (columns C and D). For instance, it can be seen that of the 200 passes undertaken during the training microcycle, 24 were executed in less than one second of processing time, whilst 54, 54, and 68 passes were performed in 1-2, 2-3 and 3+ seconds respectively. As a next step, conversion of this data from an absolute (i.e., *actual* number of passes completed – column C) to a relative format *(% of total* passes completed – column D) is important on two fronts. First, as specificity relates to how representative the training is on the focus area being developed (and not the actual volume) this allows for direct comparability with competition conditions. This can be undertaken irrespective of the volume differences which are likely to occur between the two settings. Second, it also allows for monitoring of the specificity of the skill training longitudinally, by facilitating direct week-to-week comparisons – this can also be undertaken irrespective of volume differences. This longitudinal tracking is discussed further below in section 2.2 Progression.

In column E, hypothetical information obtained from competition/matches is shown for each constraint, thereby facilitating a direct comparison with training conditions. Simply obtaining the pooled absolute difference between competition and training for each constraint and dividing by two can then be taken to define the representativeness of each (column E). For the 'processing time' constraint for example, obtaining the absolute difference of -7, 4, -1 and 4 (16), dividing this value by half and then subtracting from 100 (i.e., complete representativeness) equates to 92%. Further examples for the constraints 'pass target' and 'pitch size' reveal comparatively less representative training environments of 66% and 75% respectively. If desired, a mean value of training specificity across the three example constraints can also be obtained (which in this example is 75%).

Although a relatively simple illustration, importantly this information can be used to assign quantitative meaning to the construct of representative practice (task) design. The more detailed information relating to training constraints that is available, the more detailed an understanding of the training environment's representative design that can be obtained. It should be noted at this point that there are a number of methods in which information relating to each of these three constraints could be collected in the field. These could include common techniques such as observational coding/notational analysis, provision of data from a third party provider (particularly in competition) or using data obtained from wearable technologies such as player tracking devices. Ultimately, the key point is that athlete performance under these conditions can be monitored both acutely and longitudinally.

2.2 Progression

In the skill training context, progression can be defined in multiple ways. For instance, progression can be considered in terms of the actual improvements in skill performance of an individual, which is of course the ultimate metric. However progression may also be considered in terms of an athlete's capacity to complete and tolerate an increased skill practice load. This load can be represented using a number of methods such as an increased practice repetition volume, an increased technical demand, higher practice representativeness (e.g., speed of skill execution closer to match performance) or increased mental exertion. In this context, the notion of deliberate practice [38] is useful to consider. Deliberate practice points to a learner's capacity to develop mechanisms as a consequence of extensive training that expand their processing capacities and in turn their skill development. In terms of progression, Ericsson and colleagues [38] argued that the performer seeking to be an expert is one who deliberately constructs and seeks out training situations in which a set goal exceeds their current level of performance. Importantly to guarantee effective learning, Ericsson and colleagues [38] also suggested that the instructor is responsible for the organisation and sequencing of the practice activities. Additionally, the instructor should be involved in the monitoring of progress to determine when transitions to more challenging tasks are appropriate. While such progression may be incremental, it ultimately leads to meaningful and observable changes in skill performance. Although there has been substantial debate about the relative contribution of deliberate practice to becoming an expert performer [39], the underpinning nature of the practice qualities discussed is pertinent to this review (see more discussion on this issue in section 2.4, Reversibility).

Key factors in setting an appropriate practice goal include consideration of the current skill level of the performer as well as the relative difficulty of the skill to be practised. For instance in football, a short 5 m instep kick to a team-mate is an easier skill to perform than a curved free kick at goal from 30 m. Similarly, a professional footballer is certain to find both kicks substantially easier to perform than a young beginner. In this context, the ‘challenge point framework’ has been proposed as a means of describing the effects of practice and feedback conditions on skill learning [19]. While this framework has gone largely unexplored empirically (see [40] for an exception in a rehabilitation setting), it nonetheless provides a useful starting point for the proposed SAP framework. A key aspect of the challenge point framework is the need to understand the interaction between the information available for a performer to use (i.e., is there too much or too little?) and the actual and relative difficulty of the skill. Once understood an optimal challenge point can be developed that will ensure the athlete progresses. Similarly, the purpose of a given skill practice session also needs to be considered as there are occasions where skill progression is not necessarily the focus. For example, the development of athlete confidence may be the priority which likely will require different practice demands. The actual practice conditions that can influence progression (or the appearance / learner’s perception of progression) are now discussed.

Figure 2 provides an example of how the SAP framework can be used to monitor longitudinal skill progression in both training and competition. By using the common physical training nomenclature of frequency and intensity (or in this case, complexity), the passing load and success of the actions can be obtained respectively. In the figure, an athlete’s total passes for the week have been tracked, with the related passing error also recorded. A more complex (i.e., game-like) training environment is assumed as a proxy for increased error. Intuitively, this concept of progression is easy to interpret based on the physical training literature. For instance, by then multiplying the associated values of frequency and complexity, a corresponding skill load can be calculated (shown as the dark grey line in Figure 2), much in the same way as the commonly-used session RPE method [15, 41-42]. This value can then be used to guide the prescription of skill training loads, based on athlete responses, adaptations and performance. Progression of the player's performance in competitive scenarios can also be plotted on the graph to provide an insight into the efficacy of the prescribed volume. This has been shown as the light grey line in Figure 2 over a training 'mesocycle' (typically considered in the physical training literature as a 4-5 week block of training). Additionally, correlational analysis can be used to investigate relationships between training volumes longitudinally and performance improvements, as has been done in the physical training literature [41-42].

****** INSERT FIGURE 2 ABOUT HERE ******

2.3 Overload

Training load in the physical training domain has commonly been measured using combinations of intensity- and temporal-based measures. This concept is often further refined to include internal training load (ITL) and external training load (ETL) [43]. External load refers to the actual output of an athlete and may include GPS-derived metrics such as metres per minute, accelerations and distances covered or the amount of weight lifted. Internal load constitutes the measured response of the individual to this applied external load and is typically measured via the session rate of perceived exertion (sRPE) or heart rate of an individual [15]. The amount of overload can then be measured by assessing decreases or increases to this quantified load over the period of interest.

For skill training, such concepts are readily importable with respect to the measurement of load. In particular, load is considered both in relation to the impact of the cognitive effort demanded of the performer as well as the volume of practice accumulated.

Somewhat analogous to ITL (in particular the sRPE method), is the concept of cognitive effort [44]. Proponents of cognitive effort argue that cognition plays an important role in the learning of motor skills and consequently how it interacts with the type of practice engaged in by a performer is of critical importance. Cognitive effort is defined as the mental work involved in making decisions that underscore movement [44]. This mental work can be concerned with solving a specific technical issue related to skill execution or processing information to inform decision making in a complex environment such as team sport. In addition to the learning context it has been demonstrated that prolonged periods of demanding cognitive activity (mental fatigue) can cause a decrement in physical performance [45]. Similarly, there is some evidence to suggest that psychomotor speed (as measured by reaction time tasks) can be applied as a measure of over-reaching [46]. Consequently current monitoring approaches in concert with a skill specific RPE could be readily applied to skill training load description and prescription. As it relates to skill acquisition programming, different types of practice have been found to influence the amount of cognitive effort required by a learner and in turn the amount of skill learning that is accrued as a consequence of a given practice session. Yet an athlete’s response to practice load is rarely considered when periodising skill acquisition.

Perhaps the most researched practice construct in regard to cognitive effort or load has been the contextual interference effect (see Magill and Hall [47]; Brady [48]; Barreiros et al. [49] for reviews). In short, it has been demonstrated conclusively in laboratory settings and to some extent in applied settings that practice which promotes high amounts of mental effort (i.e., random practice) leads to suppressed practice performance but superior skill retention and transfer. In contrast, low mental effort practice (i.e., blocked practice) leads to higher levels of practice performance but poorer retention and transfer. For example, a footballer kicking 20 consecutive penalty kicks followed by 20 consecutive corner kicks is considered a blocked practice approach. Conversely, mixing the distribution of these skills across a training session (e.g., 5 penalty kicks, 3 corners, 2 penalty kicks, 5 corners and so on) is considered random practice. The simple re-distribution of practice between two different skills creates an increase in the mental effort required of the learners which confers deeper levels of cognitive processing. This re-distribution leads to more inconsistent practice performance but superior learning of the skill. Application of the contextual interference effect in practice may lead both a coach and the athlete to mistake progression (or lack thereof) due to the manner in which skill practice is organised. Further, such an effect also highlights one of the challenges previously mentioned of measuring skill learning in a fashion analogous to physical performance.

When considered in a periodisation framework, the contextual interference literature is also clear that in early learning an increasingly blocked (low mental effort) practice approach may at times be utilised and even preferable. This is because the processing demands on the learner are already substantial, particularly if the individual is learning a relatively complex skill [6]. As learning progresses, so too should the challenge demanded of the performer; in this case practice can be structured in a more random manner in order to increase the mental effort. Again the challenge point framework [19] discussed in the previous section has been suggested as one potential means of optimising the level of load relative to the learner and the skill being practiced. Similarly, the varying impact of such practice on athlete confidence cannot be ignored and presents another programming challenge for the scientist or coach, further complicating the longitudinal planning and monitoring of skill progression.

Examining the accumulated effects of prolonged practice and the rate of learning has a long history in skill acquisition research [50]. The collective results of such work typically show that performance improves according to a power function (the power law of practice) whereby rapid improvements in skill happen during initial practice but are reduced over time and performers are required to invest progressively more hours to accrue progressively smaller improvements. Also referred to as the law of diminishing returns this work tended to focus on practice volume or time, for example early research suggested there were limited learning benefits when four hours' practice per day was exceeded [51]. The theory of deliberate practice [38] introduced the concept of practice quality to the issue of practice load. While space prohibits an extensive overview of this work a common prediction one can make regarding practice load and quality is that "less is sometimes worth more" if practice is undertaken with sufficient quality. That is, quality means the athlete must be primarily motivated to engage in practice to improve performance and such practice demands attentional effort. A coach must continually program the level of task difficulty so that it matches the current performance levels of their athletes so that plateaus do not occur but rather continually create adaptation to higher amounts of practice (training) stress and, ultimately higher performance [38, 52]. Given the effortful nature of this practice approach coupled with the extensive number of hours required to reach expert levels it is also argued that such practice should be alternated with appropriate time for recovery. If not, additional practice may actually be detrimental to performance.

Other theoretical paradigms (e.g., ecological dynamics) can also be used to explain skill practice and in some respects capture the principle of overload [33]. Whichever theoretical paradigm is adopted, from the practitioner perspective the message is largely similar. Practice conditions should be set such that a performer is sufficiently challenged / loaded and is required to stretch to maintain effective skill performance. Once a period of skill stability or consistency of execution is seen, this is the signal to a coach to change the structure, organisation or information provided in practice to further load the performer. This concept is similar to the approach used in resistance training programs where the sets and repetitions are manipulated as an athlete begins to perform the various exercises with some degree of ease [53].

Figure 3, provides an illustration of how skill training overload can be assessed longitudinally. A number of ways in which load can be defined in skill training was previously discussed (see section 2.2 Progression), from the total number of actions, to the difficulty of a task or athlete-rated cognitive effort. In this example, overload with respect to the proportion of skilled actions undertaken isolating a single constraint is provided. Specifically, the athlete is intentionally constrained by a reduced time period in which to execute passes for a high percentage of all passes executed at training. This restriction is increased incrementally over each week, with the influence of the intervention on the athlete's performance along with their response (cognitive effort) tracked to evaluate its effectiveness. This systematic measurement of skill acquisition ensures appropriate levels of skill specificity can then be incorporated into the training environment in order to facilitate the desired athlete response. As data are systematically collected on the characteristics of sessions, the optimal challenge point for an individual can be defined with greater precision.

****** INSERT FIGURE 3 ABOUT HERE ******

2.4 Reversibility

The principle of reversibility dictates that athletes lose the beneficial effects of training when they cease or reduce such activities [16]. Conversely, it also refers to these detraining effects being reversed once training is resumed. From the skill acquisition perspective, the concept of reversibility highlights the importance of being able to measure the degree of learning achieved in a particular practice phase (i.e., how reversible is the learning). Many coaches find it difficult to apportion a particular practice task or practice phase to the enhancement of a specific skill, as it is difficult to quantify. A common practical issue is forecasting whether the improvement will hold or reverse before the next practice session or competition.

As illustrated throughout this paper regular measurement of the key skills being practiced and application of the SAP framework is argued to provide greater understanding and control of skill acquisition. Coupled with routine observation of skill during practice, the most effective method to assess skill learning is through retention or transfer testing [54]. As implied by the name retention testing examines the skill following a period of no practice (i.e., a retention period). This reveals whether the skill change is permanent and not directly influenced by short-term but transient performance factors such as fatigue or a previous practice session (i.e., reversible). However, the practicality of retention testing in a high performance setting is obviously difficult, given performers may be continuously practising particular skills. The alternative measure of whether reversibility has occurred is through a transfer test. In a high performance context, the ultimate transfer test condition is competition and analysis of whether the athlete can maintain a level of skill performance when under competitive stress.

A complementary research area that could be considered to extend and arguably challenge the idea of reversibility is that of memory consolidation. Evidence suggests that “offline learning” or learning when no physical practice is occurring such as during sleep or rest may play an important role in the process of skill acquisition (particularly as it applies to procedural/motor-sequence learning) [55-56]. While debate exists as to the theoretical model that explains the impact of sleep or a period of no practice [57] for the purposes of this review it is pertinent to acknowledge that “recovery” whether sleeping, napping, or simply breaking from physical or mental practice of skill is likely to be beneficial to overall skill progression. While applied research in the sport domain is yet to be undertaken, the deliberate practice literature has frequently highlighted the importance placed on napping or sleep in the practice routines of expert performers [38].

Just as the influence that incremental overload exerts from week to week can be assessed, so too can the effects of reversibility. Figure 4 provides a related example of reversibility. Given the crowded nature of most high performance programs it is a necessity to prioritise the practice of particular skills over others throughout a preparation period. The collation of data (Figure 4) provides the coach/scientist with a clear indication of when the effects of reversibility are becoming apparent. Scheduling of further practice of the neglected skills at this time can then be systematically re-introduced to the overall training program. Similarly, such routine monitoring of skill performance can provide insights into the durability of particular practice approaches and scheduling methods that manipulate practice and rest.

****** INSERT FIGURE 4 ABOUT HERE ******

2.5 Tedium

Tedium is a state of being bored due to monotony and is considered detrimental to any training program. Consequently tedium is to be avoided through the intentional alteration of one or more program variables in order to provide an optimal training stimulus [53]. In the physical training literature, increased training variety in both the short and long term has been linked with comparatively greater improvements than when using non-variable methods [7, 58]. Within the skill learning domain a popular mantra borrowed from the work of Bernstein [59] is that of "repetition without repetition". The phrase was used by Bernstein to summarise his theory of motor skill learning where he argued that movements are inherently variable and complex by nature and consequently no two movements will ever be exactly the same. A pattern of muscle excitation will cause different patterns of limb and body movements when a performer encounters varying circumstances in its environment [60]. Sport provides a terrific example of this phenomenon. Concomitantly, it is futile to attempt to practice or train in a manner whereby the aim is to "imprint" a specific movement pattern such as through the use of highly monotonous and repetitive practice. Hence, Bernstein argued that practice should be focused on repeating the means of solving the problem, rather than simply trying to repeat the solution (i.e., variety over tedium).

Inspection of skill training in sport is replete with examples that contravene Bernstein's position. An example is the use of guidance devices such as those employed in golf to constrain a movement to fit within a desired "perfect" technical model and then "groove" the particular swing pattern (see Glazier [61] for a review). Such devices are most commonly used in the early stages of learning in order to get a learner into a movement pattern bandwidth. However, it is argued that it is more beneficial for a learner to explore their movement 'repertoire', investing in greater mental effort or being placed in an information rich performer-environment practice setting. This is preferred to passively conforming to a pre-determined movement pattern that may not actually suit the learner's own organismic constraints such as strength, height, flexibility and power.

A continuum of variety can be offered to an athlete so that the skill challenge is able to be periodised in order to maximise learning. A variety of skill practice approaches have been examined, again from differing theoretical constructs that all, in essence, can be argued to highlight the importance of providing variety to offset the detrimental effects of tedium. While it is beyond the scope of the current paper to detail each of these approaches, examples include the previously reviewed contextual interference approach [47], variability of practice hypothesis [62] and 'differencial' training [63]. Importantly, while suggestions exist from this literature regarding what is an appropriate degree of variety (variability) for a particular level of performer there is little guidance on how to periodise this within the context of a longitudinal skill development plan.

Protecting against tedium can be undertaken from a range of perspectives. For instance, the amount of variety can be manipulated in a single training session or longitudinally across a training block. Two of the most pertinent ways by which this principle can be considered are through the execution of skill-specific variations or via an increase in the variety of environmental conditions experienced. In the football example used in this paper, skill-specific variety could be increased by a contextual interference approach as described previously (see section 3.1 Specificity) or by the adoption of a 'differencial' learning approach [63]. In this practice approach the same skill is practised during the session, however each repetition demands a slightly different method of execution. For example, a soccer penalty kick is performed using a different approach to the ball on each occasion (e.g., skip toward the ball-strike, run, walk, no step at all etc.). It is argued this process encourages exploration and pick up of information about the stability of a skill which, in turn, may enhance skill acquisition and performance [64].

Notwithstanding that all skill execution is coupled to the environment in which it is performed, the other useful constraint to manipulate is the conditions surrounding skill execution. Specifically, different features of the environment can be manipulated to challenge the tedium of an activity. For instance, again considering the football kick, the density and complexity of playing numbers / space around the kicker, the time available for disposal, whether the play is structured or unstructured can be all be systematically adjusted to increase variety and reduce tedium. This principle can also be expressed statistically, using a common variability metric to quantify the extent of the variety (i.e., a higher coefficient of variation in the types of skill practiced at training would equate to increased variety). There are clearly a number of methods available to increase variety and the consideration of a framework to guide such decisions can be of value. The manner in which a sample of these variations can be considered is shown as a ‘tedium/variety continuum’ in Figure 5.

A final approach that can be implemented to offset tedium relates to the level of athlete engagement demanded by the practice activity. As argued by Ericsson and colleagues [38], a high level of engagement is fundamental to a sustained level of quality practice. More recent work typically completed in the motor learning domain has demonstrated enhanced skill acquisition if a learner is provided some form of control over their practice [65]. Such work has typically studied learners rather than high performance athletes who are likely to possess a different level of engagement to begin with. However, the concept of allowing athletes to take control of an aspect of practice whether it be when feedback is provided, the amount of practice repetitions completed on a given skill or the order in which key skills are practised is argued to meet a basic psychological need [66] and in turn becomes a useful strategy to overcome tedium. An important caveat is that the choices made by the athletes need to be regulated relative to the principles detailed throughout this paper. Clearly, this is where the art and science of planning and periodising skill acquisition come to the fore.

****** INSERT FIGURE 5 ABOUT HERE ******

3. Conclusions

Using the physical training literature as a reference point, this paper developed a periodisation framework for skill acquisition in high-performance sport. Supporting evidence is provided for the adoption of the previously reported SPORT framework for use in a skill acquisition context. Whilst there is considerable overlap between the concepts investigated in physical training and skill acquisition research, the latter is yet to formulate this into a framework suitable for practical use. Often, skill training is afforded a simple time allocation in such models, without delving deeper into the intricacies of this area in the same manner as is done with physical work. It is suggested the application of such a model would provide both the practitioner and scientist with a framework on which to make systematic changes to skill performance and learning in athletes longitudinally.

One potential drawback of the method relates to the sheer type and number of constraints which are experienced by athletes in a training situation. Not only are some of these difficult to measure, but the manner in which they interact requires complex analysis. However, it is hoped that this complexity provides the stimulus required to invite inter and multi-disciplinary collaboration in this area, which has been identified as needed for over 20 years [24]. To this end a range of meaningful research questions are yet to be thoroughly investigated and become more pertinent when underpinned by such a framework. These include:

- How can the periodisation of skill training be used to elicit a sustainable performance improvement? For example, how do condensed, high volume and intensity periods of training differ with respect to the response they elicit in comparison to sustained, low volume interventions?
- How reversible is skilled performance under sustained periods of limited or no training?
- What is ‘acceptable’ variability with respect to longitudinal skilled performance in training and competition?

- Can wearable technologies be harnessed to collect skill performance information on athletes in an automated fashion? This would reduce the human burden of observational coding and notational analysis.
- Can other physical training concepts such as monotony (the mean training load of sessions undertaken during a week divided by the standard deviation) and strain (the sum of the weekly training load multiplied by monotony) [6, 67] be incorporated into the model?

Compliance with Ethical Standards

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Conflict of Interest

Damian Farrow and Sam Robertson declare that they have no conflict of interest relevant to the content of this review.

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