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K. Anders Ericsson, Deliberate Practice, and Sport: Contributions, Collaborations, and Controversies

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Abstract

In this review paper, we reflect on the work of K. Anders Ericsson and how his Deliberate Practice Framework (DPF: Ericsson et al., 1993) has particularly impacted the field of sport expertise and athlete development. We review the major tenets of the framework, including areas where there is indisputable evidence for the value of deliberate practice. We address the state of findings attesting to the mechanisms underpinning the expert advantage and their relevance to the DPF, and consider the growth in research addressing the motivational, effort and resource constraints of the framework. We document the evolving facets of, and incongruencies in, research, as well as lively debates around the operationalization of deliberate practice, whether deliberate practice is sufficient to account for sport expertise, and the role of individual differences and heritable qualities. Altogether, we acknowledge the importance and provocative nature of the DPF, recognizing it as a meta-framework that can continue to inform dialogue in the fields of skill acquisition, talent development and coaching, and notably, mark the considerable contributions made to our field by K. Anders Ericsson.

Keywords

Expertise; training; athlete development; skill acquisition; talent

Introduction

In June 2020, like many scientists across a broad range of fields, those of us interested in sport expertise were shocked and saddened at the passing of Karl Anders Ericsson. In this article, we contextualize his impact on researchers interested in sport expertise and its associated fields of skill acquisition, talent identification, and coaching. In this review, we highlight several areas where his contributions to sport are indisputable, and outline the key insights derived in our many interactions with Anders over several decades. We delimit the scope of our article by focusing on his contributions, directly and indirectly, to psycho-motor and psycho-social studies of sport expertise and talent development.

We begin by describing his formative works that gave rise to the *Deliberate Practice Framework* (DPF), as articulated in Ericsson et al. (1993). In reviewing the evolution of the DPF, we address the methodological directives in his Expert Performance Approach to empirically decipher an expert advantage (Ericsson, 2003; Ericsson & Smith, 1991) and the merits of his think aloud protocol (Ericsson & Simon, 1984) for studying cognitive processes and memory representations.

This review focuses on his direct impact on a lineage of studies exploring the nature of *deliberate practice* (DP) in sport. After 25 years and 11,000 citations (Google Scholar, February 2021), the notion of DP is central to discussions of athlete development and skill acquisition. We attempt to synthesize the scientific consensus (or lack thereof) on what DP is, and we interrogate the nature of the research focusing on the tenets underpinning the DPF and evidence for the consequences of DP in sport. Ericsson's works stimulated scholarly debates on the conceptualizations and characteristics of quality practice and resurrected dialogue about the boundaries of a nurturistic talent paradigm. We discuss the merits, limits, controversies and tensions deriving from works on DP in sport and identify unfinished business where more work is needed to either confirm, modify, or nuance the DPF.

Conceptual Foundations of the Deliberate Practice Framework

The relationship between time spent in practice and skill development is one of the oldest topics in psychology (Bryan & Harter, 1899). In now classic studies, Book (1925), Snoddy (1926), and Crossman (1959) focused on relatively simple motor tasks (e.g., typing, cigar-rolling, mirror tracing) and emphasized the strong positive relationship between time spent practicing and performance. Simon and Chase (1973), however, argued for the primacy of practice for highly skilled task performance. Their investigation of master, intermediate, and novice chess players reported that individual performance differences were limited to skills resulting from experience, rather than reflecting general information processing capacities. More specifically, skilled chess players were better able to speedily recognize and reconstruct patterns of chess play that had meaningful structure learned via training, but this was not true for randomly arranged patterns of chess pieces on a board, which would depend on general memory ability. Extending this work, Chase and Ericsson (1982) charted the skill acquisition of a single undergraduate student (SF) for a memory recall task. Over a 20-month period, SF was able to progress from basic recall processing limits of short-term memory to being able to recall up to 80 digits of randomly generated strings of numbers. The authors concluded that improvements in performance were due to changes in the structure of the acquired skill resulting from the time SF spent engaged in the effortful and focused training intervention. In the book *Peak*, Ericsson and Pool (2016) recounted how this intervention epitomized "deliberate practice."

In a study of members of the Music Academy of West Berlin, Ericsson et al. (1993) developed their argument for the importance of what they termed "deliberate practice." Their investigation revealed no differences among musicians of different skill levels on generic information processing tasks, such as measures of movement speed and accuracy, but superior performance by highly skilled performers on domain specific measures, such as a musical interpretation task. They explained these differences by time spent in DP, which were activities reported by musicians as highly relevant for improving performance, as highly effortful, that were not undertaken for immediate personal, social/financial rewards, but for longer term gains in skill. This initial exploration formed the basis of the DPF, which the authors contended could represent a generalizable approach to the acquisition of expertise. Its foundational assumption was that between-group differences in skilled performance, as well as intra-individual differences in performance, could be explained by the amount of DP accumulated over time.

Ericsson et al. (1993) contended that the time needed to achieve expertise was constrained by an individual's capability to navigate three types of constraints: (1) *motivation*, or the appropriate type and amount of motivation to drive training for an extended period; (2) *resources*, or the access to necessary resources and supports such as instructors and equipment to maximize skill development; and (3) *effort*, or the appropriate circumstances to support the high degree of exertion (often both cognitive and physical) required for maximal training adaptations and the continuity of repeated hard efforts training over long periods of time.

The initial DPF articulation drew heavily on research focusing on the marked plasticity of memory performance (Chase & Ericsson, 1981, 1982; Ericsson et al., 1980). This research highlighted the importance of DP in expanding working memory and in developing refined representations to support exceptional performance. Ericsson (2003, p. 55) later reiterated that "cognitive mechanisms" mediate examples of superior memory performance, a position aligned with Ericsson et al.'s (1993; Study 2) contention that perceptual-motor processing mechanisms mediated expertise in musicians. Thus, superior performance could be understood by empirically assessing adaptations to mental representations and exceptional refinements to information processing mechanisms, allowing experts to circumvent processing limitations (see Ericsson & Smith, 1991). The "terra firma" of the DPF was grounded in standard explanations and methodologies from cognitive psychology from the information processing era.

In both the 1993 article and later (Ericsson, 2003), Ericsson adopted a broader view of limits to performance improvement, contending that other types of mediators, including "a whole range of extraordinary physiological processes" (p. 55), could be affected by DP over long periods of time. Thus, Ericsson argued that not only could the principles of DP be used to enhance cognitive function but could explain the development of other aspects of performance such as physiological and technical aspects of sport performance.

Empirical Support for the Deliberate Practice Framework from Sport

Time Spent on Deliberate Practice

A recent review (Baker et al., 2020; see also Baker & Young, 2014) noted 33 separate sport studies directly testing elements of the DPF. These studies typically focused on accounting for time spent in training and how it could explain skill group differences. These studies generally adopted retrospective recall surveys to document the career trajectories of athletes. Findings from the vast majority of the studies supported a central tenet of the DPF; that is, time spent in DP, or proxy measures representing DP, reliably differentiates skill groups. Plots of career trajectories showed that time spent on DP increases monotonically (i.e., constant increases at each successive developmental stage), which indicates that eventual expertise depends on athletes increasingly accommodating more demanding practice over time (Baker & Young, 2014; Starkes, 2000).

On Cognitive and Information Processing Mechanisms Mediating Exceptional Performance

Substantial research supports Ericsson and Kintsch's (1995) proposition that experts develop mental representations and memory systems that convey an advantage over less-skilled counterparts. The expert advantage is mediated by elaborate and refined domain-specific mental representations that expedite the planning, execution, and evaluation of crucial sport tasks (McPherson & Kernodle, 2003). A principal source of evidence for the role of these mediating representations has been the thoughts verbalized as experts perform crucial tasks representative of their domain, with the assumption that the verbalized thoughts represent the information to which individuals have attended in working memory during performance (Ericsson & Simon, 1984). The think aloud articulations of experts are greater in quantity and richer in quality than those of less-skilled performers, highlighting their more numerous, elaborate, and refined mental representations (Arsal et al., 2016; Eccles & Arsal, 2017; McRobert et al., 2009, 2011; Shaw et al., in press). Scientists have established that experts have more sophisticated knowledge in their specific domain, which leads to superior performance in both perception (i.e., diagnosis and reading the field, interpretation of game situations), decision-making (e.g., McPherson, 1999) and action (e.g., Arsal et al., 2016). For example, McRobert et al. (2009, 2011) contended that expert cricket batters have exceptional capabilities for updating representations related to ongoing changes in bowling conditions (features of the bowler's action and style) during repeated at-bats, which facilitate their adaptable performance.

Although there has been evidence to reliably infer experts' advantage in terms of long-term working memory (LTWM), Ericsson and Kintsch (1995) proposed more fully that *extended, focused practice* leads to these exceptional adaptations to LTWM. Regrettably, there has been a lack of studies associating experts' scores on metrics for the central causal mechanism of the DPF (i.e., the practice mechanism) with their scores on tasks representing key cognitive and information processing mechanisms (i.e., performance mediating mechanisms). Only a handful of studies have effectively discriminated elite from non-elite players based on tasks representing cognitive and information-processing mechanisms, *and* also examined the co-occurrence of whether these skill groups differ for past amounts of practice (Berry et al., 2008; Roca et al., 2012; Weissensteiner et al., 2008; Williams et al., 2012). The results generally show that higher skilled groups show an advantage for past structured preparatory activities in their particular sport, typically involving cumulative measures of sport-specific practice and/or advantages for cumulative past, unorganized, sport-specific play. Only two studies have treated scores for cognitive and information processing measures for valid representative tasks and amounts of sport-specific practice in the same regression analyses. Roca et al. (2012) examined young adult soccer players employing a task that validly represented differences in anticipatory decision-making between high and low performing semi-professional players and recreational players. They regressed test scores for the perceptual-cognitive task on data for various sport activities that players recalled accumulating during childhood and adolescence. Soccer-specific practice (a proxy variable for DP) during adolescence explained 13% of variance in scores on the perceptual cognitive task, though when soccer play accumulated during childhood was added hierarchically, 22% of variance could be explained and the contribution of practice was nullified. Weissensteiner et al. (2008) examined under-15, under-20 and adult cricket batsmen on valid representative tasks for anticipatory skill. They regressed scores for tests involving the prediction of location and length of an arriving ball on data for participants' past practice histories. Hours accumulated in organized cricket were found to account for 13% and 11% of the variance in bowl type (i.e., outswinger or inswinger) and bowl length (discriminating whether an arriving ball would be a short-length or full-length delivery, at moment of visual occlusion) prediction skills, respectively. The investigators noted the contribution of organized cricket activity was modest, which may be due to their admission that their organized activity variable included a mix of many types of training activities related to competitive, individual and group sessions and was not meant to represent DP.

The absence of other works is disappointing given that in his Expert Performance Approach, Ericsson (2003) contended the following: (1) investigation of performance mediating mechanisms requires the essence of expert performance in a domain to be validly assessed with representative tasks; (2) *importantly*, researchers must also assess "whether different types of….practice activities explain the acquisition of these mechanisms and whether expert performers engage in these activities during the development of their performance" (p. 57). More of these works are required, with a particular emphasis on multiple representative tasks in any one sample as well as collecting and treating metrics for DP and not some other organized, or structured, or sport-specific variable. This would allow more rigorous testing of the nature of an expert advantage with respect to perceptual-cognitive adaptations, *specifically as it relates to testable aspects of the DPF*.

Other Contentious Issues and Underexamined Facets

The Operationalization of Deliberate Practice

Although most researchers agree that an especial form of practice leads to greater skill gains than other forms, there is much debate about how a valid metric for DP should be defined. Early efforts in music (Ericsson et al., 1993) and in sport relied on judgments of activities as being relevant for improving performance, highly effortful, and comparatively less enjoyable, but this approach has proven problematic and unreliable (see Baker et al., 2020). One consequence of the sport research is that conceptions of DP as a primarily solitary activity (e.g., in music, Ericsson et al., 1993, or academics, Plant et al., 2005) have been stretched to consider social learning venues (e.g., team practice), interactions with a coach (e.g., Helsen et al., 1998; Hodges & Starkes, 1996), and/or competitive events (Janelle & Hillman, 2003).

In the absence of a consensual metric for DP, a more open-ended approach has been employed. Macnamara et al.'s (2016) meta-analysis of DP research in sport described a broad net of classifications of practice activity that were submitted to analyses. They found, based on these highly variable metrics, very small effects attributable to DP. Ericsson (2016) refuted their findings, contending they included many broad, ill-defined DP metrics. The consequence was to illustrate significant deficiencies in methods for validly assessing DP. There is exceptionally large variance in values representing DP (Baker & Young, 2014), even within studies in single sports, suggesting issues with reliability. In recent years, Ericsson spoke of the need for an instructor/coach to be attached to DP (Ericsson, 2020), and presented purposeful practice, which does not include an instructor or coach, as being potentially distinct from DP (Ericsson & Pool, 2016). He also argued that only domain-specific methods could capture the essence of DP, such that self-report methods would need to validly understand DP in each distinct sport sample (e.g., swimming, tennis) with no possibility of collapsing samples across sports (Ericsson, personal communication, May 2016). These narratives did not necessarily help focus the operational definition or resolve methods that could be ascribed to a generalizable framework.

Another challenge to operationalizing DP is that maximal skill acquisition requires learners to adapt the constituents of DP over time, based on performance level and updated profiles of their skill repertoire (Ericsson, 2003). Very little research has looked at the changing microstructure of athletic DP (cf., Ford et al., 2010), with most using retrospective recall (Starkes, 2000), with little regard for the rationale or meta-cognitions informing such changes.

Self-Regulated Learning Correlates of Deliberate Practice

Researchers have turned to conceptualizations of self-regulated learning (SRL) to understand DP in sport. Self-regulated learners are motivationally, behaviourally, and meta-cognitively engaged in the design and engagement of their own practice activities (Zimmerman, 2006). Aspects of SRL are associated with quality training activities and efforts (Toering et al., 2011; Young & Starkes, 2006). SRL epitomizes conscious attention that learners devote to goals and intentions at practice, the monitoring of efforts, activity and outcomes, their self-reflection on training activities and results, and the process by which they make adaptive inferences they can apply to future practice efforts. SRL skills have been conceived as competencies that can be refined over time to optimize practice (McCardle et al., 2018; Young & Medic, 2008).

Using self-report surveys, SRL responses relating specifically to "reflection" have been shown to distinguish between expert and less-expert groups of athletes (Jonker et al., 2010, 2012; Toering et al., 2009, 2012). Specifically, more expert athletes have agreed to greater use of self-reflection. SRL processes, collectively, have reliably distinguished escalating skill groups of North American athletes, as have other specific processes/subscales like "self-monitoring," "planning," "evaluating-reflecting," "effort," and "self-efficacy"

(Bartulovic et al., 2017; McCardle et al., 2019; Wilson et al., in press). Young and Baker (2017) postulated that SRL mediates the association between DP and skill acquisition, and since noted that SRL metrics could represent important correlates of DP (Bartulovic et al., 2018). The merit of this SRL research is it accentuates the “deliberateness” of practice, with a focus on the athlete.

On the Topic of Mediating Mechanisms

Cognitive and Information Processing Mediators

Although there exist some efforts to study the extent to which experts and novices differ on cognitive adaptations akin to those proposed by Ericsson and Kintsch (1995), little sport-related research has been informed by these concepts (for a review, see Eccles, 2020). Further investigations are needed of how these representations develop over time, using longitudinal designs of performers in different types of activities. Eccles (2012) proposed complementary *in vivo* and *in vitro* approaches involving think aloud protocol and analyses of mental representations. *In vivo* would entail regularly testing athletes (e.g., twice yearly), as they increase their skill level across their careers, by asking them to think aloud while performing representative tasks in the ecologically valid context (Harris et al., 2020). *In vitro* would entail novices being assessed as they engage in laboratory-based practice over shorter time periods (e.g., months) on standardized tasks (e.g., golf putts), akin to the memorization protocol of Ericsson et al. (1980).

Other elements require exploration. For instance, Ericsson and Kintsch (1995) proposed experts are more apt to demonstrate superior performance in challenging situations that require them to apply their sophisticated domain-specific mental representations, a notion that was explored in sport by Arsal et al. (2016; see also Eccles & Arsal, 2017). In their study, expert and novice golfers thought out aloud while attempting short and long/challenging putts, with thoughts coded as either relating to “mechanics” (i.e., concerned with body and putter movement) or concerned with assessing “strategic putt properties” (e.g., diagnosing break) and determining the appropriate response. Arsal et al. found experts showed more effective cognitive control of ongoing performance, mediated by more elaborate strategic properties and generally more articulations, under the most challenging circumstances.

We question whether Ericsson and those in his wake did enough to explicitly marry methodological instructions for the Expert Performance Approach (Ericsson, 2003) to the conceptual tenets of the DPF. Such instructions, while labour intensive and challenging for any one study, would have been helpful for fulsome testing of the cognitively informed mediating mechanisms of the DPF. To faithfully follow Ericsson’s instructions means that any study dedicated to investigating the DPF should endeavour to test associations between DP metrics and scores representing mediating mechanisms, on a within-person basis (e.g., see Ericsson et al., 1993; Study 2 in music).

Extending beyond Cognitive Mediators

The DPF focuses on cognitive and memory representations involved in learning but has not sufficiently addressed other forms of learning. These other forms of learning, including implicit learning and learning via manipulation of environmental task constraints, suggests there may be mediating mechanisms that are less explicit than those suggested by Ericsson. There exists research suggesting athletes can learn implicitly, without attention directed to facets of a task, with little knowledge of rule structures governing mechanics of movements, and with only very broad scaffolding from a coach (Masters, 2000). Abernethy et al. (2003) considered whether such implicit learning, may be the norm, and explicit learning like DP, actually the exception, for the acquisition of movement skills. Other researchers have suggested that learners can refine complex motor skills in dynamic and unconscious ways as constraints and conditions change in their surrounding environment, with little to no cognitive address of cues or schema/ representations (Pinder et al., 2011). If less explicit forms of processing are essential to skill acquisition on the road to expertise, researchers may need to consider such links and what they mean for the DPF.

Another potential challenge is that the focus on explicit learning and overt attention required for DP may not be easily reconciled with the automaticity of expertise needed in competitive performance situations (Abernethy et al., 2003). The problem is, if one necessarily turns explicitness on during training, how do they necessarily turn it off during competition (Baker & Young, 2021)? Literature suggests explicit learning can leave elite athletes susceptible in competitive arenas where they are pressured (Masters & Poolton, 2012). One query the DPF has not responded to sufficiently is whether DP possibly creates a habitual form of explicit, cognitive processing of one's actions that could impede the free-flowing, automatic processing and execution required of expert competitors? In future, researchers need to examine when and how experts transition from explicit to automatic processing in service of learning and competitive application, respectively. For example, Arsal et al. (2016) distinguished between lower-order aspects of motor control, which are often automatic following extended DP, and higher-order strategic aspects of conscious control. Additional work is needed to model transitions between, and situated applications of, these levels of processing.

Finally, and controversially, Ericsson extended his discussion of the DPF and its mediators beyond cognitive and information processing mechanisms, to accommodate physiological adaptability. Although he went to lengths to note parallels between literature on cognitive plasticity and physiological adaptation (see Ericsson et al., 1993; Ericsson, 2003), these discussions were curious. The arguments and evidence for cognitive outcomes were strong, yet the leap to attributing DPF tenets to explain more biologically constrained outcomes (e.g., speed, endurance) may have been too great for some. In the context of contemporary science's increasing disciplinarity, the DPF felt unconventional in attributing causal mechanisms that spanned behavioural, psychological, and biological sciences. Altogether, the DPF faces challenges in accounting for non-cognitive or non-information-processing related mechanisms and feels vulnerable in its account of physiological adaptation. The trainability of physiology and adaptability of biological facets cannot be denied, however, there appears to be strong evidence for heritable constraints on many such qualities (e.g., muscle fibre type, VO_2 max, height and limb length).

On the Sufficiency of Deliberate Practice?

Perhaps the most controversial element of the DPF is the question of whether time spent in DP is "sufficient" to explain a performer's level of attainment (Campitelli & Gobet, 2011; Tucker & Collins, 2012; c.f. Ericsson, 2007, 2013). In studies of chess, Campitelli and Gobet (2011) claimed that, although DP is clearly necessary, it is not a *sufficient* condition to achieve expertise. This claim found apparent traction in sport with Macnamara et al.'s (2016) meta-analysis of 34 studies, in which DP amounts accounted for 18% in sport performance in mixed-sport samples and *only* 1% in elite sporting samples. Hambrick et al. (2014) pointed to tremendous variability in individual amounts of DP required to reach expert status, from which they inferred that not all individuals benefit from DP equally, with benefits depending on biological/genetic capacities existing within the person prior to the effects of training. Although it was not in the sporting domain, findings from a recent study by Macnamara and Maitra (2019) advocated that amounts of DP are insufficient. The researchers aimed to replicate the results from Ericsson et al. (1993) with the Cleveland Institute of Music. However, they could not prove that time spent in DP could largely account for skill group differences, found reduced effect sizes attributed to amounts of DP, and reported anomalous trends where intermediately skilled musicians had more DP than the experts. This was the case when they analyzed data representing DP alone (by oneself) and data representing teacher-designed DP.

Speaking broadly about the DPF, not specifically on sport, Hambrick and Meinz

(2011) also introduced criteria by which they suggested DP was not sufficient. First, they contended that general abilities could predict expert skill levels above and beyond cumulative DP. Second, they contended that domain-specific knowledge (attributed to DP) could not eliminate the contribution of basic working memory capacities to performance on complex domain-specific tasks. In sport, scientists have not yet substantially tested these criteria, though some work has shown that expert soccer players could be almost entirely discriminated from intermediates based on domain-specific processing tasks and not by general processing abilities (e.g., see Helsen & Starkes, 1999; Ward & Williams, 2003).

Still, critics have resurrected dialogue pertaining to the importance of general abilities. For example, Ackerman (1987) demonstrated the contribution of abilities in early learning of complex perceptual-motor tasks and how they decline (but do not necessarily disappear) in later expert performance. Ackerman (2014) clearly articulated that abilities have a position in the explanation of the highest sporting talent and described how empirical evidence to support this view was lacking within the DPF because of methodological biases and restricted sampling methods. In response to these types of criticisms, Ericsson (2014) contended that in expert performers who have reached levels obtained "by less than a handful of individuals" (p. 100), the role of abilities would be negligible. Ackerman (2014) described extreme environmentalist and extreme innate views on expertise as absurd and untenable, calling for empirical study of the interplay that abilities/traits may have with developmental factors. Seeking greater clarification from proponents of the DPF, he accentuated the need to examine factors related to early childhood interests and talent early in the developmental trajectory, critical periods of development (e.g., when individuals may be more plastic), the influence of individual differences in motivational capacity, as well as selection biases that preclude individuals from the talent pool at successive developmental stages. He also noted that proponents of DP have not satisfactorily accounted for differential acquisition functions (or learning curves) among athletes.

These critical works questioning "sufficiency" ultimately draw attention to whether boundaries need to be placed on the DPF, or whether there needs to be greater attention paid to individual difference variables (abilities, capacities) and their interplay with DP. The latter perspective suggests treating abilities as complementary explanatory variables, and dynamic moderating variables over time, provoking consideration of an "abilities" constraint within the DPF. To do this, however, would require collaborative works in a domain where Baker and Young (2021) lamented the fracturing of researchers into different scholarly camps depending on their affinity to DPF tenets. This said, no one conceptual model is meant to explain everything; such a model is neither supportable nor falsifiable (Baker & Young, 2021). Thus, perhaps more precision is needed in the methods and designs researchers use to capture the variance of any testable model related to the DPF, and to optimize our understanding of DP-related factors. In other words, future researchers might wish to accept "the DPF within its bounds as an environmental perspective" (Baker & Young, 2021, p. 26) and focus on improving the internal validity of methods to better inform aspects that can be reasonably manipulated to serve elite athlete development.

As a final note on sufficiency, researchers in the field of expertise may need to reconsider the relevance of traditional indicators of significance and validity. For instance, the 1% difference in elite-level performers attributed to cumulative DP in Macnamara et al.'s (2016) meta-analysis is seemingly very low. However, in a group that is highly homogeneous on many variables, this small amount of variance may be very meaningful. In Olympic 1500 m running, for example, it amounts to the difference in the semi-final heat between the fastest qualifying time for the final and the 20th fastest semi-final time, which missed qualifying by 10 spots. Thus, we may wish to rethink over-reliance on traditional markers for interpreting "effect size," as they may need to be unique to the context of elite sport.

What About Time Spent in Play and Sampling?

There is also the question of whether playing at sport can serve as a form of preparation that facilitates skill acquisition within the DPF. Proponents of "deliberate play" (e.g., Berry et al., 2008; Côté et al., 2007) have suggested it directly contributes to skill development at younger stages and contributes latently by setting the foundation for internalized perceptions of fun that help athletes through more difficult training later in their trajectory (Hornig et al., 2016). Ford et al.'s (2009, 2010) investigations with elite soccer players suggests that cumulative amounts of soccer-specific play may more robustly discriminate eventual skill groups than cumulative structured specific practice. Furthermore, in sporting roles that require motor creativity or tactical improvisation, deliberate play may be an important type of activity needed to reach the highest performance levels (Memmert et al., 2010). Some researchers have proposed that adaptations and acquired mediating mechanisms underpinning expertise in a target domain (e.g., soccer) can be refined by, or transferred from, sampling other sports (e.g., athletics, cycling, tennis), especially sports that share similar attributes (Berry et al., 2008), which may reduce the amount of requisite DP needed to reach expert status (see Baker et al., 2003). Ericsson never did explicitly locate play or sampling within the DPF.

Finally, one of the legacies of the DPF is a wave of research examining the value of sport diversification (or the sampling of multiple sports) versus sport specialization, when athletes are younger. DP has become the foil against which academics studying positive youth development and youth sport burnout interrogate the consequences of hard sport practice and intensive involvement at a young age. Unfortunately, thoughtful discussion of the potential costs and benefits of specialized versus diversified training has been largely lost in an expansive rhetoric, devoid of nuance, which pre-concludes specialization is "bad" in the absence of clear supporting evidence (Baker et al., 2021). Moreover, no one has questioned the seeming practice of discussing specialization and diversification as dichotomous when sport activity is likely more fluid and varying along a continuum. Despite the prominence of anti-specialization messaging in many models of athlete development, there are important open questions to be addressed empirically. Specifically, is early intensive engagement in a single sport beneficial for future expertise provided it does not preclude recreational involvement in other sports (Ford et al., 2009), and can the potential risks of specialization be mitigated through more appropriate program design such as emphasizing autonomy-supportive contexts (Larson et al., 2020)?

Merits of the Framework

We now outline the relatively indisputable and lasting merits of the work on the DPF. The DPF has helped refocus interest on practice and particularly the notion that not all practice is equally effective. Scholarly works highlight how practice needs to be purposeful, challenging and focused on areas of weakness to optimize skill acquisition and avoid arrested development. Although much of the research we have reviewed has sought to categorize types of DP activity, or document "how much" activity, the preeminent legacies of the DPF are: (a) the meaning and instrumental value of quality practice activity for acquiring exceptional levels of skill; and (b) ongoing questions about the "attributes of quality practice." Consequently, researchers have been able to re-frame discussions to position the athlete, with a lens on experiences around training, as the primary vehicle driving performance development. It has put renewed emphasis on the role of the developmental environment, especially with respect to the role of the coach, the importance of a supportive family and supportive resources, for maximizing opportunities for DP. There has been renewed emphasis on the coach as a critical asset in manipulating task constraints and for ensuring appropriate instruction and intervention during DP.

The DPF articulated, more clearly perhaps than ever before, the lengthy time courses involved in elite athlete skill acquisition. Setting up "the more DP accumulated the better" as the main consideration positions issues like training, effort and motivation over long-term developmental horizons. Consequently, the DPF has become a meta-framework from which researchers can consider the role of various smaller constructs such as sport commitment, self-regulation, and self-efficacy as they relate to optimizing practice. The DPF has also given birth to a lively debate on the need for early or more gradual specialization across career trajectories, which has implications for sport programmers and decisions in talent development systems.

Finally, no one has ever challenged the pertinence of the motivation, resources, and effort constraints for framing studies of the conditions and circumstances that curtail/support the central tenets of the DPF. This may be because relative attention has been focused on other conceptual aspects of inquiry; alternatively, it may be because these three constraints very adequately and parsimoniously provide scaffolding for appraising the ambient, contextual, or ecosystem aspects of sport expertise development. In this manner, the DPF offers a meta-framework for understanding more direct causal mechanisms related to DP and training, as well as more indirect personal and social-environmental conditions that afford, limit, or facilitate development over time.

Other Unfinished Business: Future Research on DP in Sport

Making Sense of Key Aspects of Constraints

The Motivational Constraint

Two notions are attached to the motivational constraint; first, athletes should find DP relatively unenjoyable and taxing and therefore should have to recruit high levels of motivation to engage in it; and second, athletes are likely motivated by the anticipated outcomes they believe may derive from DP. There has not been much testing of these ideas, and dialogue remains inferential (e.g., if experts clearly have to do that much training, over that many years, then they clearly must be motivated), or beholden to phrases such as experts have a "rage to master" (Winner, 1996). Although several motivational frameworks are pertinent to understanding the DPF, including sport commitment, achievement goal orientation, and competence motivation models (see Young & Medic, 2008), there is a remarkable absence of studies associating an expert advantage to motivational facets of DP.

The work that has borrowed a sport expertise lens has been exploratory. Hendry, Crocker et al. (2019) longitudinally tracked elite soccer players from under-13 and under-15 categories across two years. Self-determined motivation scores decreased from under-15 to under-17 years of age. In contrast to age-matched, non-elite peers, elite players had higher autonomy scores. The results suggested elite developing athletes have varying motivational regulations, have higher self-determination overall than less-elite peers, but that controlled motives increase over time in the elite developmental trajectory. Although Young et al. (2015) demonstrated that "deliberate practice efficacy" is a pertinent construct, analyses have yet to show how it discriminates experts from non-experts and predicts amounts of practice (LaForge-Mackenzie et al., 2016). Based on the idea that DP demands delayed gratification (Côté et al., 2003), "consideration of future consequences" was examined as both a mediator and moderator of the relationship between DP and skill, with little success (Bartulovic & Young, 2017; Tedesqui et al., 2015).

The controversy over whether an expert's DP is enjoyable has never been dismissed. This became a bit of a moving target over the years; Ericsson initially described DP as "comparatively low on inherent enjoyment" (Ericsson et al., 1993, p. 373), it was referred to as "not necessarily enjoyable" (Tugend, 2010), and research on the whole appeared to drop enjoyment as a distinctive characteristic altogether (cf., Ericsson, 2020). The notion of inherent (un)enjoyment was never resolved. If it is not an operational characteristic of DP, at minimum, it should be a point of interrogation related to the motivational constraint. It is surprising that motivational researchers have not explored the unique experiences of elite athletes around DP. The question of how some elite athletes report effortful DP as motivating and enjoyable (see Hodges et al., 2004; Hodges & Starkes, 1996; Young & Salmela, 2002; cf., Coughlan et al., 2014) seems perhaps counter-intuitive and contrary to Ericsson et al.'s (1993) notions. However, if scholars consider how individuals integrate and internalize previously unenjoyable and externally regulated activities to the self over time, which is the terrain of self-determined motivation (Ryan & Deci, 2017), the answer may be better understood.

Overreliance on self-report methodologies may partly explain the lack of advancement. Self-report measures have been cross-sectional, and highly retrospective, and in the absence of dynamic, longitudinal and complementary assessments (including qualitative research), have done little for unpacking motivational phenomena. A promising area of examination relates to what can be inferred motivationally in the choices expert athletes make with respect to their training environments. Deakin and Cobley (2003) described how more elite figure skaters were more willing to tackle the weakest elements of their repertoire in practice than non-experts, who were more inclined to spend time on aspects for which they already felt competent. In this vein, Coughlan and colleagues (2014) tested expert versus intermediate Gaelic football players to infer their decisions during practice. Following a pre-test, during a free choice skill acquisition period, experts predominantly chose to focus on their weaker skill, whereas intermediates mostly selected their stronger skill to practice. Thus, experts were more motivated to tackle weaknesses, and furthermore, this motivation likely interacted with self-regulatory competencies (e.g., self-evaluation, adaptive inferences). Notably, only the experts showed improved performance in retention/learning tests, and they rated practice as more effortful and less enjoyable. This experimental paradigm, whereby one can behaviourally identify motivations, is promising, especially when athletes may be working hard at trying to gain skill, under uncertain prospects (i.e., when outcome expectancies may not be high).

Understanding motivation will likely mean using novel approaches for investigating affect, particularly during intense sport activity. Ekkekakis et al.'s (2011) tripartite rationale for the relationship between affect and intensity seems relevant, especially the idea that there is greatest variability in how individuals associate pleasure and discomfort when they are around particular physiological thresholds (e.g., lactate threshold), but not necessarily below or above. If research could uncover similar individual differences, which may predispose some athletes to be more motivationally resilient than others at the same super-effort thresholds, this may contribute to micro-analysis (i.e., *in situ*) of the motivational constraint.

The Effort Constraint

Two elements are aligned with the effort constraint: first, expert athletes find greater capabilities to recruit and devote energies to their practice; second, expert athletes find better ways to facilitate adaptation in response to the training demand, which support continual training sessions over time (e.g., daily, week to week), which Baker and Young (2014, p.150) termed "deliberate recovery."

Role of on-task effort. There have not been dedicated works examining the first element. We do not know whether, given the same training prescription (for effort), more elite athletes tend to over-shoot the prescription, or extend the number of practice repetitions in a session at the prescribed effort, compared to less-elite athletes. Neither do we know if, given the same prescription, more elite athletes tend to hyper-focus or sustain their concentration across a session, compared to less elite peers. Nor do we know how knowledge and self-regulated choices are implicated with respect to on-task effort/concentration, at repeated practices over time. It is possible that, under strategic and appropriate conditions, elite athletes have a propensity to push the effort envelope earlier and more consistently, which would potentially describe more optimal conditions for adaptability. The limited evidence for effort comes largely from retrospective self-report methods. Hendry, Williams et al. (2019) asked national-team and less-skilled varsity female soccer adult players to provide estimates of their activity involvement during childhood and adolescence, and to judge ratings of challenge they recalled experiencing in different activities at different periods of their career. A key finding was national players participated in more play that was challenging, and engaged in more moderate to high challenge practice, compared to varsity players. When retrospective self-report methods are used, contrary evidence has been reported to suggest that skill groups (e.g., national vs. provincial vs. club level) do not judge the effort of their DP differently (e.g., Young & Salmela, 2002).

It is notable that we have not seen any behavioural observation, or coach report studies regarding differences in athlete effort. It is equally surprising we have not seen more examination of effort related to the microstructure of practice, especially considering parallels between the cognitive load characterizing DP and "cognitive efforts" induced by feedback and scheduling manipulations, as on-task conditions that heighten motor learning (e.g., Lee et al., 2001). Similarly, although sport researchers have made pertinent overtures to the Challenge Point Framework (Guadagnoli & Lee, 2004), no serious examination has applied the framework to further our understanding of effort in the DPF.

Role of rest and recovery with respect to off-task effort. To engage in daily DP over many years, individuals must avoid becoming exhausted from engaging in such practice. Ericsson et al. (1993) proposed limits on daily DP; for musicians, he suggested ~4 hrs daily, divided into individual sessions of no longer than ~80 mins. They also suggested the remainder of the day be spent resting, including naps, to enable recovery for the next day's efforts.

There have been few studies of the rest periods that accompany engagement in athletic DP (Eccles, 2020; Eccles et al., 2020), and very few that have submitted data to expert-novice differences. In a seven-day diary study, Young and Salmela (2001) examined the deliberate recovery activities used by elite and intermediate-level distance runners. No differences were reported for activities comprising body care (e.g., massage therapy), sleeping and napping, and non-active leisure. A sleep log study (Wilson & Baker, 2021) found that international and national athletes, compared to non-elite peers, reported falling asleep earlier, spending more time in bed at night, and longer daytime napping. However, international athletes reported poorer sleep quality ratings than the non-elites; international athletes attempted to improve recovery via sleep and nap strategies (e.g., earlier sleep) but these attempts were unsuccessful. While the reason for poor sleep quality is not clear, one possibility is that international level athletes are unable to detach from training activation and rumination. Balk et al. (2021) reported that higher physical fatigue in elite athletes following a day's training was related to athletes' self-reported inability to stop thinking about their sport at the end of that day, which might in turn affect sleep.

The emerging research indicates there are at least three facets of rest. The first is physical inactivity, or the cessation/reduction of training and competition (Eccles & Riley, 2014; Kellman et al., 2018), which allows for energy replenishment, repair and adaptation. The second facet is sleep, and the third involves wakeful resting experiences. Eccles and Kazmier (2019) proposed a model in which opportunities to engage in specific wakeful resting experiences led athletes to feel more mentally rested. They noted how collegiate athletes reported feeling that they are always thinking about their sport during a typical training week, which is tiring. Eccles and Kazmier noted, and showed illustrations for, how key resting experiences for an athlete involve reductions in thinking about their sport and in effortful thinking more generally.

As insinuated by the detachment literature, recovery is more than rest. For example, Wilson and Young's (2021) interviews with World Championship-level endurance athletes illustrated recovery is multifaceted, can be both approach- (i.e., oriented towards attacking the next day's training) and avoidance-oriented (i.e., avoiding staleness), multi-modal (i.e., using techniques, treatments, including self-care), and ultimately depends on personal meaning to the athlete as well as how the individual interprets recovery states and manages a recovery process. It is also possible that experts manage their recovery activity, including time spent using relaxation techniques, differently than less skilled peers (Kudlackova et al., 2013).

There have been few comparisons of expert and less-expert athletes in terms of time spent being physically inactive, wakefully resting, detaching, and recovering outside of training. Limited knowledge exists on the resting profiles of athletes at different skill levels, and how these profiles relate to the predictions of the DPF. Second, while the focus of many rest/recovery studies of DP is at the scale of a training week, research is required at longer scales, including the annual cycle, off-season periods, and four-year Olympic cycles, especially in psychologically regenerative terms (cf., Baker et al., 2005).

The Resource Constraint

On the surface, the DPF may seem like an egalitarian approach to human exceptionality; if you want to attain a specific level of skill, just work hard enough. When positioning training as the primary explanation for skill inequalities between groups, however, issues of access to high-quality training and learning opportunities become critical. The study of resources then becomes one of inequity. Considerable research has been done on the issue of training resources, and much of this work can be interpreted through the lens of "Matthew Effects" (summarized by the adage "the rich get richer, the poor get poorer" [Merton, 1968]). For example, in several of Ericsson's works he uses relative age effects to highlight the cumulative role access to resources can have on long-term development in sport. The relative age effect describes asymmetries in the birthdate distribution of elite athletes in many popular sports reflecting the greater prevalence of players born immediately following the "cut-off date" used to organize players into age groups. In sports where coaches select athletes early for "talent identification" initiatives, those who are "relatively older" are more likely to be selected than their "relatively younger" peers (i.e., those born farthest from the cut-off date; see Wattie et al., 2015).

These effects, as well as community size (or birthplace) effects, socioeconomic status effects and access to early coaching (see Wattie & Baker, 2018) are underpinned by the assumption that having access to early benefits affords some individuals advantages. These advantages possibly come through superior developmental environments due to greater quantity and quality of coaching, competing against more elite competitors, and reinforcement of competency beliefs. These advantages have additive or multiplicative effects and ultimately play important roles in long-term development (Wattie et al., 2015). To date, research in this area has been largely superficial; for example, simply exploring whether the effect exists in a given sample, rather than exploring the mechanisms and/or consequences of the effect. There is a need to catalogue the combinations of effects influencing long-term athlete development and understand their complex interactions. Baker and Young (2021) proposed that research should explore the impact of inequitable access to resources on practice quality/quantities in groups that are unfairly disadvantaged, and to model what this means for the landscape of expert development.

Addressing Individual Differences

Perhaps the biggest obstacle for the original conceptualization of the DPF is its seeming opposition to the influence of genetic or talent-related factors, which assume individuals may be predisposed to different types of achievement (or health, or behaviour) before the journey even begins. For some critics, the DPF remains a very nurturist perspective to understanding expertise, reflecting outdated thinking that assumes biological and experiential influences can be cleanly divided into nature versus nurture camps. On one hand, a solution may be to place empirical boundaries on what can be understood considering the experiential tenets of the DPF; this can be accomplished by requiring researchers to explicitly report the unexplained variance of practice/experience metrics on criterion variables. Another plausible perspective would emphasize the possible gene-by-environment interactions that could explain many of the relationships that form the evidentiary basis for the DPF (see Baker & Young, 2021).

In 1993, Ericsson et al. commented, “Several personality factors, such as individual differences in activity levels and emotionality, may differentially predispose individuals toward deliberate practice as well as allow these individuals to sustain very high levels of it for extended periods” (p. 393). They also noted, “heritable individual differences might influence processes related to motivation and the original enjoyment of the activities in the domain and, even more important, affect the inevitable differences in the capacity to engage in hard work (deliberate practice)” (p. 399). There has been much controversy since in terms of how individual difference variables, especially those that might reflect heritable predispositions in personality and other performance/development-related variables, should be considered with respect to the DPF.

Ericsson and colleagues (2007) noted that “the possibility of genetic differences in the motivational factors required for extended deliberate practice has always been considered to be plausible” (p. 32). Similarly, individual differences in the capacity to overcome constraints and stay committed to a challenging, far-off, but rewarding goal help explain why some individuals develop expertise (Duckworth et al., 2011). In sum, Ericsson never conceptually discounted individual personality differences in motivation, emotionality and general activity dispositions; equally, he neither empirically accounted for, invited or encouraged the empirical integration of such factors into the DPF.

There has been some growth in studies examining individual differences in personality as they relate to facets of the DPF. These findings should be understood with respect to estimates in broader psychology that generally indicate between 40% and 50% of personality differences are due to genetics, the rest due to environmental influences (e.g., Vukasovic & Bratko, 2015). In a study of Norwegian soccer players, Toering and Jordet (2015) found a personality trait for “impulse control” significantly explained whether players were chosen for the national team. More-elite players scored higher on a trait for “restraint,” which was also positively associated with amounts of practice. Larkin et al. (2015) found that more gritty young soccer players performed better on sport-specific perceptual-cognitive measures and reported more soccer practice than less-gritty counterparts. Tedesqui and Young (2017a, 2017b, 2018) conducted a series of studies involving 10 personality variables, ultimately finding that individual predispositions related to grit (i.e., perseverance of effort) and conscientiousness (i.e., achievement striving) positively explained variance in DP. Such work, however, would ideally be extended under the premise that DP should mediate the effects of personality variables on sport performance. For instance, Duckworth et al. (2011) reported DP fully mediated the association between grit and performance of National Spelling Bee finalists.

Concluding Thoughts

We thank the editors of this special issue for the opportunity to reflect upon and celebrate the significant contributions of K. Anders Ericsson to our field. We have attempted to provide a summary of his impact on researchers in sport expertise and its associated fields of skill acquisition, talent identification, and coaching. The review has been both gratifying and challenging. We have attempted to highlight many areas where his contributions to sport were indisputable along with some key insights we derived in our decades-long interactions with the eminent scholar and his works. However, we have also noted key limitations and areas of dispute among scholars in this area such as the inconsistencies in how DP has been operationalized and measured, whether DP is sufficient to explain skill differences between performers, the value of individual differences, ability constraints and genetic factors for understanding human achievement, among others.

In completing this review, we re-engaged with many of the earliest works in this area and were surprised by how many thoughtful propositions were made, and how many have been insufficiently explored in the near 30 years since the initial, seminal study was published. In our view, the DPF, "warts and all," remains a highly useful meta-framework for positioning quality practice in the process of sport talent development. One of the greatest values of the DPF is that dialogue and rigorous debate centered on qualities of practice can pivot to fruitful, applied discussions about optimal learning design, coaching/instruction, monitoring of training load, and accessibility to training assets. As a meta-framework, the DPF also effectively conceptualizes the varying influences on the long-term development of performers in sport and allows for the integration of motivation, effort, and resource "constraints" on DP. The DPF provides a comprehensive framework that continues to impress and guide researchers, yet has suitable latitude to adapt and evolve in response to empirical trials and as such, it will remain at the fore of research on skill acquisition and sport expertise.

A generous and thoughtful scholar, persistent, principled, and rigorous, K. Anders Ericsson's career epitomized how an eminent cognitive psychologist brokered new collaborations in the (initially foreign) sport domain, and in doing so, imparted a clear scholastic legacy. We envision that in his new resting place he will be surrounded by his towers of books and articles, thoughtfully engaged with what we have written, nodding his approval at some elements, preparing his response to those with which he disapproves, and stroking his beard over comments requiring more "deliberation." We await his proverbial saying, articulated with an upbeat and subtle Swedish lilt, "Well, if I could offer my two cents worth …"

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Authors' Declarations

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