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Capturing Expertise in Sports

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It should not be surprising that from its inception sports expertise has been studied separately from mainstream motor learning research. Although both share an interest in skill, the focus of sport expertise has been comparatively broad in comparison to those of motor learning, which have centered almost exclusively on mechanisms responsible for response selection and control per se. In addition, sports expertise has emphasized the importance of ecological validity and has therefore been faithful in its use of actual sports tasks and situations (or at least close approximations) for study. This stands in stark contrast to motor learning researchers who have studied laboratory tasks so reduced in their complexity that any resemblance of skills used in sports is all but lost. These researchers appear to have been faithful to the admonition of Adams (1971) that "The villain that has robbed 'skills' of its precision is applied research" (p. 112). However, one cannot help think that the true villain Adams railed at was empirical and not necessarily applied research. Thus the lack of a theory of expertise may explain the past reluctance of motor learning researchers to pursue sports expertise as a topic of investigation. The general theory of expertise proposed by Ericsson, Krampe, and Tesch-Römer (1993) may provide the impetus for motor learning researchers to approach their research from an expertise framework. In addition, Ericsson et al. provided a paradigm for the complementary study of expertise with actual sports tasks as well as with laboratory tasks.

Ericsson (chap. 1, this volume) has described three approaches by which to study expert performance. These are the historical approach, laboratory approach, and developmental approach. Whereas the historical approach is dependent on available public data, the laboratory and developmental approaches involve greater investigator–subject interaction. The developmental approach typically involves the use of surveys and interviews. This information relates to circumstances existing during the development of skills and/or activities engaged in over an extended period of practice. The laboratory approach emphasizes the detailing of mechanisms underlying expert performance. It seeks causal relationships that allow descriptions of mechanisms underlying skill performance. Ericsson suggests a laboratory methodology (referred to as "capturing") that involves having the expert perform a number of representative tasks. Possible processes responsible for performance are then posited. Verbal reports along with other techniques are then used to eliminate alternative processes until some limited number of underlying processes responsible for performance of all representative tasks has been identified.

The bringing of sports expertise and motor learning research together within one framework has great potential to advance our understanding of motor skill. The long history of motor learning research conducted in the laboratory provides a plethora of hypothetical constructs that need to be operationalized at the application level. For example, the ubiquitous law of practice in which performance improves as a negatively accelerating function is well documented in the laboratory, as well as in the field setting. The attractive characteristic of the laboratory setting is that it offers a way to quickly train subjects to asymptotic performance levels (see Richman, Gobet, Staszewski, & Simon, chap. 6, this volume; Shiffrin, chap. 14, this volume). However, the advantage of being able to train subjects quickly is attained at the cost of losing equivalency in practice time between the laboratory and the field setting. It is impossible to know how many days, weeks, months, or years 150 practice trials in the laboratory will translate to in the actual sports setting (perhaps 10 years?). Sports expertise research can provide this temporal equivalency. There are many more constructs that offer an opportunity for parallel experimentation in the laboratory and the field setting. The need for continuity in this process suggests that it can best be attained through the collaborative efforts of researchers working in the same program.

Our approach to this chapter is to use a brief discussion of the research presented by Starkes, Deakin, Allard, Hodges, and Hayes (chap. 3, this volume) as a starting point for a review of sports expertise-related research from two different laboratory paradigms. These will be referred to as the expert–novice and the expert modeling paradigms. The expert–novice paradigm is congruent with the "capturing" methodology described by Ericsson and consists of selecting a component function of performance (e.g., eye fixation point) that is thought to underlie a sports skill (e.g., batting in baseball, the volley in tennis, and shooting in basketball) and then test expert and novice athletes to determine differences in how they use that component to control performance. The assumption for this comparison is that if performance differences are found, then the component function is an important discriminator for success. The expert modeling paradigm has been pursued by researchers interested in talent identification. This research has used linear regression techniques and has been empirically motivated by the desire to predict achievement in sports. Moreover, this research has been pursued independent of theoretical constructs related to sports expertise. Renger (1993) pointed out that despite considerable research on the topic, there has been little progress in identification of factors that differentiate successful and unsuccessful athletes using this approach. After a reviewing the literature, Renger concluded that this inability to identify factors associated with success in sports can be attributed to theoretical and methodological problems in current research. Fleishman (1972) and his colleagues were able to use this paradigm in the laboratory setting to study individual differences in abilities and task performance. We present selected studies from Fleishman's research as a useful paradigm from which to study expertise in both the laboratory and applied sports settings.

Starkes et al.

A major basis of Ericsson et al.'s theory of the acquisition of expertise has been the defining of components of deliberate practice that are believed to lead to expert levels of performance. These include: (a) the benefits of a coach or teacher, (b) that practice is not inherently enjoyable and perceived as not always relevant to final performances, and (c) there are constraints as to the amount of practice that can be achieved before fatigue impinges on performance. This proposal that a set of general rules governs acquisition of expertise can be contrasted to the view that the greatest precision in explanation will lie with more local or domain-specific rules. Can we expect a musician practicing solo routines to report the same feelings and conditions as a team player working in an interactive, dynamic training environment? Although the components of deliberate practice proposed by Ericsson et al. appear to be accurate, their individual relevance to any particular activity may be determined by the nature of the activity and the environment in which practice is undertaken.

The studies by Starkes et al. clearly fall within the purview of the developmental approach in which a questionnaire was used to obtain retrospective reports about practice regimes from wrestlers and figure skaters. These studies offer broad support for Ericsson et al.'s general theory of expertise, but do suggest limits to the extent any particular rule will apply across domains. Specifically, these studies provide evidence that the characterization of deliberate practice offered by Ericsson et al. may need to be adjusted to admit practice that is considered relevant and enjoyable.

Other conclusions by Starkes et al. are more circumspect. Figure skating coaches were interviewed and asked open-ended questions about the identification of talent, selection of skaters for their program, and the nature of training. They were also asked to rate the relative importance of items on a list of attributes thought to influence success in skating. The presentation of findings for this study consists of a casual discussion in which we are treated to a presentation of descriptive data and illustrative quotes. There is no attempt at a systematic protocol analysis (Ericsson & Simon, 1993) consisting of the classification of comments into response categories and inferential statistical analysis of these.

The authors place importance on the ratings by skaters and coaches of attributes related to success in skating in drawing their conclusions. The ratings of skaters and coaches were analyzed and found to be significantly related. A finding highlighted by the authors was that desire and good coaching ranked first and second, respectively, and that practice ranked only third in importance for both coaches and skaters. This finding appears less impressive when the relatively high and uniform rating of these three attributes for coaches (desire, $M = 10$, good coaching, $M = 9.9$, practice, $M = 9.8$) and skaters (desire, $M = 9.6$, good coaching, $M = 9.5$, practice, $M = 9.4$) is considered in addition to the absence of an inferential analysis of the ranking data. Perhaps it is worth noting that fitness level also received a high rating for coaches ($M = 9.8$) and skaters ($M = 9.0$). This suggests that there might be a relationship of practice and fitness level, and that fitness level might be considered a by-product of the amount of practice engaged in. If one chooses to ignore the likelihood of a ceiling effect being responsible for the obtained rankings, these findings might be explained by the uniform level of expertise of the athletes. That is, a possible reason for practice not ranking higher is that all skaters were at the national level and may train for about the same amount of time. Thus variables other than practice become determining ones. Administering the survey to other skill levels and thus avoiding any effects due to population attenuation might reveal quite different findings.

Finally, we can appreciate the anecdote of Moe Norman the expert golfer, which effectively conveyed the lesson that deliberate practice may be a necessary precursor, but by itself it may not be sufficient for success. However, it is difficult to escape the conclusion that Norman attained his goal of being an excellent striker of golf balls and that deliberate practice adjusted to obtaining this goal was successful. Furthermore, we cannot be certain of the eventual level of success Norman would have attained had he remained on the professional circuit.

The Expert–Novice Paradigm

There now exists sufficient published research to assess the value of any paradigm for explaining expert levels of performance. Certainly in the last 15 years, studies investigating a variety of perception and motor performance abilities have been reported, revealing many factors relevant to the acquisition of high levels of performance across many sports. This experimentation has not, however, progressed to describe any underlying

mechanisms responsible for expertise in sport. Although propositional networks associated with declarative and procedural knowledge have been used (Anderson, 1985, 1987; MacKay, 1987) to explain perceptual-motor performance (Allard & Starkes, 1991; Paull & Glencross, in press), there has been little empirical evidence to support their utility in sports expertise.

This short review outlines various approaches to the study of expert levels of skilled behavior. Although not exhaustive of all the studies in the past 15 years, it illustrates the range of factors implicated in expert performance, the usefulness of the information to guide coaches in training athletes for expert knowledge in particular sports, and the need now to substantiate theories that will provide the framework for these empirical endeavors.

Reaction Time. Operating in the short time frames available in many sports situations suggests a cognitive system capable of reduced latencies for motor responses (Starkes, 1987). Simple reaction time (SRT) has been proposed as a measure of speed of cognitive function (Nielsen & McGown, 1985). However, SRT of athletes has not consistently been correlated with their performance level (Abernethy & Russell, 1984; Goulet, Bard, & Fleury, 1989; Nielsen & McGown, 1985). In addition, choice reaction time (CRT) as a measure of the speed of decision making has not consistently differentiated experts from novices (Nielsen & McGown, 1985). CRT, however, has been useful as a measure of cognitive operations when a task relevant to the one of interest is utilized (Goulet et al., 1989). Experts exhibit shorter decision times than novices for relevant stimuli when this is the case.

A difficulty arises in devising relevant tasks to measure decision time when performing in simulations of sports events. Abernethy and Russell (1984) found cricketers viewing films of medium-paced bowling reacted in excess of 300 ms after the ball was released by the bowler. This figure greatly exceeds the 189 ms calculated by Glencross and Cibich (1977) as the decision time available for a batsman facing fast bowling of 140 kph. Adams and Gibson (1989) required cricketers to respond on a push button at the moment of release of a cricket ball bowled by a live bowler. Error scores (response latency) were as high as 160 ms for lower grade batsmen, and averaged about 60 ms for the most expert group. This response was supposed to represent the start of ball flight information and yet this delay encroaches well into the available processing time available in a game. Glencross and Cibich's data for tennis indicate a receiver only has 253 ms to react to a 164 kph serve, but Goulet et al.'s (1989) expert subjects reacted at around 1.5 s across trials of filmed serves. In field hockey, Starkes (1987) tested players on identification of ball location and also tactical decision-making time from photographic slides. Average reaction times of 880 ms and 1,413 ms, respectively, would exceed the time available to a player in many game situations (e.g., defending close to the goal). Baseball batters in elite competition probably have less than a quarter of a second in which to commence a swing to coincide with a fastball pitch (Glencross & Cibich, 1977), but Paull and Glencross' (in press) experiments produced decision times averaging in excess of 400 ms for experts and longer for novices.

Absolute time aside, the expert–novice paradigm has shown differences between decision times for performers from different skill levels. Expert tennis players have been shown to make faster decisions than novices concerning the type of serve displayed in filmed action (Goulet et al., 1989). Abernethy and Russell (1984) found first-grade cricket batsmen make faster decisions concerning the delivery length of filmed bowling than third-grade players. In a study of baseball batting, Paull and Glencross (in press) demonstrated the earlier decision-making ability of expert batters over novices when performing to an interactive video simulation of pitching. These figures for decision times in experimental situations should be used as relative measures that indicate differences in expertise levels of players. Any attempt to infer skill level based on the absolute elapsed time in these experimental situations will not accurately reflect actual performance in fast action sports.

Accuracy. Laboratory research in which accuracy is the dependent variable has produced findings that have not had a close relationship to actual responses. Results reported for tennis (Buckolz, Prapavesis, & Fairs, 1988; Goulet et al., 1989; Isaacs & Finch, 1983; Jones & Miles, 1978), squash (Abernethy, 1989, 1990a, 1990b), ice hockey (Salmela & Fiorito, 1979), badminton (Abernethy, 1987a, 1988a), volleyball (Borgeaud & Abernethy, 1987; Wright, Pleasants, & Gomez-Meza, 1990), and baseball (Paull & Glencross, in press) all indicate the greater accuracy of experts over less skilled subjects. However, these studies show that errors may occur in up to 50% of trials and that responses may be displaced on a court in the order of many meters. These findings bear little resemblance to actual elite performance. Therefore, findings must be treated as relative indicators of performance and not absolute measures of ability.

Visual Processes. Many features of athletes' vision have been examined relative to sports performance. The conclusion generally drawn has been that it is not orientation of the eyes or physiological attributes of the visual/ocular system that lead to expert performance (Abernethy, 1988a; Starkes, Allard, Lindley, & O'Reilly, 1994). Rather, it is use of information contained in the visual array that separates expert from less skilled athletes. This "information pick-up" (Abernethy, 1987b) acts in the knowledge base an athlete has for a sport to provide recognition of pertinent information. Increased pertinence of information picked up differentiates expert performers from novices who do not understand the value of the information contained in the visual array.

The purpose of directing the eyes to particular locations in the display is to facilitate the pick-up of information to guide performance. We assume a player directs attention in line with orientation of the eyes, but visual orientation (looking) does not necessarily equate with visual attention (Abernethy, 1988b). It is the active perceiver who benefits, not from the display per se, but the information contained in the display (Broadbent, 1982). Support for this conclusion has been provided by Abernethy and Russell (1987b), who recorded badminton players' eye movements while watching films. In one film, the opponent had body parts occluded to remove these as a source of information about the shot to be executed. Both novice and expert players spent closely an equivalent time fixating the racquet and arm of the opponent when these cue sources were available. When the racquet and arm of the opponent were occluded, experts' error scores were higher than those of novices, who apparently extracted less information from these cue sources and therefore suffered less from their removal. These findings are similar to those of Goulet et al. (1989), who found that expert and novice tennis players use similar visual search patterns in the preparatory stages (ball toss and early arm movement) of a filmed opponent's service. However, experts are more accurate when the preparatory stage was the only information shown to subjects. This agrees with Shank and Haywood's (1987) finding that novice baseball batters fixate both the pitcher's head and arm during the delivery action, whereas experts only fixate the ball's release point.

Investigation of the use of cues provided in advance of the actual onset of information (e.g., a ball in flight) has used filmed displays of performers during delivery actions. Decrement in accuracy scores when advanced cues are occluded from the display are then held to indicate the existence of "telegraphic" cues (Bakker, Whiting, & van der Brug, 1990) that are available in the natural display. Abernethy (1988a, 1990a) and Abernethy and Russell (1984, 1987a, 1987b) utilized this technique in squash, cricket, and badminton. Similar studies have been conducted in baseball (Paull & Glencross, in press), tennis (Buckolz et al., 1988; Goulet et al., 1989; Isaacs & Finch, 1983; Jones & Miles, 1978), volleyball (Wright et al., 1990), ice hockey (Salmela & Fiorito, 1979), and field hockey (Starkes, 1987). The finding of superior expert performance was replicated in all these studies.

The need for more advanced technology to study the effects of visual occlusion on sports performance in natural settings has been addressed by Burroughs (1984) and others (Starkes, Edwards, Dissanayake, & Dunn, 1995: Paull & Glencross, in press). Starkes et al. used liquid crystal occlusion spectacles to study estimation of landing position of the ball in volleyball. Estimates of landing position of the ball were more accurate for skilled than for novice volleyball players. Paull and Glencross (in press) found that prediction of pitch location over the plate from early information in the pitch was more accurate for expert than novice baseball players.

Subjective Probabilities. Whenever alternative events are non-equiprobable, the situation will allow the astute player to set probabilities (expectancies) about forthcoming events in a competition (Abernethy, 1987b). Unlike the reactive visual processes discussed earlier, setting subjective probabilities by a performer is proactive, and works in advance of stimulus onset for an athlete who has developed knowledge for the game, opponents, and the competitive environment. Paull and Glencross (in press) studied the use of this strategy by baseball batters. Before half the trials in their first experiment, information about the progress of a hypothetical game was provided to allow batters to consider what type of pitch would be thrown next. Batters improved the time of their decisions by an average of 60 ms. This was not at the expense of accuracy, as these decisions were more accurate than when no game information was provided.

In summary, many paradigms have been used to examine expert performance of sports skills. The procedures for determining factors relevant to performance of many sports skills have been developed and information from additional sports is accumulating. This information is relevant to understanding the sports of interest, and particularly useful for coaches who can implement specific training to develop the knowledge base in their athletes for the highest levels of performance. It is now appropriate for researchers in the sports sciences to refocus experimental efforts and systematically examine cognitive mechanisms to substantiate theories of expert performance.

The Expert Modeling Paradigm

The method suggested by Ericsson (chap. 1, this volume) for identification of component skills in the laboratory provides a start in theoretical analysis for use of hierarchical regression or discriminant analysis and subsequent testing of predictive validity in the study of expertise in sport skills (Renger, 1993). The previously reviewed studies have used inferential statistical procedures to demonstrate expert–novice differences on component skills presumed to be important for task performance. It is of course very different to show statistically reliable differences between expert and novice performers than to show the meaningfulness of those differences. The use of regression procedures would allow the researcher to determine the relative importance of the component skill they are studying in terms of the amount of variance accounted for in performance of the total skill. This approach would allow the investigation of variables individually or in combination on performance. Moreover, it would allow researchers to develop more comprehensive models for sports expertise by systematically adding new variables to their task and removing those that account for low variance in the criterion measures.

The research program conducted by Fleishman and his colleagues concerning abilities and human performance illustrates the potential benefits of a modeling approach using regression procedures for training purposes. Fleishman (1972) regarded abilities as referring to capacities the individual utilizes in performing a task. According to Fleishman, many of these capacities are learned and develop at different rates. This view differs with that of leading motor learning theorists such as Schmidt (1988), who view abilities as strictly inherited and therefore not subject to change as a result of experience. In addition, Fleishman (1972) recognized the importance of developing a taxonomy of motor tasks based on common capacities necessary for performance rather than a taxonomy based on the structural similarities of tasks (Parker & Fleishman, 1961).

Following an earlier study by Parker and Fleishman (1961), Fleishman and Rich (1963) performed the now classic experiment supporting the changing component abilities hypothesis which proposes that the abilities underlying early performance are not the same as those underlying later performance. This hypothesis makes sense if one believes that subjects change their approach to a motor task as they become more skilled (Pew, 1966). Fleishman and Rich tested subjects for kinesthetic sensitivity and spatial orientation before having them practice 40 one-minute trials on a two-hand coordination task. The two-hand coordination task consisted of keeping a target follower on a small target disk as the target moved irregularly and at various rates around a circular plate. The movement of the target follower was controlled by simultaneous rotation of two handles, one held in each hand. The dependent measure was the total time for each trial that the target follower was in contact with the target (total time on target). Subjects received 40 one-minute trials separated by rest intervals of 15 seconds in duration. At the conclusion of the experiment, subjects' kinesthetic sensitivity and spatial orientation test scores were correlated with their two-hand coordination task scores.

Over half the variance ($R^2 = .53$) in total time on target was accounted for by the combination of kinesthetic sensitivity and spatial orientation measures. In addition, the correlation between kinesthetic sensitivity and spatial orientation measures was not significant ($r = .12$), an indication that the two tests measured independent abilities. The 40 two-hand coordination scores were grouped into 10 blocks of four trials each so that the relationship of kinesthetic sensitivity and spatial orientation measures to stage of learning could be investigated. Early in practice the correlation between two-hand coordination and spatial orientation scores was higher ($r = .36$) than the correlation between two-hand coordination and kinesthetic sensitivity scores ($r = .03$). Later in practice, however, the correlation between two-hand coordination and kinesthetic sensitivity scores was higher ($r = .40$) than the correlation between two-hand coordination and spatial orientation scores ($r = .01$).

Fleishman and Rich provided a somewhat convincing measure of predictive validity by stratifying their subjects into those who had high and low spatial orientation scores (either above or below the group median spatial orientation test score). When practice performance for these groups was compared, it was found that early in practice, two-hand coordination performance was better for the group that scored high than for the group that scored low on the spatial orientation test (this difference was significant, $p < .01$). However, by the end of practice this difference between the groups was negligible.

Fleishman and Rich went on to stratify their subjects into those who had high and low kinesthetic sensitivity test scores. Performance for these groups diverged with practice. Early in practice, there was no difference in performance between groups, but later in practice, performance was better for the group that scored high than for the group that scored low on the kinesthetic sensitivity test (this difference was significant, $p < .01$). These findings provide evidence that learners change their approach to a task with practice and so the processing structure used to regulate early performance may not be the same as that used later in practice.

Parker and Fleishman (1961) showed that knowledge of the changing pattern of abilities can be used to adjust instructions during practice so that learning is facilitated. Subjects performed 17 sessions of 21 one-minute trials each (357 total trials) on a complex tracking task that simulated flying an aircraft. Briefly, subjects used a hand-held joystick and foot-operated pedals to keep a target dot in the center of an oscillograph display. The performance measures were integrated absolute error and the time during each trial the target dot was kept in the center of the display (time on target). Before practice, subjects were administered a test battery from which two factors were identified as contributing to performance on the complex tracking task. These were spatial orientation and multilimb coordination. Figure 13.1 shows changes occurring in the importance of these two ability factors with practice.

Three groups were compared. One group received no formal instructions throughout practice. A second group received commonsense instructions throughout practice, which approximated typical instructions given to military pilots. A third group received "adjusted" instructions that emphasized the control operations appropriate to the importance of ability factors for performance at a particular time in practice (as determined by findings of the earlier analysis depicted in Fig. 13.1) in addition to commonsense instructions. Figures 13.2 and 13.3 show the integrated absolute error and time on target measures, respectively, for the three instructional groups across the 17 practice sessions. It can be seen that adjusting instructions so they were appropriate for the ability factors important for performance can increase the effectiveness of training beyond that typically given. Further, this procedure was found to result primarily in an increase in the rate of learning but not its basic character.

The foregoing experiments by Fleishman and his colleagues provide a methodology analogous to "capturing" as described by Ericsson (chap. 1, this volume) that can be used to greatly enhance the acquisition of expertise. This methodology would consist of the use of linear regression techniques to identify important component skills (e.g., visual cues, decision making, event anticipation) necessary for performance and then either adjusting instructions to complement the use of these component skills or giving independent practice on these. The underlying assumption for giving independent practice on the component skills is that the total skill will benefit as the result of the improved component skill. However, one caveat to this is that this technique may not be effective if the total skill is comprised of closely interwoven

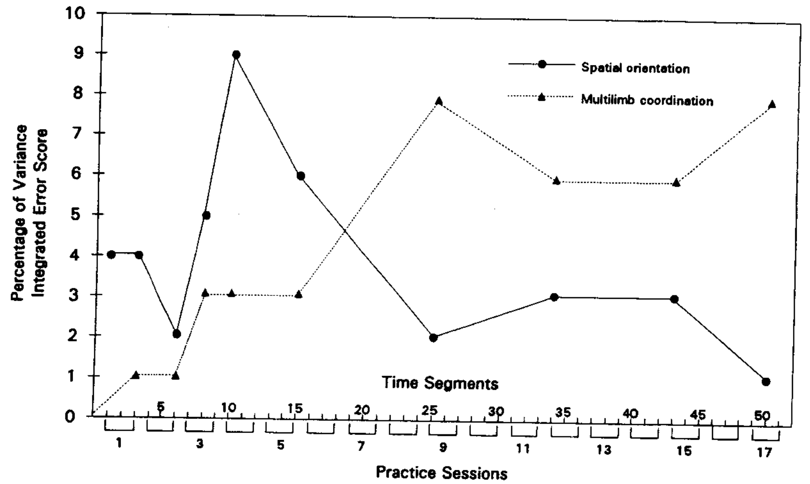

FIG. 13.1. Changes in the correlations between spatial orientation and multilimb coordination with complex tracking task performance across 17 sessions of 21 one-minute trials each (357 total trials). Adapted from "Use of Analytical Information Concerning Task Requirements to Increase The Effectiveness of Skill Training" by J. F. Parker & E. A. Fleishman (1961), *Journal of Applied Psychology, 45*, p. 297.

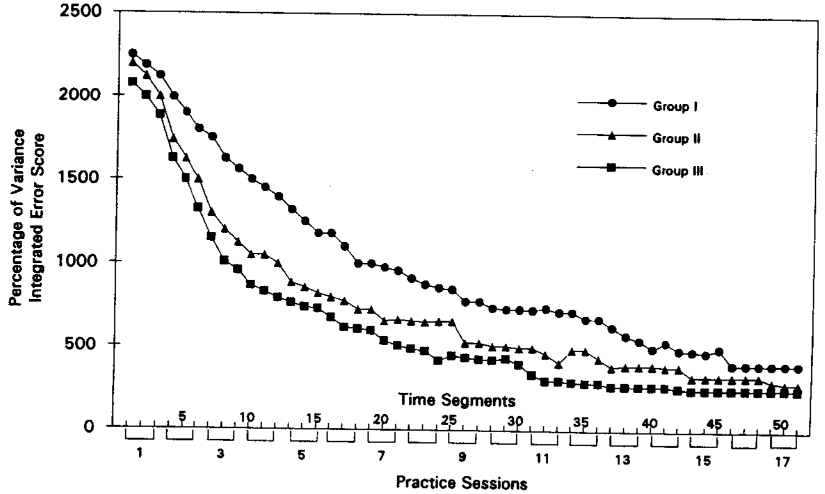

FIG. 13.2. Integrated absolute error measures for three instructional groups (no instructions, commonsense instructions, and adjusted instructions) for complex tracking task performance across 17 sessions of 21 one-minute trials each (357 total trials). Adapted from "Use of Analytical Information Concerning Task Requirements to Increase The Effectiveness of Skill Training" by J. F. Parker & E. A. Fleishman (1961), *Journal of Applied Psychology, 45*, p. 299.

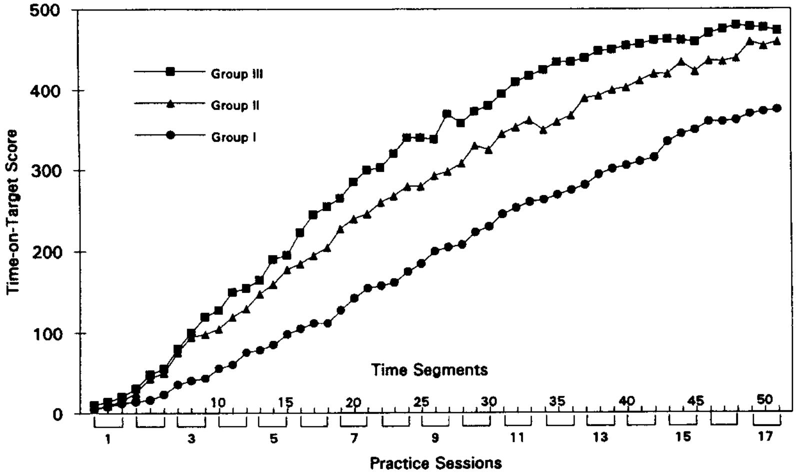

FIG. 13.3. Time on target measures for three instructional groups (no instructions, commonsense instructions, and adjusted instructions) for complex tracking task performance across 17 sessions of 21 one-minute trials each (357 total trials). Adapted from "Use of Analytical Information Concerning Task Requirements to Increase The Effectiveness of Skill Training" by J. F. Parker & E. A. Fleishman (1961), *Journal of Applied Psychology, 45*, p. 299.

components. In this case, the independent practice and improvement of any one component may not effectively transfer to the whole skill. This may be the case unless the supporting structure of the component skills has advanced to the new level necessary to support performance of the improved component. Furthermore, it may be the case that all the component skills can be improved an equivalent amount but that cohesive integration among the components will not be improved. In this case performance of the whole task will not be facilitated. It is conceivable that such practice could even negatively influence performance of the whole skill.

These early studies by Fleishman and his colleagues demonstrate that the expert modeling approach has potential to benefit the training of expert performers in sport. This must of course be demonstrated in the sports setting.

CONCLUSION

Ericsson et al. (1993) proposed characteristics of deliberate practice that lead to expert levels of performance across different skill domains. These include age of commencing practice, the use of a coach or teacher, and the resolve to spend many hours in deliberate practice of the skills required in the performance. Starkes et al. extend understanding of these factors to the sports of figure skating and wrestling. They show, however, that the attributes of deliberate practice may not be uniform across domains of skill. For example, their finding that deliberate practice can be enjoyable differs from previous evidence (Ericsson et al., 1993). Also, the perceived relevance of different factors associated with deliberate practice may differ between figure skaters, wrestlers, and skilled performers in other activities.

These findings may pose a difficulty for a general theory of expertise. This is that actual components of deliberate practice for any skill may be embedded in the domain of that skill. Therefore, the need for an inflexible rendition of a musical score will differentiate the characteristics of that task from, for example, a practice bout between wrestlers. Further constraining a general theory is the need to define expertise. The narrative by Starkes et al. of the golfing talent of Moe Norman illustrates the need to understand the difference between performance of a skill and behavior in competition. The latter must include the multitude of variation occurring in a dynamic environment, and it may be difficult to address this complexity through the capturing methodology proposed by Ericsson (chap. 1, this volume) and the expert modeling approach we have described.

Research under Ericsson's historical and developmental approaches to the study of expertise may reveal factors associated with development of expertise. These approaches, however, will not identify the mechanisms used by experts to regulate their highly skilled actions. Taking the laboratory approach as the means for such investigation, two paradigms have been outlined. Experiments that contrast expert and novice performers have provided good information across many sports about regulating perceptual and motor processes. These experiments have not been consistent in determining the contribution of any component process to actual performance. A more empirical approach would be hierarchical regression or discriminant analysis and subsequent testing of predictive validity (Renger, 1993).

The work by Fleishman and his colleagues (Fleishman, 1972) provides a useful paradigm from which to investigate the perceptual and motor processes underlying expert sports performance. This research demonstrated that the underlying processes for performance may change with practice, and that knowledge of individual differences in the capacity to use these processes allows prediction of final performance level. Fleishman and Rich (1963) showed that subjects high or low in spatial orientation or kinesthetic sensitivity either converged or diverged across practice trials. It is interesting that this occurred in spite of the fact that subjects had the same amount of deliberate practice in the experimental tasks. Although the amount of practice provided in the experiments by Fleishman and Rich (1963) and Parker and Fleishman (1961) by no means approached that which could be attained in 10 years, the findings of these studies suggest perceptual and motor capacities may interact with deliberate practice to determine final level of performance. The resolution of this question will necessitate experimental investigation.

Research in the domain of expert performance is providing exciting knowledge concerning the acquisition of high levels of skill in sport. Although findings to date are refining general notions of deliberate practice into sports-specific descriptions, there may still be a need to provide this as knowledge to coaches and athletes in applied training models. We may be answering the question "how to practice?" and leaving the question "what to practice?" unanswered. Any new paradigm to examine the contribution of any factor and how it interacts with other factors to determine the performance of sports skills should be given consideration.

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