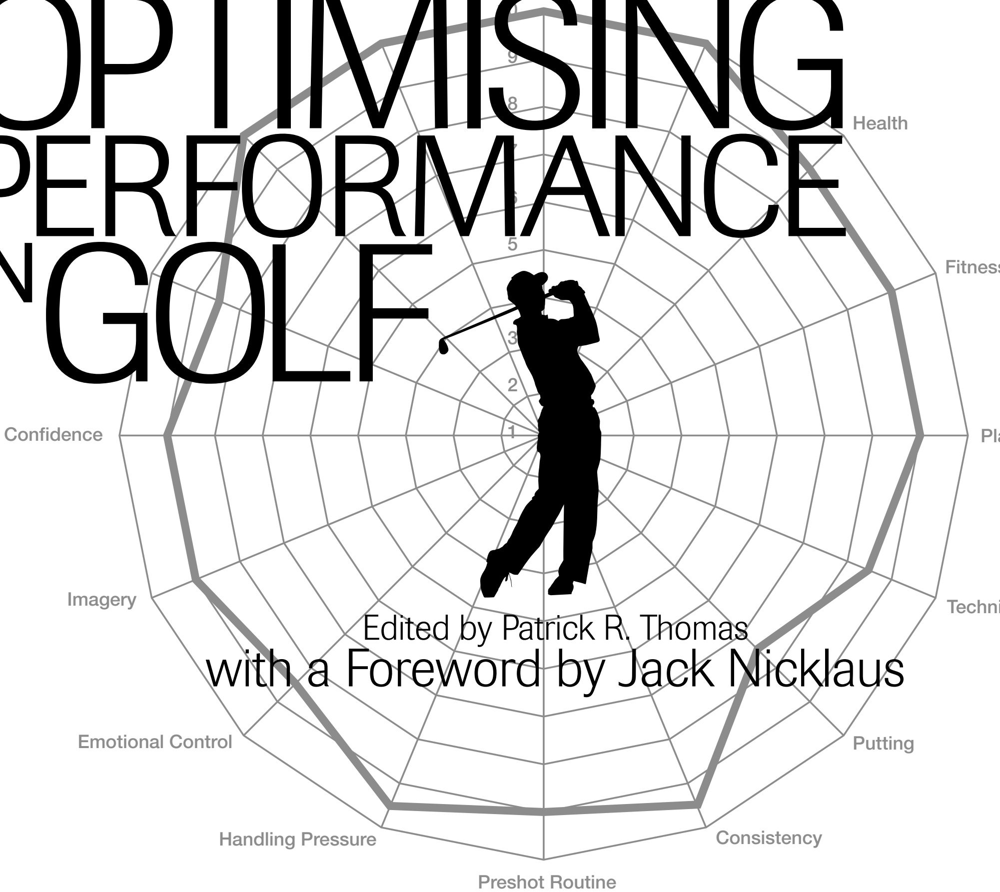
OPTIMISING PERFORMANCE IN GOLF



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with a Foreword by Jack Nicklaus

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FOREWORD

I have always maintained that the game of golf is a "work in progress" for the ambitious player. You never reach the point at which you have mastered the game, because the knowledge and skills it demands are virtually limitless. However, when a golfer has honed a golf swing based solidly on the fundamentals of the game and has developed an understanding of course management, the challenge that remains is to learn how to *win*.

Obviously there are certain innate traits which contribute to the ability to win: desire, self-confidence, self-discipline, being hungry for victory and unafraid of failure — or success.

However, these qualities alone do not guarantee a winner; and it is possible to have these traits as well as a fundamentally superb golf game and still not know the inside of the winner's circle. I maintain there are four vital keys:

1) You must learn to think clearly under pressure so that you can focus on the tasks and challenges of playing the game under competitive demands. I think this ability alone has had the greatest influence on my success.
2) You must train yourself to remain patient so that you do not succumb to judgment errors and hasty decisions that can undermine your skill and derail your competitive ability.
3) You must be self-focused so that you devote your energies entirely to optimizing your own performance rather than being distracted by the competition.
4) You must constantly rededicate yourself to mastering these skills — even more so when you are playing poorly than when you are playing well.

I am sure you will be presented with many interesting and valuable techniques for optimizing performance in golf. I suspect that you may hear these four points mentioned again. In any case, I hope you acquire a valuable perspective on methods that produce successful results.

Good Golfing,

Jack Nicklaus
September 2000

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PREFACE

Golf Science 2000, an interim conference of the World Scientific Congress of Golf, was scheduled on Australia's Gold Coast in the week preceding the Sydney Olympics. Researchers, practitioners, coaches and players were invited to share insights on the theme, Optimising Performance in Golf, from the multidisciplinary perspectives of sport psychology, exercise science and sports medicine, coaching and learning.

Despite the superb location and what was expected to be ideal timing, there were insufficient papers for a 3-day scientific program. Many of those who wanted to participate were prevented from doing so because of their professional responsibilities with athletes preparing for the Games or because of teaching commitments — in some cases calendars were rearranged to accommodate the Games and their participants.

This book contains the three outstanding keynote presentations prepared for the conference and many other excellent chapters that together demonstrate the depth of knowledge about golf performance within each discipline; the significant benefits to be derived from multidisciplinary perspectives; and the value of a sound research base for professional practice aimed at optimising performance in golf. The decision to publish an edited book rather than a monograph of conference proceedings meant chapters could be updated, modified and strengthened. It also permitted the inclusion of important work being done by some authors who would not have been able to attend the conference.

Jack Nicklaus kindly agreed to write a letter of welcome to delegates that could be reproduced as a Foreword for this book. We are indeed privileged to share the insights of such an outstanding player. Like Karrie Webb and a number of other outstanding golfers from the state of Queensland, Greg Norman's willingness to support the conference is also acknowledged with gratitude.

All of the authors responded enthusiastically to the invitation to prepare chapters, and those who originally submitted their work for conference presentation are thanked for their loyalty and patience. We are all indebted

to the external peer reviewers who must remain anonymous, for their incisive and helpful comments on each of the manuscripts.

Other members of the World Scientific Congress of Golf Steering Committee and all associated with the Trust are thanked for their encouragement and support, particularly Martin Farrally and Eric Thain. Staff at Griffith University supported the Centre for Movement Education and Research's bid to host the conference. Roger Hunter, Marilyn McMeniman and Neil Dempster allowed me to pursue these goals, and Pamela Steele helped turn them into reality. Colleagues who served on the conference Organising Committee: Laurence Chalip, Rod Edwards, Greg Gass, Ian Robilliard, Dwight Zakus, and particularly Dick Roebuck, the Conference Manager, are thanked for their encouragement and advice. Christine Clarke provided graphic design support, and Chris Thomas developed and managed an excellent web site. Ray Over and Gerry Fogarty's highly valued advice is also acknowledged with much gratitude.

Finally, Stephen May and his staff at Australian Academic Press provided the expertise needed to publish this book. Stephen offered the flexibility we needed when originally planning to publish conference proceedings. He remained very supportive when these plans changed and has always displayed a commitment to excellence in publishing standards that is highly commendable.

When Professor Struther Arnott, Principal, University of St Andrews, opened the Third World Scientific Congress of Golf in 1998, he commented that if delegates gained just one good idea from the work presented, then their attendance at the congress would have been well worthwhile. There are many excellent ideas throughout this book. My hope is that these ideas contribute significantly to the development of golf science research and practice, and help all of us optimise our performance in golf.

GRIFFITH UNIVERSITY

The Path to Expert Golf Performance: Insights from the Masters on How to Improve Performance by Deliberate Practice

K. Anders Ericsson

Most people interested in a sport can recall, often with surprising clarity, amazing achievements by outstanding athletes. The performance of these athletes sometimes seems to transcend the humanly possible, allowing us to glimpse the extraordinary. These experiences are filled with such strong and complex feelings that most people are reluctant to analyse these magical phenomena. It is therefore reasonable to assume that these individuals have characteristics that make them qualitatively different. These characteristics allow outstanding athletes to perform repeatedly at the level far superior to that of amateurs and less accomplished athletes in the same domain. It is tempting to explain these amazing and consistently superior performances by inborn differences and innate talents. This interpretation is particularly common for sports such as golf, archery, rifle shooting and darts, where most individuals reach a stable level of performance after months or years of active participation when the actions are elicited seemingly automatically. It is difficult for individuals who have reached this modest level of stable performance to conceive of any alternative account for large individual differences in achievement.

In this chapter I will propose a very different framework for explaining the path to expert performance in a wide range of domains such as chess, medicine, music, and sports, including, of course, golf. The central idea is that expert performance has a complex structure and is gradually acquired by deliberate practice over years and even decades of focused training. When we observe athletes and other experts perform, we are unaware of the many years of training, the thousands of hours that were necessary for these individuals to reach their current level of performance. Expert performance is similar to an iceberg, where only one tenth of the iceberg is visible above the surface of the water, and the other nine tenths are hidden below it. When fans observe an elite athlete perform at a competition lasting a few hours they may not be aware of the over 10,000 hours of practice that preceded this display of elite performance. The fans can only see less than a thousandth of the activity that was necessary to produce that performance.

I will show that the necessity for relevant experience and practice applies to everyone attaining superior expert performance — even the most "talented." In the words of the golfer voted the best player of the 20th century, Jack Nicklaus (1974, p. 204, italics in original) agrees:

> Nobody — but *nobody* — has ever become really proficient at golf without practice, without doing a lot of thinking and then hitting a lot of shots. It isn't so much a lack of talent; it's a lack of being able to repeat good shots consistently that frustrates most players. And the only answer to that is practice.

Most individuals active in a domain believe that performance increases with experience and practice but after the attained performance reaches a stable level within months or a year it becomes automatic and thus seemingly impossible to control consciously. According to this popular view, the stable level of attainable performance is limited by basic innate capacities and anatomical differences which cannot be changed by training and practice. Later in this chapter I will show that these beliefs are incorrect for most aspects of expert performance.

Drawing on accounts from masters and data from scientific research, I will describe types of practice that allow future expert performers to keep improving and increasing control over their performance during years and even decades of sustained practice. This type of practice is quite distinct from the types typically engaged in by amateurs. I will discuss how individuals can acquire mechanisms to control performance even when it is rapid and seemingly automatic, such as hitting by baseball players, rapid movement sequences by pianists, and even the golfer's swing. Unfortunately, some discussion of golf performance will be speculative because the necessary scientific studies have not been published, at least not to my knowledge.

To what extent do individuals' anatomy and basic capacities constrain the level of performance that they can attain? Scientists often try to explain the human body by drawing analogies to machines, such as the explanation of blood circulation by the heart working as a pump and the explanation of movements by coordinated contractions by muscles akin to puppets on strings and mechanical robots. The brain is even compared to a computer where it is easy to modify the computer programs (software) but impossible to change the electronic hardware that executes the programs. Unlike machines, however, the human body consists of living biological systems that can change in response to external events. We all know that the body — unlike machines — can heal itself after an injury, such as after a cut or a broken bone, and that the body becomes more efficient with extensive use, rather than wears out as machines tend to do. The human body's remarkable capacity to respond to emergencies reveals the potential for adaptation and change that might be induced by extended periods of intense practice.

Before outlining the main topic of my chapter, namely the study of expert performance, I want to convince you that humans of all ages, even adults, can alter seemingly basic characteristics and follow the path to expert performance. I have selected examples of large improvements in the performance of rather basic functions, such as memory and motor performance, to show how performance of adults assumed to reflect basic functions can be changed by the acquisition of complex mechanisms that circumvent basic constraints or alter physiological functions.

Scientific Analysis of Large Improvements in Basic Functions

Anytime one argues against rigid limits on performance and the possibility of improvement, it is essential to distinguish the scientifically-based argument for flexible limits from the largely unscientific claims that "anything is possible if one believes in oneself and works hard enough." Scientific reviews of the claims for the self-made man have found virtually no rigorous evidence for self-generated fundamental change and attained success among large representative groups (Ericsson, Krampe, & Heizmann, 1993). The difficulty of changing abilities and performance, especially among adults, has led to the popular view that adults' abilities and performance are determined by fixed innate capacities.

My personal search for evidence of plasticity in adult abilities led to a study with Bill Chase that was eventually published in *Science* (Ericsson, Chase, & Faloon, 1980). Bill Chase and I were interested in whether one could improve the capacity of short-term memory. One of the key discoveries in cognitive psychology is that adults have a very limited ability to remember unrelated pieces of information, especially when they are presented briefly. George Miller (1956) found that the number of unrelated items that could be recalled was surprisingly invariant with the same limit of around seven items for many types of materials, such as letters, colors and numbers — the equivalent of most seven-digit phone numbers. Figure 1 shows the digit memory performance of four randomly selected college students, whose initial recall was limited to around seven digits. All of the participants increased their memory by 200%, to over 20 digits, after around 50 hours of practice on this task and two of them by more than 1000%, to over 80 digits, after 200–400 hours. Analysis revealed that their performance was mediated by acquired knowledge and skills which closely matched the demands of the trained task (Chase & Ericsson, 1982; Ericsson, 1985, 1988). In other words, their acquired abilities tended to be task specific. In spite of the large improvement in their memory for digits, their memory performance for other material, such as letters, remained at their original unexceptional level.

Research shows that the effects of practice are far greater on the specifically trained activity than most people believe possible. The examples from motor performance are particularly striking. A musician recently broke the record for sustaining a continuous tone on a wind instrument. An amateur musician might be able to sustain a note for about a minute. Saxophonist, Kenny G, played a continuous note for over 45 minutes. This performance is easily explained by the acquired method of circular breathing, where the musician is able to breathe through the nose while the mouth exhales air at a constant stream. Just one other example: How many push-ups can a college student in a Physical Education class complete in a row? Around 20, plus or minus 12, that is between 8 and 32. How many are possible after special

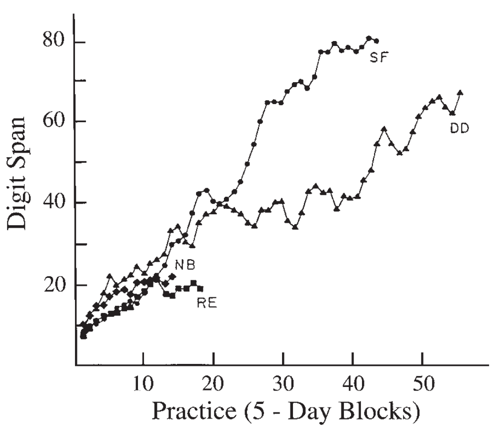

Figure 1

The average digit span for four college students (SF, DD, RE, and NB) as a function of number of practice sessions.

practice? In 1966, the record was almost 7,000, but that has been broken and currently is over 20,000. Even more impressively, the Guinness-book record for one-arm pushups is now almost 9,000 in a row!

The changes in performance on tasks originally designed to measure stable capacities of short-term memory and anaerobic fitness are dramatic. These demonstrations of improvements by 1000% to 10,000% wouldn't be possible if these functions were tightly constrained by unmodifiable genetic factors. Even more compelling is the nature of the mechanisms that mediate these large improvements in performance. The untrained original performance can either be fundamentally changed, as is the case in push-ups, or circumvented by acquired specific skills and adaptations, as it is in short-term memory for digits and continuous playing of notes. It is important to note that these large improvements are very specific adaptations to particular tasks and situations. They do not lead to superior memory for all materials or strength to perform any physical activity.

Outline of Chapter

It is only possible to study expert performance with scientific methods when we can specify an observable empirical phenomenon. Scientific methods, such as analysis and experimentation, require that the phenomenon is reproducible. My colleagues and I therefore limit our investigation to those aspects of expert performance that can be consistently reproduced at a superior level by individuals in competition and practice. In the first section on general characteristics of expert performance, I will first argue that once we define superior achievement in domains of expertise as valid reproducible performance, we can capture that performance under standardised conditions. When we constrain our claims to this type of reproducibly superior performance then an interpretable picture of findings emerges. For example, I will show that even the performance of the most skilled practitioners develops gradually and, with rare exception, takes at least 10 years of active involvement within a domain to reach an international level (Ericsson, 1996, 1997, 1998; Ericsson & Charness, 1994; Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Lehmann, 1996). However, the vast majority of amateurs active in domains of expertise such as golf and tennis show minimal performance improvements even after decades of participation. The first section will be concluded with a discussion of the difference between mere participation in domain-related activities and activities designed to improve performance — deliberate practice. In the second section of my chapter I will for the first time apply the expert performance framework to capture expert performance in golf and discuss how it might be acquired through training. The final section of the chapter will integrate the new findings from golf with more extensively studied domains of expertise and discuss the development of golf performance in a life-span perspective and the cognitive mechanisms mediating deliberate practice.

The Scientific Study of Expert Performance

Many of the most amazing accomplishments, such as those by the famous musician, Paganini, and the famous mathematician, Gauss, refer to events that cannot be independently verified and are likely to reflect distortions and misunderstandings (Ericsson, 1996, 1997, 1998). Outstanding sports achievements are often performed in front of large audiences and their authenticity is not in question. However, would these athletes be able to reproduce their exceptional achievement repeatedly? For example, would a golfer be able to sink a decisive 40-foot putt in the championship again and again, if given the opportunity to make the same putt several times? Only those aspects that can be reliably regenerated can be explained by stable attributes of the expert performer. To study exceptional achievement scientifically, it is necessary that we distinguish astonishing anecdotes and singular successes from empirical evidence reflecting stable phenomena that can be independently verified and reproduced under controlled circumstances. Reviews (Ericsson & Lehmann, 1996; Ericsson & Smith, 1991) show that restricting research to this clearly defined empirical evidence yields an orderly and consistent body of knowledge.

In most domains of expertise, individuals have been interested in assessing the level of reproducible performance under fair and controlled circumstances. Most competitions in sports are highly standardised and even approach the level of rigorous control of laboratory studies of performance. In a similar manner, musicians, dancers, and chess players perform under controlled conditions during competitions and tournaments. Individuals who display superior performance from competition to competition meet the standards of reproducible superior performance. In golf, the number of strokes necessary to complete one or more rounds of an 18-hole golf course differs reliably between golf players. This measure of golf ability is related to aspects of components of golf playing in tournaments, such as the average accuracy and distance of drives and average number of putts for amateurs (Reddy, 1990; Riccio, 1990; Thomas & Over, 1994a) and professionals (Belkin et al., 1994; Rotella & Boutcher, 1990).

Is it reasonable to extend the concept of expertise to any domain of activity where individuals become increasingly experienced and knowledgeable, as the pioneering researchers of expertise (Chase & Simon, 1973; Glaser & Chi, 1988) had proposed? As a first step to identify reproducible performance, Ericsson and Smith (1991) discussed how various types of professional expertise could be measured by performance under comparable conditions. Recent reviews show that only experts in certain domains perform at a consistently superior level to less experienced individuals (Ericsson & Lehmann, 1996). For example, highly experienced psychotherapists are not more successful in treatment of patients than novice therapists (Dawes, 1994) and stock-market experts and bankers were not able to forecast stock prices better than university teachers and students (Stael von Holstein, 1972). If we are interested in understanding the structure and acquisition of excellence in the representative activities that define expertise in a given domain, we need to restrict ourselves to domains in which experts exhibit objectively superior performance.

If expert performers can reliably reproduce their performance in public, it is likely that they could do the same during training, and even under laboratory conditions, a finding confirmed by recent research (Ericsson & Lehmann, 1996). Unfortunately, the conditions of naturally occurring expert performance are quite complex and frequently differ markedly across domains. For example, musicians are allowed to select their own pieces of music for their performance, the sequence of moves that chess players make in a game is never the same and the exact sequence of shots required by different golfers playing the same course in a tournament will differ considerably.

Capturing Expert Performance under Standardised Controlled Conditions

Is it possible to present all performers with the same set of tasks or situations so their performance can be directly compared? Ericsson and Smith (1991) proposed that the naturally occurring performance should first be analysed to identify critical activities that capture expertise in the domain. Next, representative situations should be identified and performers be instructed to perform the associated tasks. Once the tasks that represent typical demands in the domain are recognised, it should be possible to reproduce expert performance under controlled laboratory conditions so that investigators can identify the responsible mediating mechanisms.

Figure 2 illustrates three types of tasks believed to capture the essence of expertise, where the measured performance is closely related to the level of naturally occurring performance. First, when studying chess expertise, players at different skill levels are asked to find the best move for chess positions that have been selected from chess games between masters but would still be unfamiliar to the tested players. Any chess player who can select consistently better chess moves than other chess players for virtually any chess position would almost by definition have to be a superior chess player. Secondly, given that expertise in typing should generalise to any type of material, we can simply give all typists the same text material and ask them to type it accurately as fast as possible. Lastly, when studying music expertise, we need to confront the problem that the expert musicians typically perform pieces of music that are too difficult for less accomplished musicians to master. It is possible to instruct all musicians to play familiar or unfamiliar pieces of lower difficulty, then ask them to repeat their performance. When musicians are instructed to repeat their original performance, experts can do it with much less deviation than less skilled musicians, thus exhibiting greater control over their performance.

When capturing golf expertise, it should be possible to present golfers of different ability with a series of the same ball placements on a course and ask them to execute each of these shots several times. In each of these tasks the golfer has to decide how and where to hit the golf ball before actually striking it, a task which relies on both cognitive and perceptual-motor abilities. Golfers differ in where they aim the golf ball as well as in their execution of the actual shot. Consequently, if we want to assess golfers' control over their shots, we should assess their variability and control over specified shots. For example, Hill, Ericsson, and Watson (1999) asked golf players to perform an even simpler task, namely reproducing the same putting stroke many times, and found that expert golfers were much less variable than golfers with higher handicaps. To determine some of the cognitive factors mediating the

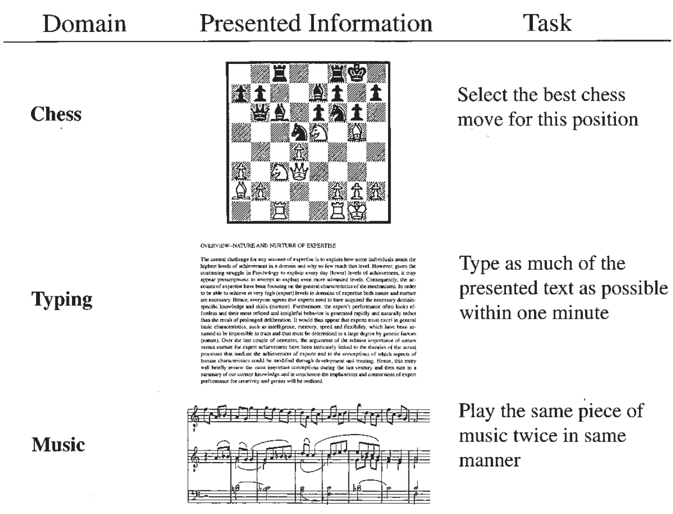

Figure 2

Three examples of laboratory tasks that capture the consistently superior performance of domain experts in chess, typing and music. (From "Expertise," by K. A. Ericsson & Andreas C. Lehmann, 1999, *Encyclopedia of Creativity*. Copyright by Academic Press.)

preparation of a specific shot, we might also ask the golfers to indicate where they are aiming the golf ball and its projected trajectory toward the intended target (Hill et al., 1999).

When we consider only the superior reproducible performance of experts, it is possible to identify several claims about expertise that generalise across domains. Next, I will show that expert performance is primarily acquired, and that extensive domain-related experience is necessary but not sufficient for its development.

The Necessity of Domain-Specific Experience and Practice

Recent reviews of the development of expert performance in a wide range of domains of expertise (Ericsson, 1996; Ericsson & Lehmann, 1996) show that extended engagement in domain-related activities is necessary to attain expert performance in that domain. There are several types of evidence for the necessity of domain-specific experience. First, when performance is measured under the same test conditions over years and decades, performance is found to improve gradually, as illustrated in Figure 3. There is no evidence for abrupt changes in the reproducible performance from one time to the next. Even the performance of child prodigies in music and chess, whose performance is vastly superior to that of their peers, shows gradual, steady improvement over time when measured by adult standards.

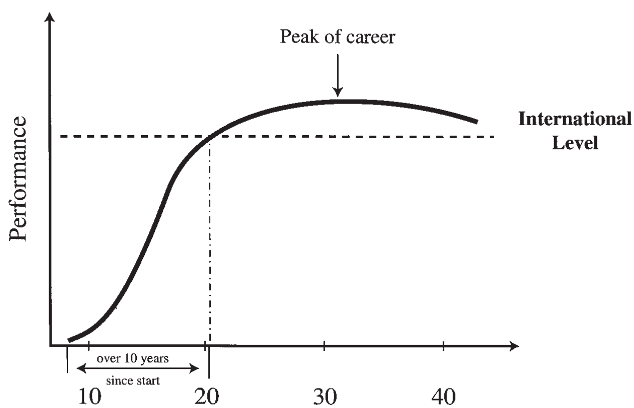

Figure 3

An illustration of the gradual increases in expert performance as a function of age, in domains such as chess. The international level, which is attained after more than around 10 years of involvement in the domain, is indicated by the horizontal dashed line. (From "Expertise," by K. A. Ericsson & Andreas C. Lehmann, 1999, *Encyclopedia of Creativity*. Copyright by Academic Press.)

Similarly, outstanding, "talented" swimmers, tennis players, musicians, and chess players frequently start at very young ages. Parents often encourage their children to begin practice in some domains as early as 3 or 4 years of age, with average starting ages for the most elite performers of around 6 years of age (Ericsson, Krampe, & Tesch-Römer, 1993). An analysis of the top nine golf players voted the best of the 20th century (based on the average ages given in Barkow & Barrett, 1998, and Goodner, 1978) gave a mean starting age of 8.8 years. When young elite performers from all these domains first participate in competitions with adult standards as adolescents, their high level of initial achievement must, at least in large part, reflect the results of many years of intense involvement and practice. Later in this chapter I will discuss evidence suggesting that early experience and practice in domains, especially those involving perceptual-motor activities, might induce physiological and anatomical changes that will facilitate the level of performance that can be attained in adulthood.

If elite performance were limited primarily by the functional capacity of the body and brain, one would expect performance to peak around the age of physical maturation — the late teens in industrialised countries. However, experts' best performances are often observed many years, or even decades, later, as illustrated in Figure 3. The age at which performers typically reach their highest level of performance in many vigorous sports is the mid- to late 20s; for fine-motor athletic activities and the arts and science, it is a decade later, in the 30s and 40s (Lehman, 1953; Schulz & Curnow, 1988). It is generally assumed that skilled aspects of performance improve with experience until these benefits are offset by inevitable decrements in the physiological capacities due to increased age (Schulz, Musa, Staszewski, & Siegler, 1994). The peak performance of elite golfers is generally observed when they are in their 30s (Schulz & Curnow, 1988). However, the age-related decrements in performance of elite athletes, especially professional golfers, are remarkably small (Ericsson, 1990; Spirduso, 1995).[1] When the golf performance of the top 10 players from the PGA and Senior PGA tour, respectively, were compared, the differences in all categories, including driving and percent greens in regulation, were found to be remarkably small (Spirduso, 1995). In fact, at the age of 50, Raymond Floyd won the Doral Ryder Open tournament in 1992. More recent laboratory studies of performers with maintained expert performance, such as expert pianists in their 60s (Krampe & Ericsson, 1996), have raised doubt about the explanations based on inevitable aging decrements, which I will return to later in my chapter.

Finally, the most compelling evidence for the role of vast experience in expertise is that even the most "talented" need around 10 years of intense involvement before they reach an international level, and for most individuals it takes considerably longer. Simon and Chase (1973) originally proposed the 10-year rule, showing that no modern chess master had reached the international level in less than approximately 10 years of playing. Subsequent reviews show that the 10-year rule extends to music composition, as well as to sports, science, and the arts (Ericsson, Krampe, & Tesch-Römer, 1993). An informal analysis of the top nine golfers of the 20th century (Barkow & Barrett, 1998) showed that they won their first international competition at around 25 years of age, which, on the average, was almost 16 years after they started golfing. Gary Player was the only player in this group to achieve international success in less than 10 years — it took him 7 years. However, Gary Player started playing golf unusually late, at age 15 (Barkow & Barrett, 1998). It is likely that his early involvement in "cricket, rugby, soccer, track, swimming, and diving" (Barkow & Barrett, 1998, p. 147) contributed significantly to his unusually rapid acquisition of golf performance. In sum, the fact that prolonged engagement in specific, domain-related activities is necessary to acquiring expertise is well established. Most importantly, given that very few individuals sustain a full commitment toward reaching one's highest level of performance in a sport for more than a few months, much less years, the rest of us will never know the upper limit of our performance.

Extensive domain experience is clearly a prerequisite for the select group of elite individuals who reach very high levels. On the other hand, extensive experience is necessary but not sufficient. For example, once the necessary training has been completed the length of professional experience has often been found to be a weak predictor of performance in representative professional activities, such as medical diagnosis (Norman, Coblentz, Brooks, & Babcook, 1992; Schmidt, Norman, & Boshuizen, 1990), auditing (Bedard & Chi, 1993; Bonner & Pennington, 1991), text editing (Rosson, 1985), and judgment and decision making (Camerer & Johnson, 1991; Shanteau & Stewart, 1992). Furthermore, consider the stability of the modest performance of recreational golfers, tennis players and skiers even after decades of active involvement in the domain. A more detailed study of the differences in the development of elite and amateur performers reveals differences in the particular types of domain-related activities they engage in.

Bloom's (1985) retrospective interviews of international-level performers in many domains show that elite performers are typically introduced to their future domain in a playful manner. As soon as they enjoy the activity and show promise compared to their peers in the local school or neighborhood, they are encouraged to seek out a teacher and initiate regular practice. Bloom and his colleagues have shown the importance of access to the best training environments and the most qualified teachers. The parents of the future elite performers spent large sums of money for teachers and equipment, and devote considerable time to escorting their child to training and weekend competitions. In some cases, the performer and their family even relocate to be closer to the teacher and the training facilities. Bloom (1985) has argued that access to the best training resources was necessary to reach the highest levels, but obviously not sufficient.

Given the limited opportunities available to work with the best teachers and training resources, only the individuals perceived to have the most promise for success are admitted at each stage. Could it be that superior training resources do not really enhance the rate of improvement, and that highly selected individuals would improve just as well by themselves? The best single source of evidence for the value of current training methods comes from historical comparisons (Ericsson, Krampe, & Tesch-Römer, 1993; Lehmann & Ericsson, 1998). The most dramatic improvements in the level of performance over historical time are found in sports. In some events there have been only very minor changes in rules and equipment over time, which allows us to infer that increases in performance reflect genuine increase in the elite performers' ability and skill. For example, in the marathon and swimming events, many serious amateurs of today could easily beat the gold medal winners of the early Olympic games. Furthermore, after the IVth Olympic Games in 1908, they almost prohibited the double somersault in dives because they believed that these dives were so dangerous that no human would ever be able to control them. Similarly, some music compositions deemed nearly impossible to play in the 19th century have become part of the standard repertoire today. In golf, large increases in elite performance have also been documented. During the last 100 years the number of strokes in the British Open have been reduced by almost 10 strokes per round (Hale & Hale, 1999). Changes in golf clubs, balls, and course management may explain part of these changes but much of the improvements in golf performance are clearly due to other sources, such as training and practice. In sum, large improvements in performance over the last centuries imply that expert performers do not automatically reach their highest level. Furthermore, large increases in performance that cannot be attributed to improved equipment implicate better and more extensive training.

If the best individuals in a discipline already differ from other individuals at the start of training with master teachers and coaches, how can we explain these differences in performance prior to this advanced level? To determine which activities could improve performance development prior to advanced training, we should first consider which conditions facilitate effective learning and performance improvement. A century of laboratory research has revealed that learning is most effective when it includes explicit goals, such as improving a specific aspect of performance; feedback that compares the actual to the desired performance; and opportunities for repetition, so the desired level of performance can be achieved.

In an attempt to assess the role of practice in attaining very high levels of performance my colleagues and I (Ericsson, Krampe, & Tesch-Römer, 1993) searched for a domain where the techniques for training outstanding performers have been refined over a long period of time. We selected the domain of music because historically music training of expert musicians has started at relatively young ages (often around 5 to 7 years), and has for many centuries been conducted by professional teachers who developed training methods and improved pedagogy. Based on interviews with expert violinists at the music academy in Berlin, we identified activities for which we could trace the duration of the music students' engagement during the period prior to their entry in the music academy. We were particularly interested in those activities that had been specifically designed to improve performance. When individuals engage in these activities with full concentration we call these activities deliberate practice. A good opportunity for deliberate practice is the music students' solitary practice in which they can work to master specific goals determined by their music teacher at weekly lessons. We were able to compare the time use among several groups of musicians differing in their level of music performance, based on daily diaries and retrospective estimates. Even among these expert groups we were able to find that the most accomplished musicians had spent more time in activities offering opportunities for deliberate practice during their development (see Figure 4) and that these differences were reliably observable before their admittance to the academy at around age 18. By the age of 20, the best musicians had spent over 10,000 hours practising, which is 2,500 and 5,000 hours more than two less accomplished groups of expert musicians, respectively, and 8,000 hours more than amateur pianists of the same age (Krampe & Ericsson, 1996).

Several studies and reviews have found a consistent relation between performance level and the amount of activities offering opportunities for deliberate practice in chess (Charness, Krampe, & Mayr, 1996), sports (Helsen, Starkes, & Hodges, 1998; Hodges & Starkes, 1996; Starkes et al., 1996) and music (Krampe & Ericsson, 1996; Lehmann & Ericsson, 1996; Sloboda, 1996). The concept of deliberate practice also accounts for many earlier findings in other domains (Ericsson & Lehmann, 1996), as well as for the results from the rare longitudinal studies of elite performers (Schneider, 1993).

The Distinctive Characteristics of Deliberate Practice

Many people find it difficult to believe that expert performance can result from practice, because of their conceptions of practice which differs

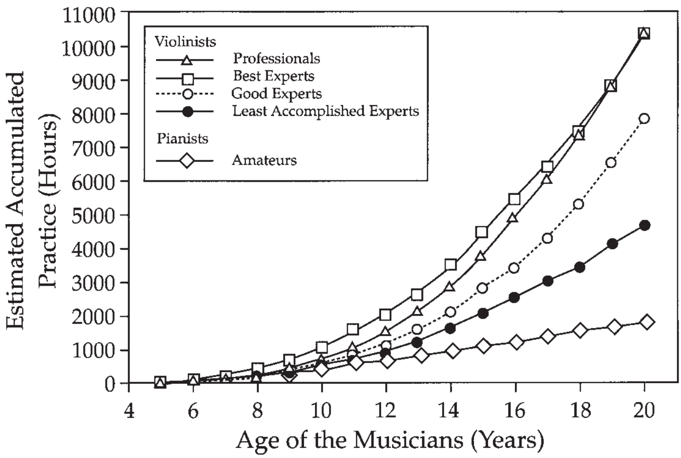

Figure 4

Estimated amount of time for solitary practice as a function of age for the middle-aged *professional* violinists (triangles), the *best* expert violinists (squares), the *good* expert violinists (empty circles), the *least accomplished* expert violinists (filled circles) and *amateur* pianists (diamonds). (From "The role of deliberate practice in the acquisition of expert performance," by K. A. Ericsson, R. Th. Krampe & C. Tesch-Römer, 1993, *Psychological Review, 100*(3), p. 379 and p. 384. Copyright 1993 by American Psychological Association. Adapted with permission.)

markedly from our definition of deliberate practice. When most people imagine a child practising the piano, they tend to think of someone mindlessly repeating the same short piece, while the sound remains unmusical, aversive, and without any noticeable improvement. Nobody could seriously argue that poor or mediocre piano students could become outstanding musicians merely by spending more time on this type of mechanical practice. Mindless repetition is the direct opposite of deliberate practice, when individuals concentrate on actively trying to go beyond their current abilities. Consistent with the mental demands of problem solving and other types of learning, deliberate practice is done in limited periods of intense concentration. Diaries of the expert musicians revealed that they only engaged in practice without rest for around an hour and they preferred to practise early in the morning when their minds were fresh (Ericsson, Krampe, & Tesch-Römer, 1993). Even more interesting, the best expert musicians were found to practise, on the average, the same amount every day, including weekends, and the amount of practice never consistently exceeded 4 to 5 hours per day. The experts told us during interviews that it was primarily their ability to sustain the concentration necessary for deliberate practice that limited their hours of practice. And their diaries reveal that the more the experts practised, the more time they spent resting and sleeping — the increased sleep was primarily in the form of afternoon naps. Our review of other research (Ericsson, Krampe, & Tesch-Römer, 1993) showed that deliberate practice or similarly demanding activities by elite performers was limited to 4–5 hours per day for a wide range of domains of expertise. For instance, famous authors restricted the amount of daily writing to around four hours in the morning and they spent the rest of the day recuperating. Furthermore, unless the daily levels of practice were restricted, such that subsequent rest and nighttime sleep allowed the individual to restore their equilibrium, individuals would encounter overtraining injuries, and eventually incapacitating "burnout" (Ericsson, Krampe, & Tesch-Römer, 1993).

Do the best performers in a domain also need deliberate practice to perfect their skills, or are they fundamentally different? Do they make better — and different — use of the same training activities than their less "talented" peers? Fortunately, many of the famous musicians and acclaimed music teachers have been interviewed about the structure of their practice, so we have the perspective gained from their experience. Their answers are remarkably consistent (Ericsson, in press) and are eloquently summarised by one of the best-known violin teachers and virtuosi, Emil Sauer (1913, p. 238):

> One hour of concentrated practice with the mind fresh and the body rested is better than four hours of dissipated practice with the mind stale and the body tired.… I find in my own daily practice that it is best for me to practise two hours in the morning and then two hours later in the day. When I am finished with two hours of hard study I am exhausted from close concentration. I have also noted that any time over this period is wasted.

It is clear that the need for specific types of practice, such as etudes and scales, diminishes for musicians who have already attained technical mastery, but not the need for deliberate practice in mastering new pieces: "With the limited time I have practice nowadays, I apply myself immediately to works that I am preparing" (Katims, 1972, p. 238). Many elite musicians are able to engage in mental practice: "I have a favorite silent study that I do all of the time, I do it before I start practising. I do it on the train during my travel, and before I come out on the platform. I do it constantly" (Primrose, 1972, p. 248).

Remarkably similar statements are made by coaches and outstanding athletes in domains involving fine-motor skills, such as billiards, darts, bowling and golf. Jack Nicklaus (1974) said that even in his mid 30s he maintained a regular level of play during the whole year, but that his overall amount of practice was reduced from his early career as he mastered the basics of his swing and as his practice became more efficient (p. 197):

> whenever I do go out with a bag of balls I have a very specific objective in mind and, once I've achieved it, I quit. All my life I've tried to hit practice shots with great care. I try to have a clear-cut purpose in mind on every swing. I always practise as I intend to play. And I learned long ago that there is a limit to the number of shots you can hit effectively before losing your concentration on your basic objectives.

When professional golfers keep practising too much, Nicklaus (1974, p. 197) suggested that "they often weaken their games by letting their practice become pointless through sheer monotony or fatigue." The famous golf coach Jim McLean (1999, p. 127) recommends that "Practise only as long as you can concentrate. Stop when you're not having fun or if you lose focus. Short, focused practice sessions are often the most productive."

After reading many books on the development of elite performance in music, golf and many other fine-motor activities, I find it interesting how often individual differences among young performers who practise similar amounts of time are attributed to differences in the quality of their practice. The famous violin teacher Ivan Galamian (1972, p. 351) argued:

> If we analyse the development of the well-known artists, we see that in almost every case the success of their entire career was dependent upon the quality of their practising. In practically each case, the practising was constantly supervised either by the teacher or an assistant to the teacher. The lesson is not all. Children do not know how to work alone. The teacher must constantly teach the child how to practise.

Kroen (1999, p. 53) similarly explained the lack of improvement of golfers' swings, despite much practice:

> Many players confuse hitting balls with practice. If you watch golfers at a crowded driving range you will see many who are hitting ball after ball with the same club (usually a driver) without ever checking their grip, stance or alignment. Every shot in practice should be hit at a target with concentration on the fundamentals and an evaluation of the result.

Sam Snead (1989, p. 159), who was voted the 4th best golfer in the 20th century, also emphasised the difference between the enjoyment of mastered movements and the demanding process of improvement:

> It is only human nature to want to practise what you can already do well, since it's a hell of a lot less work and a hell of a lot more fun. Sad to say, though, it doesn't do a lot to lower your handicap. … I know it's a lot more fun to stand out on the practice tee and rip drivers than it is to chip and pitch, or practise sand shots with sand flying back in your face, but it all comes back to the question of how much you're willing to pay for success.

An essential prerequisite for deliberate practice is sustained concentration, but even concentration appears to be subject to practice. For example, Ben Hogan (1948, p. 172) claimed that:

> While I am practising I am also trying to develop my powers of concentration. I never just walk up and hit the ball. I decide in advance how I want to hit and where I want it to go. ... Adopt the habit of concentrating to the exclusion of everything else while you

are at the practice tee and you will find that you are automatically following the same routine while playing a round in competition.

More generally, Starkes et al. (1996) showed that the duration of daily training given future expert performers was very similar across several domains, such as music and sports. During the first year, the daily level of practice was around 15–30 minutes, on average, with steady increases for each additional year, reaching 4–5 hours after around a decade. Starkes et al. found an intriguing similarity between increases in the amount of practice for sports when the athletes started practice around age 12, and music, when start of practice is closer to 6–7 years of age. If this pattern of results is found consistently across all domains, it would suggest that the level of increased training may require a slow physiological adaptation to increased demands of habitual practice. This slow adaptation may be relatively insensitive to chronological age.

The attainment of expert performance requires an extended period of high-level deliberate practice, where the duration of practice is limited by the ability to sustain concentration, a capacity which appears to increase as a function of years of practice in the domain. Consequently, a certain amount of deliberate practice may be necessary to reach the highest performance levels, and individual differences, even among experts, may reflect primarily differences in the amount and quality of practice. However, most people would argue that there are distinct limits to the influence of practice, and that inborn capacities and innate talent will play a very important role in determining performance, especially at the highest levels within a domain. Sternberg (1996) has even proposed that individuals with more innate talent would be more successful during practice, and thus more willing to engage in practice — possibly explaining at least part of the relation between amount of deliberate practice and performance.

In the next section of this chapter, I will propose that expert performance can be viewed as the end product of an extended series of psychological modifications and physiological adaptations. Furthermore, I will explain how expert performance is mediated by complex memory mechanisms and representations which have been acquired as a result of practice, and how these mechanisms are critical to continued performance improvement. There are many general characteristics of acquiring expert performance that appear to be invariant across domains. However, an analysis of how expert performance is acquired in a particular domain, such as golf, through deliberate practice, must explain the acquisition of the unique characteristics of expert golf and thus be specific to that domain. In the next section I will develop an expert-performance framework for golf, where the reproducible performance of expert golfers is first captured, then analysed and finally the acquisition of its mediating mechanisms and representations is related to deliberate practice reported by the golf masters. The development of this framework has been a challenge for me, because I didn't know hardly anything about golf until a couple of years ago. During my subsequent reading of a large number of books on golf, I have been searching for quotes by eminent golfers that would express my own ideas on expert performance, as well as disagree with them. In the following section I have included quotes by expert golfers to support critical points, which shows that several of the most knowledgeable individuals about the acquisition of expert performance in golf share these ideas on expert performance and deliberate practice.

The Structure and Acquisition of Expert Performance in Golf

The popular conception of how everyday skills are acquired has little in common with our view that expert performance is acquired through deliberate practice. In contrast to the rapid automatisation of everyday skills, such as preparing food or driving a car, and the emergence of a stable level of performance, expert performance continues to improve as a function of increased experience and deliberate practice, as illustrated in Figure 5. The key challenge for aspiring experts is avoiding the arrested development associated with generalised automaticity of performance and acquiring the cognitive skills that support continued learning and improvement. Expert performers achieve this by deliberately acquiring and refining cognitive mechanisms to enhance their control and monitoring of performance. For example, they deliberately construct training situations that induce discrepancies between their actual and desired performance. By comparing their performance to that of more proficient individuals in their domain of expertise, they can identify differences and gradually reduce them through extended deliberate practice. Given that expert performance is an adaptation to the task constraints of the representative domain activities, we need to study those constraints in order to understand the mechanisms underlying expertise and the associated deliberate practice activities.

The Essence of Golf: Capturing Expert Golf Performance

When we examine the structure of expert golf performance it becomes clear that there are no magical techniques for hitting the ball or shortcuts to attaining elite performance. To hit a golf ball to an exact location is more than difficult. It is impossible even for the best golf players to do so consistently — at least for shots and putts traveling more than a few feet. The belief that a player would be able to control the motion of the ball so completely that it would always reach its exact desired destination is fundamentally incorrect. The motion of the golfers' limbs and clubs and the induced path of a golf ball

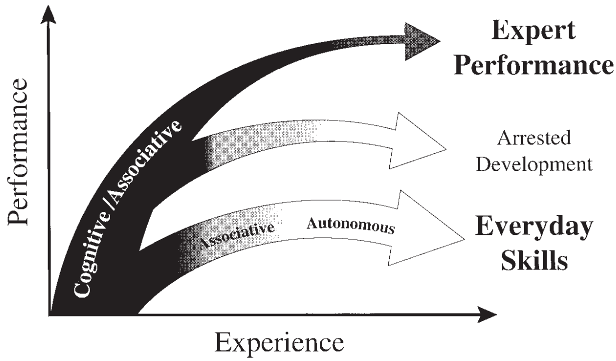

Figure 5

An illustration of the qualitative difference between the course of improvement of expert performance and of everyday activities. The goal for everyday activities is to reach as rapidly as possible a satisfactory level that is fixed and "autonomous." After individuals pass through the "cognitive" and "associative" phases they can generate their performance with a minimal amount of effort (see the gray/white plateau at the bottom of the graph). In contrast, expert performers counteract automaticity by developing increasingly complex mental representations to attain higher levels of control of their performance and will therefore remain within the "cognitive" and "associative" phases. Some experts do not continue to seek improvement through deliberate practice and thus their performance will be automated prematurely. (Adapted from "The scientific study of expert levels of performance: General implications for optimal learning and creativity" by K. A. Ericsson in *High Ability Studies, 9*, p. 90. Copyright 1998 by European Council for High Ability.)

will always be to some degree unpredictable. Furthermore, the motion of a golf ball rolling on grass is also influenced by many uncontrollable factors. The essence of expertise in golf is, thus, to increase the players' level of control and reduce the unpredictability of their shots.

To what degree are shots and putts controllable? It is difficult to assess how much control an expert golfer has while playing. When a golfer drives the ball off the tee on longer holes, an observer cannot tell if the ball has landed exactly where it was aimed, as long as it reaches the fairway — after all, few golfers intentionally aim for the rough! However, when the expert golfer is close enough to reach the hole either by a single shot or a putt and it is reasonable "to go for the flag," we can infer that any deviation between the resting place of the ball and the hole was unintended, and thus is reflecting uncontrollable factors. Analyses of the putting performance by professionals (Cochran & Stobbs, 1968; Diaz, 1989; Tierney & Coop, 1999) show them to be rather inaccurate, especially at the longer distances, as is illustrated in Figure 6. Most interestingly, when 20 pros were asked to guess the probability of sinking a 6-

foot putt on the PGA Tour (Diaz, 1989), they predicted the probability to be over 70% — well above the Tour average of around 55%. "The only player who guessed lower than the Tour average was the acknowledged best putter among the pros, Ben Crenshaw" (Diaz, 1989, p. 77).

In order to assess the maximal level of putting performance, Cochran and Stobbs (1968) built a putting machine and found that on "perfect greens" this machine could sink 97% of 6-foot putts, only 50% of the 20-foot putts, and a mere 20% of the 60-foot putts. Similar estimates have been obtained by other mechanical putting devices (Hill et al., 1999; Pelz, 1989, 1994). Consistent findings are found for other types of shots when the variability of human and mechanical devices have been compared (Olsavsky, 1994).

To understand the development of expert performance in golf it is necessary to realise that golf shots and putts are relatively uncontrollable events. Someone might contest this claim by pointing to golf players' amazing accuracy when they are "hot" during competitions. However, scientific studies of elite basketball players suggest that "hot" streaks are not reliable effects. These streaks of outstanding performance can be explained by a series of chance occurrences (Gilovich, Vallone, & Tversky, 1985). For example, even a putting machine, such as the one developed by Pelz (1989, 1994) or Hill et al. (1999), would exhibit streaks of successful putts just by chance. During my reading I have found claims even by professionals that seem too good to be true. For example, even the analytical Tom Watson

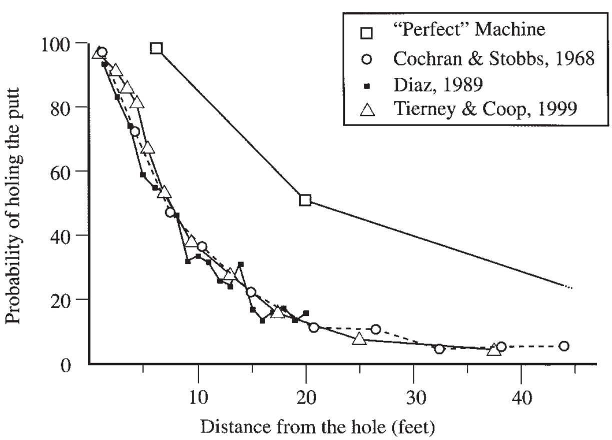

Figure 6

The relation between successful putting and the putts' distance from the hole for three samples of professional golfers and Cochran and Stobbs' (1968) mechanical putting device operating under "perfect green conditions."

(1983, p. 43) says "When I am putting well, I can place two balls 40 feet from the hole, putt the first ball and then putt the second ball without looking up — and hit the first ball with the second." Based on the earlier reviewed evidence with mechanical putting devices, I believe this feat might have been due to chance, that Tom Watson would not be able to consistently putt that accurately even on days when he is "putting well." It is reasonable to assume that a golfer would not be able to putt better than, or even as well as, the mechanical putting devices operating under "perfect green conditions" (Cochran & Stobbs, 1968).

Elite golfers sometimes comment on the unpredictability of shots. Cohn (1994, p. 19) quotes David Edwards as saying: "You can hit a great shot and end up 10 to 15 feet from the hole, or you can hit a lousy shot and it goes in the hole, and that's just the nature of golf." During play in tournaments there is no way to tell if a better shot could have been produced consistently because only a single shot is allowed. When elite players discuss differences between good and bad rounds they appear to disregard the possibility that chance factors (outside their control) played an important role (Kirschenbaum, O'Connor, & Owens, 1999) and often attribute their performance to poor concentration, tenseness, and poor imagination and feel (McCaffrey & Orlick, 1989). However, some elite golfers do seem to accept limits to control. McLean (1999, p. 96) cites Jackie Burke as claiming that:

> golf is basically a game of hitting circles. The first circle is the area in which you're trying to drive the ball. …When you are on the green, you're trying to hit the ball into roughly a 3-foot circle around the cup. Once you get into that 3-foot circle, you putt to the ultimate and smallest circle, the cup.

Ben Hogan (1957, p. 113, italics added) claimed that he gained a dramatic increase in confidence when:

> I had stopped trying to do a great many difficult things *perfectly* because it had become clear in my mind that *this ambitious overthoroughness was neither possible nor advisable*, or even necessary. All you needed to groove were the fundamental movements — and there weren't so many of them. Moreover, they were movements that were basically controllable and so could be executed fairly well whether you happened to be sharp or not so sharp that morning.

In conclusion, the fact that many elite golfers seem to have difficulty determining the limits of their control and accepting the role of chance factors is important for a couple of reasons. First, if the elite golfers generate methods to control what are inherently chance factors, these methods will be neither valid nor reliable. The role of "superstition" has been well documented in golf (Melvin & Grealy, 1999) and other sports, such as baseball (Ciborowski, 1997). The possible use of spurious methods means that it is necessary to carefully evaluate reports by elite golfers to distinguish those based on consistent, controllable elements and observations from those that are not. Second, even when misses are due solely to uncontrollable chance factors, they will have emotional effects which in turn may influence subsequent performance (Kirschenbaum et al., 1999). However, the complex issues regarding control of negative emotions and cognitions are outside the scope of this chapter and the reader is referred to other chapters, reviews by Rotella and Lerner (1993) and Zaichkowsky and Takenaka (1993), and some recent intriguing proposals for ironic control processes by Janelle (1999; Hall, Hardy, & Gammage, 1999; Taylor, 1999).

The challenge of controlling golf shots. When one observes elite golfers, their swings and putts look effortless and natural. However, when one tries to build a mechanical device to generate the same types of shots or to instruct a novice golfer to duplicate them, the difficulties become apparent. Based on extensive tests under controlled conditions, Cochran and Stobbs (1968, p. 144) found that the club head of a driver moves with a speed of 100 miles per hour at the time of contact with the golf ball. After about 0.0005 seconds, the ball springs clear of the club head and moves with speed of around 135 miles per hour. For a perfect shot, the driver head has to make contact with the ball exactly at the "sweet spot" (p. 120) — deviation of less than half an inch will noticeably reduce the length of the drive. The orientation of the driver has to be correct to avoid hooking or slicing the shot, and even one to three degrees of deviation may send the ball into the rough (p. 124). Similarly during putting, the time of contact between the club and ball is only 0.0006 seconds. These extremely short periods of contact between club and ball make adjustments during that time completely impossible.

How are golf shots controlled? Extensive research (see Ericsson & Lehmann, 1996, for a brief overview and references) shows that any type of rapid movements must be prepared well in advance of their execution. Highly skilled athletes are able to anticipate situations before they actually happen and thus start preparing their overall movements well in advance. For example, someone who catches a ball has prepared the catching movements before the last 0.2 seconds prior to contact and can complete the action even if an experimenter turns off the lights during that period. Cochran and Stobbs (1968) found that golfers were able to complete their swings normally in the laboratory even if the lights were turned out during the downswing. In fact, the participants could not even tell when the lights were turned out; "if the lights went out at the beginning of the downswing, most thought it went out at about impact" (p. 102). Even more intriguing they found that "If the light was switched off at the very beginning of the back swing, when the club head was only a few inches away from the ball, nearly all the players were able, in total darkness, to carry on to the top of the swing, and come down and through the ball in a perfectly normal way" (p. 102). The stroke has to be preprogrammed and aimed and if the light was switched off even *before* the backswing had been initiated, that is *before* "the club head was drawn away from the ball, very few could hit the shot consistently" (pp. 102–103). However, seeing the ball prior to initiating the stroke cannot be absolutely necessary because blind golfers have been able to acquire the skill to strike balls in a consistent manner. Later in this chapter I will discuss how expert golf players are able to hit shots to accommodate wind and overhanging branches and other obstacles. To attain a desired ball trajectory the expert golfer must sometimes vary the shots systematically to create fades and draws to accommodate lie and direction. Regardless, in order to aim and program the stroke in advance for an accurate trajectory, the striking action must be predictable and highly reproducible. However, not even athletes can make major adjustments within the last 0.2 seconds, which is the shortest possible reaction time for visual stimuli. For example, cricket players cannot catch a ball that bounces unpredictably on a rough surface (McLeod, 1987).

The requirement that expert golfers' drives and putts have to be reproducible has strong implications for deliberate practice and how to develop optimal conditions for competitive play. During play in a golf tournament golfers are allowed only a single chance to hit the ball without penalty, so it is virtually impossible to assess the reproducibility of a given shot. However, under practice conditions a golfer can attempt to hit the same shot many times on the same or even different days to assess the distribution of outcomes. Unless golfers have swings and shots that remain reasonably reproducible across golf competitions and seasons, it is difficult to see how gradual improvements could occur.

Characteristics of Expert Performance in Golf

The key measure of golf performance is the number of strokes per round or series of rounds of a tournament. However, professional golfers engage in many types of activities during a tournament besides playing their rounds, some of the activities aimed to improve performance are illustrated in Figure 7. The performance during a round (see Figure 7) is the sum of the strokes required for each of the 18 holes. Among expert golfers who can control their emotions and are in good physical condition, one would predict that performance on different holes would be independent of each other and reflect stable characteristics of the golfer. However, the strokes taken to complete a given hole are not independent, because each shot will influence the nature of the following stroke. Consequently, it is necessary to consider the sequential relationship between strokes and how experts might improve their performance by planning the sequence of potential shots for a hole to reduce the total number of strokes.

Before discussing planning for sequences of shots I will discuss the characteristics involved in preparation and execution of individual shots, as is illustrated in Figure 7. I will begin by discussing the issues surrounding reproducibility of shots and discuss the challenges involved in attaining the high degree of motor control which is ultimately responsible for making the club hit the golf ball (see the final element in Figure 7). I will continue my discussion by commenting on potential procedures that can be executed before individual shots to increase the reproducibility of the intended shot. Then I will describe processes involved in aiming shots and deciding on the intended force at impact, before concluding with a brief discussion about planning. This review will be selective and focus on those characteristics that are consistent with reports by elite players and coaches, and are supported by empirical data from golf and related domains of expertise.

The acquisition of reproducible shots. When older children and adults start playing golf they do not learn the shot from scratch but rely on previously acquired similar movements. An important problem for beginning golfers is that they try to hit the golf ball with the rigid club, as though it were a sledge hammer, rather than swinging the club as though it was a sling. Harry Vardon (1914, p. 5) observed the typical problems with driving results when:

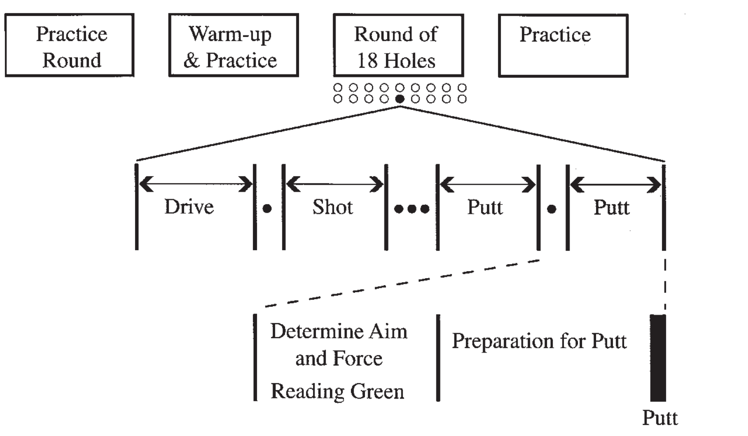

Figure 7

A description of some of the activities preceding and following a round of tournament golf. At a more detailed level the playing of each of the 18 holes can be viewed as a sequence of shots which in turn can be broken down into stages involved in the preparation and execution of a particular stroke.

> The player induces such a state of rigidity in his resolve to hit with desperate force that he simply cannot swing the club freely. …What he usually does — unwittingly, but none the less surely — is to begin to stop the club before it reaches the ball. His arms are not sufficiently free to allow the driver to do the work for him.

Expert golfers know that "You can strike it harder with a swinging action than you can in any other way with the power at your command" (Jones & Brown, 1937, p. 51). However:

> A swinging action must begin smoothly and rhythmically, and the force producing it must be applied gradually. There can be no quick jerky movement at any stage of the procedure. …Steadiness, not speed, is the keynote (Jones & Brown, 1937, p. 51).

Consistent with our discussion of the difficulty of actively controlling the swing once it is initiated, Jones and Brown (1937) discouraged such attempts and recommended that the swing be allowed to run its course. After extended practice, the swing becomes more controllable and predictable.

For a long time it was believed that there was an ideal natural swing that "talented" individuals would find through extensive repetition. However, after analysing the swings of the best golfers, it is clear that there is no single superior swing, there are many varieties of effective swings (McLean, 1999; Price, 1999). Adlington (1996, p. 10) even claimed that "Golf swings are unique; they are like fingerprints. Because no two are alike, it is risky to assume that what works for one will work for another."

The primary characteristic that distinguishes expert from less accomplished golfers appears to be that their putts and swings are more consistent. To grasp the most basic elements underlying consistency in golf shots, let us first consider some of the issues in building a mechanical device that will generate shots as reliably as possible, before turning to the complexities of human performance. The mechanism should be simple with few sources of variability, such as a pendulum, and constructed so the club could be firmly attached in a specific position. The frame should be rigid with firm grounding so it wouldn't shake during the set-up or initiation of the movement of the pendulum toward the ball. These attributes are easily observable in the putting device designed by Cochran and Stobbs (1968).

What are the physical elements of expert golfers' effective shots? Most introductory golf books start by describing the importance of selecting a grip that can be repeatedly reproduced. The preferred grip should reduce the degrees of freedom and facilitate the reproduction of the movements involved in the shot. According to Hogan (1957), one should practise the grip for 30 minutes daily for at least a week to make the subsequent learning easier. Similarly the stance and posture are designed to support the necessary movements and to maintain adequate balance during their execution.

Furthermore, extraneous movements should be reduced to make each shot very consistent. For example, Cochran and Stobbs (1968) reported that the foot placement of expert golfers was more similar when asked to make the same shot on several different occasions than was the foot placement of less accomplished golfers.

Hogan (1957, p. 38) claimed that it is necessary to acquire "a correct, powerful, repeating swing ... It really boils down to learning and practising a few fundamentals until performing them becomes as instinctive as walking." Like many golf coaches, he recommended that players acquire a few fundamental strokes, where the distance of putts and chip shots are regulated by the length of the downswing. In support of this claim, Delay, Nougier, Orliaguet, and Coello (1997) showed that experts have the same fundamental movement for putts of 1, 2, 3, and 4 m with only the length of the takeaway varying as a function of the distance. In contrast, amateur golfers rely on different movements for each of the distances. Analyses of variability in movement patterns during the swings with the driver and irons show a similar pattern. Expert golfers showed less movement of their shoes and less variability of the force pattern than less skilled players (Koening, Tamres, & Mann, 1994) suggesting greater stability and body control. Expert golfers were found to be less variable in the temporal and spatial characteristics of their swings than were novices (Neal, Abernethy, Moran, & Parker, 1990, p. 11): "Clearly as skill develops the player is able to refine the control of the swing so that trial-to-trial variability and deviations from an optimal swing pattern are minimised." At the same time, efforts to identify generalisable characteristics of the swing that mediate strokes with different clubs and for different distances have been relatively unsuccessful. However, golfers clearly view their swing as a stable and generalisable action pattern. When they make adjustments to play balls lying in difficult and variable locations on the golf course, they alter their stance (Nelson, 1946; Player, 1980) and avoid changing the fundamental swing.

In a recent review on the biomechanics of the golf swing, Dillman and Lange (1994) discussed the challenge of controlling and coordinating a very large number of motor units during the execution of the swing. In contrast to the simple mechanical devices with a few sources of variability, the human golfers' movements are influenced by a large number of dynamic interactions, such as the level of activity in the many parts of the motor system. Abernethy, Neal, and Moran (1990) found indirect support for these interactions and higher level invariances by failing to find any simple sequential pattern of activation of the muscles involved.

There are two important ways that human golfers control reproducibility by indirect means. First, there is considerable evidence that the downswing is "automatic" in the sense that it cannot be improved by intentional corrections. However, there is emerging evidence that experts acquire skilled movements where the motor system can make implicit adjustments even during ballistic movements, such as hitting a ball in table tennis (Bootsma & van Wieringen, 1990) and other racquet sports (Abernethy & Burgess-Limerick, 1992). In these cases the variability of the hitting movement for experts is greater at the initiation of the ballistic movement than it is at the critical time of subsequent contact with the ball — the ballistic movement execution serves as a funnel. Cochran and Stobbs (1968) reported comparisons between expert golfers and amateurs showing that the initial variability of experts' swings was reduced as the contact with the ball approached, unlike that of the amateurs.

Second, the motor system is highly complex and makes "automatic" adjustments for a wide range of factors, even muscle tension induced by anxiety. To generate the same action repeatedly with a high degree of consistency it is important to reproduce the same mental and physiological state on each occasion. Laboratory research shows that skilled golfers are more able to reduce the respiratory movements and associated EMG activity during the swing than less skilled golfers (Kawashima, Takeshita, Zaitsu, & Meshizuka, 1994). Barclay and McIlroy (1990) and Abernethy et al. (1990) found less variability in relevant and extraneous muscles by skilled compared to less skilled golfers. More generally, expert golfers follow a relatively set routine after they have decided on a preferred ball trajectory, as documented in the interviews by McCaffrey and Orlick (1989). The purpose of this routine is to induce a specific state of mind and body prior to executing the shot. During this routine and execution of the shot, the player is fully concentrated to minimise the disturbance from external and irrelevant stimuli.

A complementary method used consistently by expert golfers (Hogan, 1948; McCaffrey & Orlick, 1989) is to warm up and take shots on the driving range and putting green prior to the competition, as illustrated in Figure 7. Ben Hogan (1948, p. 171) described his extended warm up that "seldom varies. I start with the short clubs, usually a nine iron and hit the ball easily" and goes through playing each club ending up with the driver, to make certain that he can "hit each shot exactly where I want it to go." Although this process has the function of making the muscles more limber, it may also be beneficial in rehearsing and calibrating each shot before the round of competition.

In sum, expert golfers have acquired highly reproducible swings that differ among the experts. The execution of the downswings, once initiated, cannot be intentionally controlled, leading the golfer to focus on controlling the preparation and the initiating conditions. Jack Nicklaus (1974, p. 77) pointed to the set-up as "the single most important maneuver in golf. It is the only aspect of the swing over which you have 100 percent conscious control." Experts have uncovered methods to increase their indirect control over their shots by influencing their mental and physical states prior to initiating their swing and putts.

Aiming and shot selection. An individual or a mechanical device that could execute all types of shots with great consistency would still require additional skill and mechanisms for aiming the shots. Virtually all shots in golf follow complex trajectories. For example, the ball path of a drive might be influenced by wind, and more importantly, the ball will not stop exactly where it lands but it will bounce and roll until it reaches its end state. Similarly, the ball path of a putt will not be completely straight. Its path will be influenced by the undulations and slopes of the green. An expert golfer needs to be able to predict the likely ball paths associated with different types of shots. In addition, shot selection and aim will be influenced by strategic factors, such as optimising the circumstances for the subsequent shots.

Beginning golfers are likely to aim in an unsophisticated way and through experience make corrections to their natural aim. It is likely that their natural aim will reflect prior adjustments based on idiosyncratic striking motions and deviations from hitting the ball with a straight club. For example, most putts would have to be aimed to adjust for their "break" where a straight putt toward the hole will break away from its original path in a curvilinear manner on slanted surfaces, especially as the ball slows. For many amateur golfers, these adjustments become essentially automatic so that they don't have to figure out the ball trajectory, especially when they play on the familiar greens. Having misjudged a break on one putt, they may try to make a large break adjustment next time they encounter similar circumstances. Given the large number of factors that might influence ball trajectories, including weather, it is clear that golfers who make frequent corrections in response to misses are unlikely to gradually refine their mechanisms for accurately aiming shots.

A very different approach is advocated by elite golfers, such as Jack Nicklaus (1974, p. 79), who insisted that:

> I never hit a shot, even in practice, without having a very sharp, in-focus picture of it in my head. It is like a color movie. First I 'see' the ball where I want it to finish, nice and white and sitting up high on the bright green grass. Then the scene quickly changes and I 'see' the ball going there; its path, trajectory, and shape, even its behavior on landing.

But he acknowledged that less accomplished golfers are likely unable to "go to the movies." Nicklaus (1974, p. 78) argued that to produce this mental simulation of the intended shot he needs to be very deliberate in his assessment of the situation and "that's why setting up takes me so long." In particular he emphasised his preparation for "a putt that I'm trying to make. Then I need time to concentrate on all the factors of speed and line and grain involved" (p. 78).

The ability to generate similar types of "movies" or mental anticipations of outcomes is well documented in other areas of expertise and it is very plausible that these abilities can be empirically validated in golf. Tiger Woods' father (Woods, 1997, pp. 62-63) described how mental images of a putting situation were deliberately developed by having Tiger alternate looking at the hole and the ball as many times as necessary to "see the picture of the hole" without looking at it. Tiger was asked to "Putt to the picture." This ability to mentally represent the green is developed gradually over time by making the distance to the hole longer and trying it under more challenging conditions, such as slow, wet greens. Eventually golfers are able to build an elaborate representation of the situation during set-up that includes judgments about how much the ball will break, leading them to aim

> at a corresponding distance to that side of the hole. This permits the golfer to focus on distance rather than direction because distance control is more important than direction control. By putting to the picture and allowing the human computer to function, the golfer is free *to concentrate only on stroking the ball to the picture.* (p. 63, italics added)

In a recent study Hill et al. (1999) examined the mental representations of situations involving putting for expert (less than 5 handicap) and novice (over 25 handicap) golfers. In this experiment we tried to assess golfers' ability to report aspects of the set-up for putts and learn whether golfers knew what kinds of adjustments would be necessary under hypothetical changes in putting conditions. We found that the experts reported a reliably larger number of factors, such as wetness, length of grass and physical contour that they would consider during set-up than the novices. We also found that when we asked the participants questions after they had determined how to aim a putt in a given putting situation, such as "How, if at all, would the line that you have chosen for this putt change if the green was wet with dew?" (Hill, 1999, p. 52). The experts were reliably better at reporting appropriate adjustments to putting conditions than the novices.

We also analysed the putting lines reported by experts and novices for 10 actual putting situations to assess the amount of predicted break. To evaluate the accuracy of their prediction we derived the "true" putting line by a putting device that we designed without knowledge of Pelz's (1989, 1994) work with his "true roller." Overall, we didn't find any statistically reliable advantage of the experts over the novices in their respective putting lines. However, when we restricted the analysis to the longest putts with more than a single break, the experts' initial line was reliably superior to those reported by the novices. Our results were consistent with those of Pelz (1989, 1994), who found a small average advantage for the best golfers, without reporting if the differences were statistically reliable. In sum, our studies provide support for the expert golfers' development of advanced representations that allow them to respond to changes in conditions and generate putting lines in complex putting situations. At the same time, we found that both experts' and novices' putting lines indicated consistently less break than our putting device, thus replicating Pelz's (1989, 1994) earlier pioneering results. In several ongoing studies we are trying to understand the factors that might explain these large discrepancies between the true and estimated putting lines and relate them to documented deviations in visual alignments for both expert and amateur golfers (Coffey et al., 1990; McGlynn, Jones, & Kerwin, 1990), as well as other potential differences between the putts by our device and human golfers.

Planning and strategic processes during course management. Expert golf performance involves sequential planning that goes beyond aiming and hitting individual shots. It requires the ability to examine the challenges of a hole and come up with a plan for how to reach the green in a reliable and efficient manner. Tom Watson (1993, p. 57) wrote "Good pool players are thinking not only one shot ahead but several shots ahead. That's how you make a run. The essence of laying up in golf is the same: Plan ahead to leave yourself in good position for the next shot, whether you're laying up short of trouble off the tee or on your subsequent shots on up to the green." Prior to playing in a competition at an unfamiliar golf course, professional players conduct "a practice round to formulate your game plan." (p. 85). During the practice round Watson (1993, p. 85) explained that " I want to learn where I can and cannot miss a shot. If I do miss a shot I want to be sure I can recover and not incur a big score on the hole." Based on the expert golfers' understanding of the accuracy of their respective shots, the prevailing weather conditions, and the structure of the golf course, they select shots that will lay up for the next shot. "A consistent golfer gives himself the percentage play most times. He isn't afraid to lay up" (Watson, 1993, p. 58).

Expert golfers avoid risky carries and deliberately plan to increase the likelihood that they can approach the hole up the slope of the green with a full shot with their favorite club from a flat lie. Unfortunately, I don't know of any systematic studies confirming that realistic planning is related to performance among expert golfers. In recent studies with regular golfers (average handicaps around 20), Kirschenbaum et al. (1999) found that around 80% of the players generated overly optimistic plans for their shots given their accuracy and length of their drives. Kirschenbaum et al. (1999) were able to influence an experimental group to use more appropriate club selection with a better outcome for a particular shot, but disappointingly, the total number of strokes for the corresponding hole was not reliably improved.

In sum, a number of complex interacting characteristics distinguish expert from novice level golf performance. Expert golfers have attained control over their shots and can reproduce the same stroke consistently with more predictable outcomes. They have acquired more knowledge about the external factors influencing ball trajectories and can reason out methods of play in hypothetical situations better than less skilled players. Finally, there are suggestions that expert players have developed complex procedures to prepare for competitions. All distinguishing characteristics of expert golf performance depend on the predictability and control of shots. Without a thorough understanding of the variables that can affect a shot, planning the appropriate approach for a given hole would be difficult. It would be impossible to project potential ball trajectories without being able to accurately read the conditions of each situation. Given the central importance of executing consistent shots, I will focus the next part on the acquisition of that skill.

The Acquisition of Superior Shots through Deliberate Practice

In this part I will discuss the golf masters' insights into the hallmark of expert golf performance, namely the ability to strike the ball so it ends up closer to its intended target than amateur players. The primary distinguishing feature of experts' swings was their reproducibility. Many of these swings look so natural that one might believe that they were just discovered suddenly one day and then effortlessly retained. This is not so, however. The available evidence suggests that the swing should be viewed as a feat of skilled mastery resulting from supervised training and extended deliberate effort in acquiring other expert motor skills, as is the case for dancing ballet and playing the violin. To quote one of the elite golfers, Nick Price (1999, p. 41, italics added), "An efficient golf swing incorporates the fewest moving parts while producing maximum results in terms of direction, distance and ball flight. These factors add up to control, and to me *the ultimate art of golf is in controlling the ball*. It is an attribute common to all the top ball-strikers." The demand for control may seem a little puzzling for many people because they associate high consistency with a machine that reproduces the same action repeatedly and expect that consistent human action would also be automatic and devoid of control. I will first briefly discuss some differences between how amateurs seem to acquire their swing and how expert coaches recommend that it should be acquired. I will then turn to a discussion about how the experts can increase their control of the swing and thereby reduce its variability from time to time.

In one of the earliest books on "Advanced Golf," Baird (1908, p. 173) criticised the average golfer for having "no definite system," when "Playing one tee shot he will have the open stance, and the next one it may be almost square; while in one case the ball may be brought opposite the left toe, and in the other it may be back again much nearer the right." Baird (p. 173) recommended "serious practice — that is to say, practise alone, and with one club or a few. It is such practice as this that makes the quickest and surest improvements in a player." Expert golfers and golf coaches generally agree that stroke consistency is critical for improvement in golf performance as long as the elements of the stroke are fundamentally sound. Most of the books on golf instruction break the swing into its basic elements. They nearly always recommend a sequence of mastery akin to the instructional sequences for mastery of the violin. The instruction starts with the acquisition of a consistent grip, the adoption of an appropriate stance and posture, then the backswing and the downswing. Most instructional schemes recommend mastering the iron clubs and then end up with the driver.

Few individuals who begin playing golf as adults are patient enough to follow the recommended sequence of successive mastery and want to drive the ball as far as possible as soon as possible. On the other hand, if beginning golfers followed these instructions and mastered the corresponding elements, shouldn't the only remaining step be to entrench and automate the sequence of steps? Many researchers studying golf draw on Fitts and Posner's (1967) theoretical framework for understanding skill acquisition in golf. According to their framework mastery of skilled activities is mediated by a sequence of stages, in which a task and its associated goals are first understood and then suitable procedures are developed — which roughly corresponds to understanding the sequential steps of the swing, then the elements are mastered and coordinated. During the final stage these procedures are automated in a manner consistent with the influential work by Shiffrin and Schneider (1977; Schneider & Shiffrin, 1977). As I explained when discussing Figure 5, my problem does not refer to the application of this theoretical account for amateur golfers who reach a stable level of performance within months or a year or two. My disagreement concerns the hypothesis that expert golf performance can be explained as a mere extension of continued practice.

The theory of automaticity proposed by Shiffrin and Schneider (1977; Schneider & Shiffrin, 1977) and its application to the final stage of skill acquisition (Anderson, 1982) explains well how performance can become faster when automated, but not how a variable motor action can become more consistent. Let us consider how a sequential procedure would be automated through practice. For example, when children learn to add digits they typically start by counting out each added element, such as "three plus three" is "three, four, five, six," where "six" is the answer. This type of process can be automated by eliminating intermediate steps in the original sequence of steps by directly retrieving the answer "six" in response to "three plus three." It is important to notice that the accuracy of the generated answer remains high throughout practice and it is primarily the speed of retrieving the answers that increases. For these types of cognitive activities, the initial mental states, such as "three plus three" remain roughly the same before and after the automation. In contrast, during motor activities such as a golf swing, the mental states cannot contain a description of all relevant aspects of the motor activity. A very large number of muscle fibres and joints are simultaneously engaged in interactions to maintain balance and posture any time a human merely stands. Given the limitations of our attention and cognitive systems, it is clearly impossible to control all, or even a large number, of the basic elements. The key message is that control over the motor system is never perfect and is typically attained by indirect means and in gradual increments. My argument with respect to the gradual improvement of expert golf performance is that it is not a process of automating its procedures but rather an extended quest for increased control.

Once the problem is posed in terms of controlling a highly complex interactive motor system, it is easy to see how "simple activities," such as generating a consistent grip and assuming a reproducible stance, can be executed more consistently. It becomes clear that for every motor act there is variability and differences and that it is essential for players to develop their ability to perceive those differences and acquire the appropriate "feel." Improvements in control will thus require an interaction between the development of systems for monitoring (perception) and for control (action). Let me support my somewhat speculative argument with a few examples along with some supporting quotes by elite golfers.

In an earlier section I reviewed evidence showing that concurrent intentional control is impossible during the downswing. How can expert golfers then improve the reproducibility of their downswing? Expert golfers seem to agree that beneficial intentional corrections during the downswing are not possible, which would explain why less skilled golfers experience difficulty when trying to make corrections during the downswing (Moore & Stevenson, 1991, 1994). The intentional control of the downswing has to be completed during set-up and prior to the initiation of the downswing. Before Nicklaus (1974, p. 99) hits a shot in competition he spends considerable time setting up and getting ready for the shot:

> I must stress, however, that no matter how many things you think about at address, you are, so to speak, merely programming the computer. Once you throw the switch, the computer must take over. The golf swing happens far too fast for you consciously to direct your muscles. Frequently I can make very minor adjustments in midswing, but they are always instinctive, never conscious.

Nick Price (1999, p. 46) pretty much agreed:

> The secret in golf is to have a backswing so sound that on the course you don't have to think about the downswing. … The correct backswing will set up the conditions that make it much more likely that the right things will happen later.

The most important method for controlling the motor system is developing techniques for controlling those aspects that can be monitored and controlled during set-up. In addition, it may be possible to attain indirect (unintentional) rapid adjustments to the motor system by acquiring representations that encode and monitor the intended goal or "feel" of the swing, as discussed earlier.

How are the representations acquired that allow expert golfers to distinguish differences in the states during set-up and address prior to the swing? The representations do not appear to emerge automatically as a function of mere playing, but do require the expert golfers' intentional efforts to attain deliberate control over their set-up and associated shots during practice. Ben Hogan (1957, pp. 37–38) wrote:

> Golf also seems to bring out the scientist in a person. He soon discovers that unless he goes about observing and testing with an orderly method, he is simply complicating his problems. In this general connection, I have found out that it helps me immensely to bring along a notebook and pencil to the practice tee and to write down after each session just what it was I had been working on, exactly how it was coming, and precisely where it was that I should resume my testing the next time I went out to practice.

Price (1999) even published excerpts of his own diary on the observations during practice. Elite golfers are not satisfied with a single straight shot and acquire a range of variations of shots that require controlled adjustments of the set-up. Jack Nicklaus (1974, p. 203) said that during practice he often intentionally varies his shots and

> in a session where I'm basically trying to fade the ball. I'll intentionally hit two or three draws out of every twenty shots. It's challenging to 'work' the ball, and it's also highly instructive to learn just what causes what results.

Nicklaus (1974, p. 99) discusses a number of different aspects that he might attend to during the address of his swing, such as "keeping my head in a certain position on the backswing; keeping my hands low going back." The number of things that Nicklaus feels that he can focus on at address (prior to the initiation of the downswing) is often "only one or two swing keys." Bobby Jones (1966, p. 203) is even more adamant:

> It has never been possible for me to think of more than two or three details of the swing and still hit the ball correctly. If more than that number have to be handled, I simply must play badly until by patient work and practice I can reduce the parts that have to be controlled. The two or three are not always the same, sometime a man's swing will be functioning so well he need worry about nothing; then, of course, on those rare occasions, the game is a simple thing.

The practice techniques that elite golfers recommend provide another source of evidence that underscores the importance of deliberate development of representations for perceiving and control action. Many of these exercises do not have any simple relation to the actual execution of shots during tournament play. For example, Gary Player (1980) recommended exercises involving shots made by a single arm, especially the left arm, to improve control for right-handed golfers. He also recommended that players hit shots while balancing on a single foot as a means to attain a higher level of balance and control. With respect to improving feel, Price (1999) recommended practice in the dark and practice with a baseball bat. Future case studies and designed field experiments with observed performance would be desirable to assess the benefits of associated exercises and evaluate whether they result in refined representations and mechanisms of improved control for expert golfers.

A golf swing requires frequent tune-ups as well as continued maintenance with adjustments throughout a golf season and a career of golf playing.

> The golf swing is not a static entity. It changes as the knowledge changes, as the body changes, as the particular desired shot pattern changes. My swing probably has changed every year, and it looks a lot different today than it did 20 years ago, or even two years ago. For me it has been a series of steps forward and steps back and steps forward again. (Kite & Dennis, 1990, p. 37).

Acquired representations play an important role in maintaining the execution of shots as noted by Bobby Jones (1966, p. 211):

> It is of great value to have a clear understanding of the successive movements making up a correct golf swing; this much is needed in order to enable one to recognise and correct faults as they appear. But no human is able to think through and at the same time execute the entire sequence of correct movements. The player himself must seek for a conception, or fix upon one or two movements concentration on which will enable him to hit the ball.

Nicklaus (1974) reported that he is able to deal with most changes during "the normal day-to-day fine tuning," but sometimes he has developed more complex flaws that require "major surgery." For this purpose Nicklaus recorded all television broadcasts of his golf playing to help him analyse his performance and to identify unintentional changes that eventually lead to performance problems.

Finally, it is necessary for expert golfers to acquire general skills for setting up shots under all types of conditions on the course, because only putting and driving are done under relatively standardised conditions. Most approach shots have to be executed in varied situations where the area with the ball is not level, thus requiring the golfers to adjust their stance and posture. There may be obstacles in front of the ball that require directing the path of the ball toward the left or the right or making it flatter or steeper. There may be obstacles behind or near the ball that will constrain the normal swing path. Consequently, expert golfers need to acquire representations and skills that would allow them to set up a shot during a tournament without any opportunities for test shots. To acquire refined representations to deal with varied conditions on the golf course should be the most challenging and difficult even for elite golfers. In support of that hypothesis, Cochran and Stobbs (1968) found that these types of varied approach shots revealed the largest differences between the most and least successful British professional golfers that they studied. To improve these representations and the associated performance the golfers may need to engage in "on-course practice" of the type recommended by Sam Snead (1989) where the player plays two or three balls from each ball position. Snead (1989, p. 160) recommends that you play

> your next shot from where the worst ball lies. Not only will this improve your short game, but it will also help you develop the shots you need to scramble out of trouble, as well as teach you just how much you can realistically afford to gamble when in a jam.

More generally, there is remarkable consensus among experts and coaches about the methods for gradually attaining increased control over golf strokes. Even the reports by elite athletes that during peak performance "skill execution felt automatic and required minimal conscious effort or attention" (Moore & Stevenson, 1991, p. 281) can be reinterpreted as stating that no additional conscious control seemed necessary during highly successful performance. Even if athletes were quite able to control and adjust their swings prior to the initiation of the downswing it is unclear why anything should be changed as long as it works very well. Moore and Stevenson's (1994; Ravizza & Osborne, 1991) recommendations to release control during the actual execution and "let it go" is consistent with the proposed idea of limiting control to the events prior to initiation of the downswing, although the theoretical rationale differs. From my reading, I found ample evidence for deliberate efforts to acquire and refine representations to monitor and adjust those aspects of the set-up and the address that can be controlled, in line with the pattern predicted in Figure 5. Unfortunately, there are no laboratory studies that provide objective evidence for the performance benefits of these types of representations. In my concluding remarks I will review some experimental evidence from other domains of expertise involving perceptual-motor performance, which makes the proposed mechanisms mediating expert performance in golf more plausible. Before discussing those issues I will briefly comment on the relevance of expert golf performance for amateur golfers.

Implications of the Acquisition of Expert Golf Performance for Amateur Golfers

Our analysis of the acquisition of expert and novice golf performance illustrated in Figure 5 presents a bleak picture for anyone who wants to discover some simple and easy method for improving amateur performance.[2] There is no known shortcut to skilled performance. The requirement for gradual development of reproducible shots is inconsistent with the beliefs and conceptions of most amateurs. This was recognised by Ouimet (1914, pp. 109–110) at the start of the 20th century:

> It is hard to understand how a golfer can try one style of putting, to-day, another tomorrow and a third the day following and hope to improve that important department of his game. The trouble with him, as a rule, is that every time he sees another golfer get first-class results with a style of putting dissimilar to that which he most recently adopted, he either consciously or unconsciously adopts that new style. Or, he sees one golfer do exceptionally well with a style of putter that is different from his own and immediately jumps mentally to the conclusion that it is not his putting style, after all, that is at fault, but his style of putter.

Some expert golfers, such as Ray Floyd (1989, p. 166), have explicitly rejected the idea of short-cuts and dramatic improvements: "I said early in this book that you can enjoy golf without playing it particularly well, without improving. That's the beauty of it. If you are satisfied at that point, bless you and have fun. But if you want to lower your score, you'll have to make an effort." He summarises "I don't know any other way to improve, whether you are building your game or trying to get out of a slump. And it works, not always immediately, but eventually" (p. 166).

According to the framework outlined in Figure 5, amateur golf performance typically improves most rapidly within the first couple of years before reaching a stable level that is maintained as long as the player keeps playing. As the middle curve illustrates, it is possible to maintain systematic practice for longer periods and thus reach a higher level performance before stabilising or automating performance at that level. It would be possible for golfers to play in a relaxed and "automatic" manner even at very high levels. Nicklaus (1974, p. 77) claimed that "In a casual round of golf with friends I can walk up to the ball, put the club down, draw back, and pop it in no time flat" but the results would not be good enough for tournament golf. This account by Nicklaus is consistent with the general framework outlined in Figure 5, where even experts have to refine and maintain their representations to have the level of control necessary to achieve their best performance.

Very little was known about psychomotor skills of amateur golfers and their relation to practice and other performance enhancing activities until

Thomas and Over (1994a, 1994b) developed their questionnaire where they asked amateur golfers to rate their agreement with a large number of statements related to psychological and psychomotor skills in golf. There are now several studies that have examined the relations between these ratings and reported golf performance in golfers below the age of 20 (Ellis, Filyer, & Wilson, 1999) and above the age of 20 (Thomas & Over, 1994a, 1994b). Over and Thomas (1995) focused on analyses of older golfers, which I will discuss further in my concluding remarks.

Given the focus of my chapter on expert performance I will limit my discussion to Thomas and Over's (1994a, 1994b) and Ellis et al.'s (1999) findings relevant to their factor analyses of statements relevant to psychomotor skills. Both studies uncovered three similar factors for both samples of golfers of different ages. The factor most closely related to golf performance (self-reported handicap) consisted of statements describing driving and the reliability of shots and was defined by a negative loading on items, such as "Lose more than one ball per round" and "Drives depend on luck and chance." Thomas and Over (1994a, 1994b) called this factor "automaticity," because other statements loading on the factor emphasised the consistency, but in a subsequent study of ten-pin bowling Thomas, Schlinker, and Over (1996) used the label "consistency" to refer to a similar factor in close agreement with our general framework. In the study of teenaged golfers Ellis et al. (1999) found a similar factor that loaded highly on the statements cited above, but they emphasised the variability induced by striving for distance and called it "grip it and rip it" — the more variability the worse the golf performance. Both studies identified a second factor related to putting skill, which was not reliably related to golf performance.

The third factor related to practice and other activities associated with efforts by golfers to improve and would be of particular interest to our framework. Ellis et al. (1999) found that "practice" for teenaged golfers could be measured by high agreement for items like "Lessons with a golf professional" and "Hit practice balls before a round." Agreement with these items was reliably related to better golf performance. For older golfers (over age 20), Thomas and Over (1994a, 1994b) found a factor that loaded on the above "practice" items along with statements about other improvement-related activities, such as "Learn by watching professionals play," "Changed clubs to improve performance," and "Watched golf instructional video." However, this "practice" factor was not reliably related to better golf performance for the older golfers (Thomas & Over, 1994a, 1994b). In sum, the reliable correlation between self-reported consistency of the swing and handicap for both samples of amateur golfers ($0.4 < r < 0.5$) is remarkable for a questionnaire study using rated agreement with statements and is consistent with our framework. Furthermore, the reliable role of practice for the younger sample (Ellis et al., 1999) but not for the adult sample (Thomas & Over, 1994a, 1994b) is, at least, consistent with our framework. We know that amateurs increase their performance most when they are first introduced to golf and it is during this period that attitudes toward practice and instruction would be likely to have greatest benefits. When golf performance has reached a stable level during adulthood, which kinds of practice activities are known to improve older amateurs' performance?

Within the framework of deliberate practice many enjoyable activities believed relevant to improvement, such as watching elite golfers play, watching instructional videos, and imaging their best performance, can be used to improve performance within the context of deliberate practice. However, Ray Floyd (1989, p. 166) argues "Reading an instruction book or watching a videotape can give you knowledge, but it won't give you feel. To really learn a swing or a shot or a putt, to build the muscle memory that will let you repeat it consistently on the course, you have to practise it." Without deliberate practice to translate this knowledge and implement reproducible changes to performance, these imaging and observational activities may have limited benefits for performance. Furthermore, amateur golfers may need to increase their level of weekly deliberate practice to gradually refine performance and to maintain changes. It seems highly unlikely that a couple of hours of practice by themselves could lead to stable increases in consistent shot-making, which is consistent with the difficulties of many experimental studies to demonstrate immediate improvement of golf performance, especially among experienced golfers. Studies with successful interventions (Cohn, Rotella, & Lloyd, 1990; Thomas & Fogarty, 1997) typically involve long-term interventions or follow-ups where changes in practice behavior become possible or even likely mediating factors. In my final and concluding section I will argue that the necessary level of deliberate practice for reliable sustained improvement in experienced golfers may be higher than generally assumed.

Toward an Integrated Perspective for the Acquisition of Expert Performance

Following the path to expertise in golf is not easy, even for the most "talented." The path is hard to follow even when we can study the routes taken by elite golfers who have completed the journey, and these golfers don't seem to have uncovered any shortcuts to excellence. In this final section, I will summarise our knowledge about how expert performance is acquired and maintained in domains that have been studied more intensively than golf and propose potential parallels between those findings and phenomena in golf. Once one realises the long and specialised preparation that is necessary, even for the most "talented," to reach elite golf performance then it doesn't seem necessary or appropriate to explain this elite level of performance by natural ability.

Deliberate Practice across the Life Span

Attaining expert performance in many domains takes the entire healthy life span. The most successful performers start at young ages and remain active as long as they can, until their 60s, 70s, or even 80s, for many musicians and scientists. Why does the acquisition process tend to start so early and how are some of these individuals able to sustain remarkable levels of performance into advanced age?

Practice during the early years. In my introductory remarks, I showed that early practice in a domain appears to increase the chance of reaching elite levels and that this is particularly true for domains involving perceptual-motor activities, such as music, dance, and most sports. There appear to be distinct benefits to an early start as long as children are not pushed into premature "burn out." First, starting practice early provides children with a head start in acquiring necessary skills. Given that virtually all competitions for children involve competing against children in the same age group, a child who has studied music or practised golf for several years will perform much better than a child of the same age with only a single year of training. This initial advantage is particularly important in domains where teachers and coaches search for children with "innate talent" to admit them to programs for talent development. Children with extensive prior practice and training will perform at a higher level, seem more "talented," and are thus likely to gain access to the best teachers and coaches and their superior training environments.

Second, when children learn their first motor skills, or even their first language, there appear to be some benefits to learning essentially from scratch. Subsequent, related learning will often be more efficient because that learning can draw on earlier acquired skills. When skills are adapted from other activities, the transfer is inexact, because these skills don't match the fundamentals of the target domain. Adaptation and relearning will be necessary. When children's initial learning is closely monitored by an expert coach or teacher the children have the opportunity to acquire the correct fundamentals from the beginning of training. Early supervised learning by highly skilled teachers has been documented for nearly all of the outstanding musicians (Lehmann, 1997; Lehmann & Ericsson, 1996) and some outstanding golf players, such as Tiger Woods (Woods, 1997).

Third, when the practice activity imposes mental and physical strain on the body and the nervous system (Ericsson, 1998, in press), the body and the nervous system will eventually adapt to perform the desired activity more efficiently. The types of anatomical and physiological adaptations observed depend on the stage of development of the individual as well as the domain requirements. For example, there appears to be a narrow window in the development of children between the ages of 3 and 5 years when any normal child seems able to acquire perfect pitch — the ability to recognise tones when presented one by one (Ericsson, 1996; Takeuchi & Hulse, 1993). Early intense training in music has also been correlated with changes in the structure and organisation of the brain that facilitates the execution of demanding perceptual and motor activities (Elbert et al., 1995). As the bones become calcified during development, the range of the joints becomes fixed. Intense training prior to this fixation is correlated with range of motion allowing ballet dancers to exhibit "turn out" and baseball pitchers to extend their throwing arm far behind their head (Ericsson & Lehmann, 1996). More generally, training during particular periods in childhood and adolescence is known to result in irreversible physiological changes that may give these individuals an acquired advantage in certain activities (Ericsson, 1996). Though I have not found firm evidence for irreversible changes in the domain of golf, I am confident that such differences will soon be discovered.

Fourth, children who start practice and build a daily schedule around their practice and competition have already attained a high level of daily deliberate practice. Not only do they have the advantage of previously acquired skills, these individuals are learning a practice regimen that will help them continue to improve at a higher rate, as the increase in the daily amount of deliberate practice develops gradually over a long time (Starkes et al., 1996).

Finally, when children start with an activity at very young ages their initial performance is very unimpressive when evaluated with standards used for older children and adults. However, adults often feel that they are able to see future potential of some "talented" children by observing their raw and untrained behaviour and spotting signs of talent. However, there is no scientific evidence to support those beliefs and recent reviews of the evidence for early signs of talent show that early talent does not accurately predict the level of performance attained after training (Ericsson & Lehmann, 1996; Howe, Davidson, & Sloboda, 1998). In fact some of the evidence from sports shows that coaches who search for talent then confuse it with age-related variability in size and physical maturation. When soccer players start playing together at around 6–8 years of age children are grouped according to age with birth dates ranging from August 1st in one year to July 31st of the next year (Helsen, Starkes, & van Winckel, 1998). Hence, the age difference between the oldest and youngest can be close to a year. Research has found that the soccer players with the highest relative age are far more likely to succeed, giving rise to a higher proportion of professional soccer players having birth dates in the most favorable months. These findings (Helsen, Starkes, & van Winckel, 1998) are consistent with a confusion of "talent" and relative age of young soccer players that leads to differential development of their soccer performance. Similar findings have been reported for ice-hockey players from Canada where the relative-age effects appear to be even greater (Boucher & Mutimer, 1994). It is interesting to note that the relative-age effects on professional performance appear to be most consistent and pronounced in domains of sports where the search for "talented" children has been developed to its most advanced level, such as ice hockey in Canada and soccer in the Netherlands. In sum, these findings show that the identification of "perceived talent," even in the absence of objective correlates, will influence motivational support and access to training opportunities that are known to facilitate development of expert performance (Ericsson, 1996).

Reaching and maintaining peak levels of reproducible performance. It is well-known that sustained regular involvement in aerobic exercise or other comparable forms of intense physical activity are necessary to maintain high levels of aerobic fitness (Shephard, 1994). Similarly, regular training is necessary to maintain endurance and strength. Even in activities such as piano and violin performance, and non-vigorous sports, high-level performers engage in practice on basically a daily basis. Many of you are familiar with the famous quote by music virtuoso Ignacy Jan Paderewski (Crofton & Fraser, 1985, p. 118): "If I don't practise for one day, I know it. If I don't practise for two days, the critics know it. If I don't practise for three days, the audience knows it." Famous golfers, such as Sam Snead (1997), claim to "practise every day" and those golfers who do not practise regularly are rare and controversial exceptions.

Is it necessary to keep up this daily practice to maintain expert performance? If so, why would that be? Most people's acquired skills, such as swimming, bicycling, and typing, appear to be maintained virtually indefinitely, seemingly without practice. Those experiences are not inconsistent because the expert performers do not forget how to swing or to play the violin within a few days. The difference in performance after days or weeks without practice is a matter of degree. The loss of "feel" and refined control of performance might not be relevant to amateurs, but it may well be a critical difference between performers at the highest levels.

Research on swimmers and other athletes in vigorous sports shows that muscle fibres involved in particular activities, such as swimming, are closely attuned to the metabolic demands of daily practice, and within days after termination of regular practice, large changes have been observed in them. After weeks, months, and years without practice, additional changes take place. The distinctive physiological characteristics of athletic expertise are gradually lost (see Ericsson, 1990; Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson & Lehmann, 1996; Robergs & Roberts, 1997, for reviews).

These changes in the adaptation of muscle fibres and other cells in the body will have implications even for skilled activities, such as music and golf. By executing the fundamental movements during practice, the components of the motor system can be adjusted to produce a coordinated action. Given that the critical motor activities in golf and music require movements that are not part of daily living, they will be lost without specialised practice. Without appropriate practice, coordination will decrease over time with associated decrements in performance. Changes in muscles will reduce the successful coordination of the muscle groups into precision movements. These human physiological changes over time are analogous to the more familiar changes observed in some music instruments, such as violins and pianos. After a period of disuse the strings of the instrument have to be tuned before each performance to produce the desired sound. In sum, continued practice appears to be necessary to maintain the adaptation of individual cells and to sustain the coordination of muscles that are critical to precision activities.

The reciprocal relationship between practice and high level of performance in golf and music potentially explains several phenomena. It accounts for why expert performers maintain regular practice and avoid long periods without any relevant activity. After long periods of disuse due to injury, individuals need to gradually reestablish the lost adaptations and coordinated actions before they can regain their old level of performance. Many adaptations require extensive intense practice to be attained, but once acquired they can be maintained with less, though still regular, practice with maintained intensity (Shephard, 1994).

The need to maintain high levels of practice may explain some performance decrements attributed to age. In domains which require physical precision, it is well known that some older individuals in their 50s and 60s are competitive with younger experts, and occasionally win national championships. At age 85 Sam Snead (1997, p. xv) claimed that "I can still shoot even par when my putting cooperates." Older musicians, such as Horowitz and Ravi Shankar, are famous for their remarkable ability to perform at the international level. In a recent study, Ralf Krampe and I (Krampe &

Ericsson, 1996) studied both amateur and expert pianists in their 20s and in their 60s to understand the effects of aging on speeded precision movements in piano-related tasks. Interestingly, we found that only the older amateurs exhibited the typical decreases in speeded performance. In contrast, the older expert pianists who maintained sufficient deliberate practice (around 10 hours per week) matched the performance of younger expert pianists when tested on representative tasks for piano playing. It appears possible for pianists to maintain expertise into their 60s, with regular deliberate practice. Reduced levels of performance in older individuals may reflect, to a large degree, reduced levels of practice. Comparisons between the amount and intensity of practice among young athletes and older master athletes suggest that much of the age-related difference in performance can be attributed to differences in practice (see, Ericsson, 1990, for a brief review). The finding that experts tend to peak at certain ages may be, at least in part, a result of motivational factors. It is difficult for individuals to focus completely on their practice and career development for years and decades as well as to gradually regain earlier levels of elite performance after disuse due to injury. For older golf professionals there are alternative careers in golf that may be better paid and less demanding than professional play in golf tournaments. On the other hand, the recent establishment of competitive events for master athletes grouped by their ages have led to large increases in the top level of performance for older athletes, especially among athletes in their 70s and 80s.

Research on the relationship between aging and golf performance shows a reasonably consistent picture. The performance of older elite golfers on the senior tour is surprisingly close to that of younger players on the regular PGA tour (Spirduso, 1995; Wiseman, Chatterjee, Wiseman, & Chatterjee, 1994),[1] and thus remains superior to the vast majority of young players. Analyses of all currently active amateur golfers' performance handicaps has shown remarkable performance stability from the 40s to the early 70s (Lockwood, 1999). In a retrospective longitudinal study, Over and Thomas (1995) found that the decrement in reported performance over a 10-year period for golfers in their 60s was statistically reliable. However, Over and Thomas (1995) did not find a uniform decrement in golf performance of the older golfers' performance, and for around half of them the performance had remained stable, or even improved. Further research is necessary to assess the factors that influence age-related decrements in golf performance and to what extent these factors are mediated by changes in the quantity, quality, and intensity of practice.

In sum, the acquisition and maintenance of expert performance in golf appears to follow a pattern similar to that found in many other domains involving perceptual-motor skill. Once we view the future and current expert performers as biological systems, many requirements for acquiring and maintaining expert performance become apparent. The bodies and brains of the expert performer are complex systems that adapt to the demands of daily activities, such as extended deliberate practice. The future expert performers need to gradually increase their level of practice over years of involvement in the domain and then maintain high levels of practice to sustain the current level of adaptation. When expert performers decrease the amount and intensity of their daily practice then the body will change resulting in a new level of adaptation typically with reduced functionality. The reduction in performance of older performers and golfers appears to be in large part the result of reduced levels of practice and physical activity.

The Path to Increased Control

One of the most important insights about the game of golf for me, as a non-golfer, is how difficult it is to hit correct shots in a reproducible manner. Even the best mechanical devices, designed for the sole purpose of driving or putting golf balls cannot produce completely consistent shots. And neither can the best players! All golfers need to accept that there is inherent variability in golf that is outside human control, just as there is in playing the roulette, tossing a coin, or throwing a pair of dice. They must also accept that humans are all-purpose organisms that are constantly changing and adapting to a wide range of regular activities and demands. In light of this unavoidable variability, the task of acquiring expertise in perceptual-motor domains means acquiring the mechanisms to reduce variability by monitoring and controlling one's performance, striving for consistence, and gaining knowledge of one's variability, in order to produce the most effective performance under specified conditions.

The focus on acquiring mechanisms that reduce variability makes the search for quick fixes or sudden insights in golf seem unrealistic. It is hard to imagine any chance discovery that could elevate the level of consistent performance of a recreational golfer to the level of expert golfers. Furthermore, it is obvious why improved golf performance is attained only by gradually reducing sources of variability over years or even decades. The consistency of golf shots can be increased by designing practice activities that allow repeated opportunities to get feedback on shots that are the same or intentionally varied by the golfer. Increased consistency of shots will facilitate the development of representations for predicting ball trajectories and of strategies for planning one's shots for particular holes on golf courses.

In a more speculative vein, I propose that attaining and maintaining high levels of performance in golf require the acquisition of representations that allow individuals to monitor and control aspects of their swing and putting. According to this argument, expert performance cannot be fully automated because it requires continued adjustment and control (Ericsson, 1996, 1998). Let me illustrate my argument by discussing another exceptional motor activity that has been studied experimentally, namely juggling. Jugglers monitor the trajectories of the juggled objects at the summit of their arch — the rest of the visual field can be occluded without decrements in performance (Beek, 1989). After assessing any deviations from the preferred path of an object at the summit, the juggler adjusts the throwing action a fraction of second later when that object reaches the juggler's hand. Control of rapid movement appears to be attained by anticipatory processing where an expert performer is able to predict necessary adjustments to allow programming of the ballistic motor action in advance.

This general type of anticipatory adjustment of rapid movements has been demonstrated in many sports, such as, baseball, hockey, volleyball, and tennis (Abernethy, 1991). For example, expert racquet players are able to predict the ball trajectory of a tennis serve better than novice players — in fact, they are able to predict the ball path better than chance *even before* the serving tennis player has made contact between the ball and racquet by reading the preparatory movements that set up the serve. This form of anticipatory processing allows experts to prepare their motor actions well in advance of the brief impact between ball and club/racquet — "programming the computer" to use Nicklaus' (1974) phrase. It is probable that expert golfers engage in this type of preparation before a shot, when they plan and image the desired trajectory clearly, and then proceed to align and set up and making potential adjustments before they initiate the downswing to hit the ball with their club.

Our current knowledge about the representations that allow expert golfers to control their performance better is limited. In the absence of experimental evidence from expert performance in golf, I will base my discussion on the existing knowledge from other domains of expertise, such as music and chess. Research on music expertise (Ericsson, 1997, 1998; Lehmann & Ericsson, 1997a) has revealed evidence for the development of three general types of interacting representations illustrated in Figure 8. One type of representation allows the expert performer to create an image of the desired goal, such as the sound of the music performance. In the case of golf, this would correspond to the desired ball trajectory for a shot where the terrain, weather conditions, and consistency of the required shot are taken into account. Another type of representation allows the expert to translate the goal into an appropriate sequence of motor actions, where the musicians generate the speed and loudness necessary to produce the desired sound.

Because musicians must sometimes perform music without prior opportunity to prepare and rehearse their interpretation, called sight reading, they have to be able to plan mentally how their fingers will strike the keys during their music performance (Lehmann & Ericsson, 1993, 1996). Expert pianists retain control over their motor performance even after a piece has been memorised and they have been shown to be able to perform the piece without additional practice under changed conditions, such as in a different key or at a slower tempo (Lehmann & Ericsson, 1995, 1997b). Similarly, during tournament play the golfer has to generate the appropriate stance, alignment and other adjustments, such as producing a fade, to achieve the intended shot without the opportunity to try out various shots in advance.

The third and final type of representation allows the expert to monitor and compare their concurrent performance with their desired goal, such as the intended musical sound or the intended sequence of a pianist's finger movements. In some recent studies Woody, Lehmann, and Ericsson (1998) documented this ability of expert musicians by observing them reproduce several different versions of an expert's prerecorded interpretations of pieces of music. Furthermore, expert pianists can rapidly identify their incorrect

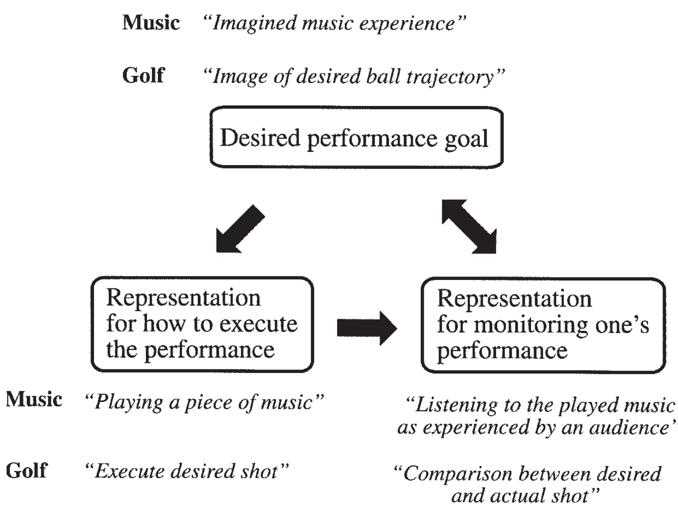

Figure 8

Three types of internal representations that mediate expert music and golf performance and its continued improvement during practice. (Adapted from "The scientific study of expert levels of performance: General implications for optimal learning and creativity" by K. A. Ericsson in *High Ability Studies, 9*, p. 92. Copyright 1998 by European Council for High Ability.)

keystrokes on the piano and "hide" their mistakes by modifying their subsequent playing. A similar type of representation should allow a golfer to identify missed putts based on very early cues — well before the ball comes to a stop. This assessment should allow them to distinguish misdirected shots and incorrect reading of greens from normal variability of ball trajectories that would not require adjustments. Ideally, the expert golfer should not only be able to identify the error, but also localise the source of the miss, which would allow them to make adjustments or at least be able to assess the component that requires correction during subsequent practice. In accord with these speculations, expert golfers report that they engage in practice after competitive rounds to correct faults and errors (Jones, 1966; Nicklaus, 1974). Furthermore, expert minigolfers exhibit better memory for their performance during a round than less accomplished players and they can better recall the types of strokes made during the round (Bäckman & Molander, 1986).

How are these representations acquired? Many expert golfers report seeing visual images of the desired ball trajectories when they play and also when they reflect back on events during a competition. It is tempting to believe that novices might benefit from engaging in similar visual imagery as well as watching experts perform. However, from extensive research in many other domains of expertise, such as music and chess, we know that these representations do not result from mere experience or even passive observation of experts' performance. For example, a music student is not likely to attain the performance of a virtuoso violinist by merely observing video recordings or even trying to recall images of those performances. In order to benefit from rehearsing visual memory images, the memory image should correspond to the perceived events and situations.

A vast body of research on memory has shown that in many domains there is close correspondence between level of expertise and the ability to reproduce representative stimuli after a brief exposure (Chase & Simon, 1973; Ericsson & Kintsch, 1995; Ericsson & Lehmann, 1996; Ericsson, Patel, & Kintsch, 2000). For example, the memory for briefly presented chess positions increases slowly as the performers' chess skill increases and associated representations develop and become increasingly refined. Expert chess players have been shown to collect books and magazines with the recorded games of chess masters (Charness et al., 1996). They can play through the games to see if their selected moves correspond to those originally selected by the masters. If the chess master's move differed from their own, it would imply that they must have missed something in their planning and evaluation. Through careful, extended analysis, the chess expert is generally able to discover the reasons for the chess master's move. Similarly, the chess player can read published analyses of various opening combinations and supplement their own knowledge by examining the consequences of new variations of these openings. Serious chess players spend as much as four hours every day engaged in this type of deliberate practice (Charness et al., 1996; Ericsson, Krampe, & Tesch-Römer, 1993). The memory of chess players improves gradually and when they reach the level of chess master they are able to play games under blindfold conditions without any perceptually available chessboards. However, this memory is not visual or photographic, because if the same pieces from a chess position are scrambled before they are blindfolded, the chess masters' memory is reduced to virtually the level of beginner.

In a manner similar to chess, one would predict that golfers would need to deliberately acquire valid mental representations by engaging in the type of practice activities described earlier, where the expert golfers systematically explored the consequences of different types of variations in the shots. As the acuity and validity of the representations increase, the expert golfer can benefit from engaging in mental practice akin to the chess player thinking about chess problems and the musician thinking about musical interpretations. They will also be able to benefit from studying their own performance and other expert performance on video recordings. However, it is less clear that watching tournament events will by itself improve their performance, though it might give golfers some ideas that would be implemented later over many practice sessions (Floyd, 1989).

In sum, many people think of golf and other sports, such as archery and darts, as simple where there seem to be restricted room for improvements through practice. However, once we start focusing on consistency of shots and efforts to exert increased control over our bodies and the motor system then the complexity of elite golf performance becomes apparent. The expert golfers' ability to perceive minute differences and exert control of the ball trajectories did not emerge naturally but through the process of acquiring refined representations for perceiving, monitoring and controlling the motor system. The beginning golfers cannot easily find the long and difficult path to the successful acquisition of the fundamental strokes in golf. Beginning golfers need a guide in the form of a teacher or a golf professional who can support their development of the required representations for monitoring and control. They need to understand that expert golf performance is based on consistency and control of shot-making and that these aspects of performance are the results of extended deliberate practice where golfers seek out training activities that provide reliable feedback and opportunities for repetition. As the causal link between training and improvements of golf performance is better explicated I believe that an increasing proportion of young aspiring golfers will be motivated to engage in regular deliberate practice and will seek guidance of golf coaches. These potential developments would bring golf closer to other domains of expertise, such as music and dance, where the technical proficiency of elite performers provides motivation to beginners, especially children and adolescents, to seek the guidance of a qualified teacher to find the extended and challenging path to expert performance.

As our scientific analysis of the highest levels of performance produces new insights into the complexity of skilled performance that is attainable after many thousands of hours of deliberate efforts to improve, I believe that we will uncover a deeper understanding of how effective learning and specialised practice methods can be used to target particular training goals. Instead of celebrating signs of innate talent and natural gifts, I would recommend that we marvel at the discipline and the monumental effort that go into mastering a domain.

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Footnotes

1. Given that senior PGA is not played under exactly the same course conditions as the regular PGA, it is not appropriate to infer that a comparable number of strokes for the two groups of players implies the absence of differences in performance. It is generally assumed that the preparation of courses for the regular PGA differs from that for senior PGA events. During regular PGA events the course is designed to be more difficult with a narrower fairway and more difficult placement of the hole on the greens.
2. In my chapter I am only concerned with efforts to increase the consistency of performance of amateurs beyond previously attained levels. It is clear that when the performance of amateurs decreases due to the sudden emergence of a problem, such as performance anxiety or inability to concentrate, then there may be short-term effective methods to restore the original performance.

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