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A review of primary and secondary influences on sport expertise

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Sport scientists have examined numerous factors influencing the acquisition and manifestation of high levels of performance. These factors can be divided into variables having a *primary* influence on expertise and variables that have a *secondary* influence through their interaction with other variables. Primary influences on expertise include genetic, training, and psychological factors while secondary influences include socio-cultural and contextual elements. This paper reviews the factors affecting the development of expert performance in sport and suggests directions for future research.

In the past century, researchers have typically been divided over the respective importance of environmental and biological (i.e., genetic) contributions to exceptionality. Dedicated environmentalists support a position that people begin as blank slates and everything that occurs after conception is the result of experience and learning (for an excellent review see Pinker, 2002). The opposite position, held by those supporting genetic determinism, is that a person's personality, their strengths and weaknesses, indeed their ultimate potential is decided by biological factors. Although these dichotomous positions are still maintained by a devoted few, it is more widely believed that human performance is the result of the interaction among elements from both areas. The inter-relationship between nature and nurture may be best described by Kimble (1993) who suggested that 'asking whether individual differences in behavior are determined by heredity or environment is like asking whether the areas of rectangles are determined by their height or width' (pp. 13–14).

Sport researchers have examined the various factors that influence the acquisition and manifestation of high levels of performance. For instance, Singer and Janelle (1999) presented an overview of the respective roles of genetics, training and

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resources in the development of expertise. However, they spent little time addressing contextual or socio-cultural factors that may also contribute. While prior research has examined an extensive range of variables affecting the development of elite performance, these variables can be divided into variables having a *primary* influence on expertise and variables that have a *secondary* influence through other variables. The purpose of this paper is to review these factors and identify areas of future research in order to further our understanding of the development of expert performance in sport.

Primary influences

Primary factors have a direct influence on the acquisition of expert performance and include all elements that an athlete contributes (either intentionally or unintentionally) to their own performance. Generally, they can be categorized into genetic factors, training factors and psychological factors.

Genetic factors

Although sports differ in the skills required for successful performance, one thing they share is the blending of physical and mental faculties into appropriate action. There is a significant literature attesting to the hereditary nature of specific physiological and cognitive characteristics, many that are relevant to sport performance (for a review of current findings see Rankinen *et al.*, 2001, 2002). Studies of hereditary characteristics are essentially interested in how a person's genetic makeup (i.e., their genotype) influences the expression of specific behaviours or capacities (i.e., their phenotype). To examine these relationships, researchers typically examine twins and/or members of a family. Two of the largest and best-known genetic studies are the HERITAGE (**HE**alth, **RI**sk factors, exercise **T**raining, **A**nd **GE**netics) family study (C. Bouchard *et al.*, 1995) and the Minnesota Study of Twins Reared Apart (MISTRA; T. J. Bouchard *et al.,* 1990). While other large-scale studies of genetic influences have been conducted (e.g., Fuentes *et al.,* 2002), we will limit our discussion to the findings of these two studies for two reasons. First, we can provide a more detailed description of the methods and samples used in these studies and thereby present a common context with which to discuss research findings and second, these two studies examine the role of genetics in distinctly different areas. The HERITAGE Family Study examines genetic influences on health and exercise variables while MISTRA deals almost exclusively with psychological variables. Although there is some overlap between the studies, collectively they provide a detailed profile of the role of genes in human behaviour.

The HERITAGE Family Study. The objective of the HERITAGE Family Study is 'to study the role of the genotype in cardiovascular, metabolic, and hormonal responses to aerobic exercise training and the contribution of regular exercise to changes in several cardiovascular disease and diabetes risk factors' (p. 722, C. Bouchard *et al.*, 1995). Families participating in the study include both biological parents and at least three biological children. Further, participants must be healthy but essentially untrained (i.e., sedentary), meet body mass index and blood pressure requirements and have an absence of medical conditions or diseases. Participants in the HERITAGE study complete a battery of tests including questionnaires related to health and physical activity, anthropometric measurements, and blood tests. In addition, the participants complete six maximal exercise tests; three prior to a 20-week standardized aerobic training programme and three at the conclusion of the training programme.

Results from the HERITAGE study have been impressive and indicate that several variables related to physical performance are genetically constrained. For instance, measures of cardiorespiratory function, such as maximal aerobic capacity (C. Bouchard *et al.*, 1998), sub-maximal aerobic capacity (Pérusse *et al.*, 2001), resting blood pressure (Gu *et al.*, 1998) and resting heart rate (An *et al.*, 1999), are related to genetic factors. Perhaps more importantly, an individual's response to exercise training also appears to be influenced by their genetic makeup (e.g., C. Bouchard *et al.*, 1999; Rice *et al.*, 2002). These findings indicate that significant amounts of inter-individual variation in cardiorespiratory function can be attributed to the presence or absence of specific genes. They also suggest that the level of attainment in activities where these factors are important (e.g., marathon running) will be affected by having an advantageous genotype.

The Minnesota Study of Twins Reared Apart. Lykken *et al.* (1992) suggested there are limitations to genetic investigations that target only family members. They argue that some traits and behaviours are the result of a complex interaction among genes and would only be evident through examinations of individuals sharing all of the same genes. To this end, MISTRA examines genetic influences with twins and other 'multiples'. The study of monozygotic and dizygotic twins has long been the method of choice for genetic researchers. Monozygotic twins are especially appealing because they have the same genes (i.e., 100 per cent of their DNA is shared), while dizygotic twins share approximately 50 per cent of their genes. However, a major obstacle for researchers examining genetic influences using twins is separating the effects of their shared environment from the effects of their shared DNA. MISTRA attempts to avoid this limitation by examining twins that were separated in infancy and reared apart. More than 100 sets of twins or triplets reared apart completed the weeklong battery of tests at the University of Minnesota, which includes approximately 50 hours of medical and psychological assessment.

Results from MISTRA indicate that genes can account for a significant portion of the inter-individual variation in psychological measures. For instance, general intelligence (T. J. Bouchard, 1997), work values e.g., altruism and autonomy (Keller *et al.*, 1992), job satisfaction (Arvey *et al.*, 1989), and several measures of personality (e.g., DiLalla *et al.*, 1996; Tellegen *et al.*, 1988) have been linked to genetic factors through MISTRA. In domains where these psychological characteristics are essential to the acquisition and demonstration of high levels of performance, genetic factors will play an important role.

Although the results of the HERITAGE and MISTRA studies are compelling, there are a number of problems with applying current findings from genetics research to high levels of performance. First, neither the HERITAGE Family Study nor MISTRA have results that are generalizable to all populations. For instance, twin studies in general and MISTRA in particular typically examine subjects from specific sub-sections of the population (e.g., middle to upper class) and may not be generalizable to other groups. T. J. Bouchard warns, 'heritability estimate[s] should not be extrapolated to the extremes of environmental disadvantages' (1997, pp. 137–138). Furthermore, by not including participants from the extremes, researchers remove important inter-individual variation and may inflate the contribution of genes. A specific concern relative to MISTRA is that their findings are built on the assumption that the placement of twins reared apart is random, an assumption that some researchers argue is problematic (Joseph, 2001). A final concern is the lack of research on elite athletes. Typically, genetics researchers examine participants from the general population and these results are extended to other groups. The HERITAGE study, for example, examined only families that began sedentary and tracked performance changes after 20 weeks of training. In contrast, elite athletes have performed enormous amounts of structured training designed to perpetuate physiological and cognitive adaptations in order to increase performance. The long-term effects (> 10 years) of this type of training on the body are not well understood and further research is necessary to elucidate the body's ability to adapt to training stress over long periods of time.

Training factors

Considerable research attention has been given to the acquisition of motor skills. Previously, researchers such as McCloy and Young (1954) supported the existence of a general motor ability. While the idea of a general ability to perform motor tasks and/or a general ability to learn motor tasks (e.g., Brace, 1927; McCloy, 1937) is intuitively appealing, there is little empirical support for this position (Gire & Espenschade, 1942; Gross *et al.*, 1956). In fact, there is strong support for the opposing position, that skilled performance is highly specific to the performance task and that there is little association between skills even in similar tasks. A classic example is the study by Drowatzky and Zuccato (1967) examining subjects' performances on six different balance tasks. The correlations among the tests of balance were surprisingly low ($r = .31$ was the largest) indicating little association even across tests derived from the same skill set (i.e., balancing).

Typically, researchers examining differences between expert and non-experts in the cognitive aspects of sport have revealed no differences in stable physical abilities such as reaction time and visual acuity (termed 'hardware' by Starkes & Deakin, 1984); however, experts and non-experts do differ on information processing strategies that can be influenced through training (termed 'software' by Starkes & Deakin, 1984).

For instance, studies examining the visual cues used by expert cricket (Abernethy & Russell, 1984), badminton (Abernethy, 1991; Abernethy & Russell, 1987), soccer (Williams & Burwitz, 1993) and squash players (Abernethy, 1990) have indicated that experts use body position cues obtained from their opponents pre-contact (i.e., before they bowl or before they strike the birdie or ball) to provide information about how best to respond. Indeed, at the elite level of competition in these sports, reliance on visual information obtained post–opponent–contact (i.e., after the opponent bowls or strikes) is often problematic, for it leaves too little time to react. Therefore, experts from these sports have learned to rely on visual cues from their opponent's arm and wrist position to predict where their opponent will place the ball. They then make the necessary adjustments in response to their prediction.

Consistent findings with both experts and non-experts on learned capacities and abilities provide support for the relationship between training and expertise. Researchers examining the accumulated effects of prolonged practice and the rate of learning have indicated a robust positive relationship between practice and performance. The relationship between practice and performance is so strong that some researchers (e.g., Ericsson *et al.*, 1993) support the notion that an adequate amount of high quality training is the only necessary ingredient for elite level achievement. Ericsson and colleagues (Ericsson *et al.*, 1993; Ericsson, 1996; Ericsson & Lehmann, 1996) advocate that increases in performance in any domain are the result of adaptation to task constraints through training or practice.

The '10-year rule' presented by Simon and Chase (1973) stipulates that a 10-year commitment to high levels of training is the minimum requirement to reach the expert level. This 'rule' has been applied successfully in many domains including music (Hayes, 1981; Sosniak, 1985; Ericsson *et al.*, 1993), mathematics (Gustin, 1985), swimming (Kalinowski, 1985), distance running (Wallingford, 1975) and tennis (Monsaas, 1985). The theory of deliberate practice (Ericsson *et al.*, 1993) extends the work of Simon and Chase by suggesting it was not simply training of any type, but the engagement in 'deliberate practice', that is necessary for the attainment of expertise. According to Ericsson *et al.*, deliberate practice activities are not intrinsically motivating, require effort and attention and do not lead to immediate social or financial rewards. In a review of studies on skill acquisition and learning, Ericsson (1996) concluded that, with few exceptions, level of performance was determined by the amount of time spent performing a 'well defined task with an appropriate difficulty level for the particular individual, informative feedback, and opportunities for repetition and corrections of errors' (pp. 20–21). By continually modifying the level of task difficulty, future experts can prevent learning plateaus and perpetuate adaptation to higher amounts of training stress.

Although the theory of deliberate practice was developed through research with musicians, Ericsson and colleagues indicated that the theory also applies to expertise in sport (Ericsson *et al.,* 1993; Ericsson, 1996). To date, researchers examining the application of the theory of deliberate practice to the domain of sport have investigated figure skating (Starkes *et al.*, 1996), karate (Hodge & Deakin, 1998), wrestling (Hodges & Starkes, 1996), soccer (Helsen *et al.*, 1998), middle distance running

(Young & Salmela, 2002), field hockey (Helsen *et al.*, 1998; Baker, Côté & Abernethy, 2003a), triathlon (Baker *et al.*, in press) basketball and netball (Baker, *et al.*, 2003a). Typically, the relationship between hours spent in sport-specific practice and level of attainment is consistent with the tenets of deliberate practice theory. Expert athletes accumulated more hours of training than non-experts (Starkes *et al.*, 1996; Helsen et al., 1998; Hodge & Deakin, 1998). Moreover, not only do experts spend more time in practice they also devote more time to specific activities most relevant to developing the essential component skills for expert performance (Baker, Côté, & Abernethy, 2003b; Deakin & Cobley, 2003). For example, Baker *et al.* (2003b) found that expert athletes from basketball, netball, and field hockey accumulated significantly more hours in video training, competition, organized team practices and one-on-one coach instruction than non-expert athletes. Similarly, Deakin and Cobley (2003) reported that elite figure skaters spent more time practicing the technical aspects of performance such as jumps and spins than competitive or test skaters. Differences between experts and non-experts on both quantity and quality of training are strongly supported in sport and other domains (e.g., chess; Charness *et al.*, 1996).

The deliberate practice paradigm, however, is not without its problems. Researchers examining the acquisition of expert sport performance have necessarily been limited to using retrospective techniques. While these investigations have been quite useful in identifying the quantity and quality of training required for expertise, they do not provide evidence of a causal relationship due to the absence of control groups (Sternberg, 1996; Abernethy *et al.*, 2003). The addition of systematic, experimental evidence would add considerable support for training-specific approaches to expertise development. However, the logistical and financial difficulties associated with this type of long-term research make this an unattractive option for most researchers.

Psychological factors

The acquisition and manifestation of expert performance also requires specific psychological characteristics. Empirical evidence indicates that psychological factors are consistent predictors of performance (e.g., Orlick & Partington, 1988; Smith & Christensen, 1995). However, research examining the psychological makeup of elite athletes has been somewhat ambiguous, in large part due to the unique requirements of different sports. For instance, the psychological requirements for proficiency in sports such as golf and martial arts are appreciably different (cf. McCaffrey & Orlick, 1989; d'Arripe-Longeville *et al.*, 1998). Nevertheless, there are common mental characteristics essential to high levels of performance in any sport. Furthermore, these factors can be divided into characteristics necessary for the acquisition of expertise and those necessary for the manifestation (i.e., the demonstration) of expertise.

Psychological characteristics necessary for the acquisition of expertise. In order for athletes to acquire the volume of training described in the previous section, specific psychological characteristics are critical. Without question, a high level of motivation is essential to success (Singer & Orbach, 1999). Contemporary investigations of motivation in sport have examined a variety of theoretical perspectives including achievement goal theory (Nicholls, 1984; Duda, 1992), self-efficacy theory (Treasure *et al.,* 1996; Bandura, 1997), attribution theory (Biddle, 1993), and self-determination theory (Deci & Ryan, 1991). While each of these perspectives addresses the issue of motivation in a different way, commonalities are evident. For instance, in an integrated model of motivational orientation in sport, Weiss and Chaumeton (1992) suggested that intrinsic or mastery orientations were superior to extrinsic or outcome orientations in developing the motivation to persist in an activity. Regardless of the theoretical perspective taken, without the proper motivational disposition, it is unlikely that an athlete would be capable of attaining any significant level of proficiency. Furthermore, our understanding of the motivational factors underlying the acquisition of expert performance at different stages of development is particularly limited and is an important area for future research.

Psychological characteristics necessary for the manifestation of expertise. To be considered an expert, a performer must reliably exhibit exceptional levels of skill (Ericsson, 1996). In order to consistently demonstrate these skills, expert athletes must also negotiate situational psychological requirements. For instance, the ability to focus on a given task (Cox, 1990) and/or to manage the anxiety inherent to competition (Gould *et al.*, 1987) is essential to successful performance. Early investigations (e.g., Morgan, 1980) used the Profile of Mood States to examine the psychological characteristics of elite athletes and found that those who were successful tended to demonstrate an ‘iceberg’ profile (i.e., higher than average on vigour but lower than average on tension, depression, anger, fatigue and confusion).

In the decades following these initial studies, researchers have examined the psychological characteristics of successful sport performers. In a recent review of this body of work, Williams and Krane (2001) reported that successful performers have higher levels of self-confidence, better concentration and are less likely to be distracted from their performance. They are also more pre-occupied with and think about their sport in a more positive way. Further, successful athletes experience less anxiety before and during competition and are able to control what anxiety they do experience in a manner than facilitates performance (e.g., using anxiety to ‘psych up’). Lastly, successful athletes have a greater ability to rebound from mistakes than their less successful counterparts. Gould *et al.* (2002) confirmed these characteristics in a recent study of Olympic gold medallists.

In addition to the characteristics outlined by Williams and Krane (2001) and Gould *et al.* (2002), Anshel (1997) reported that elite athletes are typically predisposed to higher amounts of risk-taking, sensation seeking and competitiveness than non-elite athletes. Further, he reported that elite athletes are distinguishable from non-elites on a number of behavioural tendencies, cognitive strategies and performance expectations.

While the possession of specific psychological characteristics is essential for the development and demonstration of expertise, the absence of detrimental characteristics may be equally important. Singer and Janelle (1999) suggest, 'the presence of behavioural disorders and difficulties in psychosocial adjustment will contribute to lessened capabilities to be productive in a sport setting' (p. 129). As suggested by Starkes *et al.* (1996), Canadian golfer Moe Norman is an example of an individual who developed incredible skills, but who never achieved the degree of success that these skills warranted, primarily because of an intense shyness that made interaction with others difficult. Norman has been widely recognized as one of the greatest ball strikers in the history of golf, but a lack of interpersonal skills resulted in minimal success on the professional circuit. Stories abound of Norman deliberately 'throwing' tournaments on the final holes because of an unwillingness to make the compulsory acceptance speech, or winning the tournament and then hiding during the awards ceremony (Rubenstein, 1990). Achieving success in sport is about performing the requisite skills, but it is also about dealing with numerous distractions and obligations. Those who are better able to deal with all that is extraneous to their actual performance are at a distinct advantage.

While the qualities outlined above provide useful information regarding the psychological factors that influence the development and demonstration of sport expertise, our understanding is far from complete. Further research is needed to fully explore the relationship between personality characteristics and expert performance. Certainly, without the appropriate psychological characteristics, the development and manifestation of expertise becomes unlikely.

Interaction of primary influences

Generally, comprehensive models of human performance incorporate the interaction of primary factors in the development of expert level performance. While significant amounts of training are clearly essential for elite levels of performance, there is no conclusive evidence indicating that training is the only factor. It is likely that innate predispositions facilitate the completion of required amounts of training. For example, an athlete with a genotype allowing them to complete large amounts of high intensity training without suffering from injury may be at an advantage over an athlete with a less resilient makeup. However, upon examination it would appear that training was the distinguishing factor between the two athletes. As mentioned earlier, research from the HERITAGE study indicates that the effect of a training stimulus is influenced by the presence of specific genes that predispose some to greater training effects than others (e.g., Bouchard *et al.*, 1999). Additionally, findings from MISTRA suggest genetic factors play a role in shaping an individual's psychological composition (see Neubauer & Neubauer, 1996 for a review of genetic effects on personality).

One analogy often used to describe the relationship between nature and nurture is the metaphor of the empty bucket; specifically that genes determine the size of the bucket while the environment determines the contents. Lewontin (2000) suggests that this position is flawed; instead human behaviour should be viewed as 'the consequence of a unique interaction between the genes it carries, the temporal sequence of external environments through which it passes during its life, and random events of molecular interactions within individual cells' (pp. 17–18).

Similarly, Bray (2000) suggested that the role of genes and environment on an outcome could be direct or indirect. For instance, the onset of an aerobic exercise programme has direct effects on aerobic performance (e.g., through increased blood volume) but also has indirect effects by altering the action or expression of specific genes that influence the same outcomes (e.g., genes affecting aerobic enzyme activity). Researchers in behavioural genetics (Plomin & Bergeman, 1991; Plomin, 1994) advocate that the way forward in research examining human performance is by investigating the interplay between biology and environment.

Dynamic approaches to human behaviour (e.g., dynamic systems theory; Davids *et al.*, 2001) speculate that human performance is best described using models that illustrate the inter-relation between biological and cognitive sub-systems. For example, performing a 'free throw' in basketball involves the cohesive interaction of muscular-skeletal, metabolic and cognitive systems. Using a dynamic approach to performance (e.g., Davids *et al.*, 2003), an athlete with an advantageous genetic makeup but without the desire to train at sufficient intensity is not pre-disposed to higher levels of performance than an athlete who has completed significantly more intense training.

Secondary influences

The role of the primary influences outlined above is often influenced by *secondary* factors relevant to the sport performed. For example, individual cultures will value different sports (e.g., Kenya and running) and may provide societal resources to promote increased involvement and the development of higher levels of skill in that sport (hypothesized in Figure 1). In turn, societal support may provide important extrinsic motivation to continue involvement, leading to a greater ease of training that facilitates the accumulation of practice hours in that sport. On the other hand, sports without societal endorsement may not have the same quality of available resources

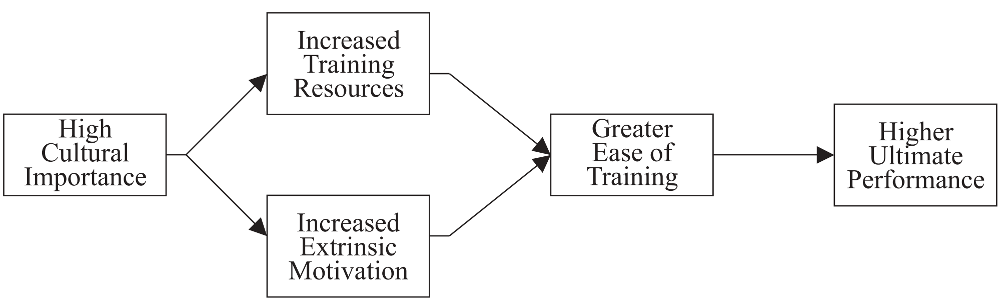

Figure 1. Example of the secondary effect of socio-cultural variables

and support making the path to expertise more difficult. Important moderators and mediators of the relationships between primary influences and sport performance include socio-cultural and contextual factors. The influence of these variables comes through their indirect effect on primary factors (i.e., they have no direct effect).

Socio-cultural factors

Socio-cultural factors are a significant and often overlooked influence on the development of expertise. Although an extensive review of the range and impact of socio-cultural factors is beyond the scope of this paper, several factors are briefly examined here.

Cultural importance. The importance that a society places on a particular sport can have a significant influence on any success achieved. For instance, Canada has a long and storied history in ice hockey and is one of the pre-eminent nations in producing the game's stars. Numerous factors contribute to this phenomenon. Canada has a climate that is conducive to ice hockey, as it is possible to play outdoors for a number of months each year. In addition, hockey heroes are revered in Canada, and hockey games receive generous attention in the national media. As a result, child participation rates are extremely high in the country. In fact, Canada has 3.5 times more children playing ice hockey than Russia, Sweden, Finland, the Czech Republic and Slovakia combined (Robinson, 1998). In Austria we can see a similar pattern at work, but for alpine skiing rather than ice hockey (Coakley, 2001). The combination of the natural environmental advantages and the cultural emphasis Austrians place on skiing has undoubtedly contributed to the large number of high profile downhill racers that the country produces.

Instructional resources. Access to essential resources such as knowledgeable coaches during the learning process also influences skill development. Recent research into expert performance has identified time spent with an instructor as crucial to an athlete's overall development (Young, 1998; Deakin & Cobley, 2003). Given that a coach normally constructs a high percentage—in some cases virtually 100 percent—of an athlete's practice time, the ability of the coach to devise an environment that fosters optimal learning becomes a significant key to athlete development.

The ability to maximize time in practice is one hallmark of coaching expertise (Deakin & Cobley, 2003). Another is the ability to convey information effectively to athletes during that practice time. In a study of swimming coaches, Rutt-Leas and Chi (1993) found that differences between expert and non-experts extended to the quality of instruction that was imparted to athletes. When presented with a number of different swim strokes to analyse, novice coaches offered a somewhat superficial analysis using vague descriptions. Expert coaches, on the other hand, were very precise in their assessment and specific in their recommendations for improvement.

Access to high quality coaching would appear to be an important component in maximizing athlete development.

Familial support. Bloom's (1985) work on talented youth, and Côté's (1999) and Côté *et al.*'s (2003) subsequent model of talent development in sport emphasize the crucial role that family members play in the acquisition of expert performance, particularly parents. Both authors outline the multi-faceted nature of parental involvement in their child's chosen domain, and how that involvement changes as the child grows older and skill levels increase. In early stages of involvement, parents provide leadership in a number of ways, from initially enrolling their child in the activity, to providing instruction or coaching, to arranging transportation and access to facilities. As the child moves from 'sampling' to 'specializing' to finally 'investing' significant amounts of time and energy into an activity (see Côté *et al.*, 2003 for a more extensive review of these stages), the nature of parental involvement changes. Leadership aspects tend to decline, while financial and emotional support remain important as parents help to mitigate the pressures that are part of being an elite performer.

Contextual factors

The specific requirements of the sport under examination will determine the amount of training and the role of specific genes and psychological factors on performance. A sport's maturity and the number of active competitors are examples of contextual factors that moderate the role of more direct factors.

Sport maturity. A sport's maturity will influence the amount and type of training required to become an expert. In sports that are relatively new or less developed, expertise will be attained with less training. To illustrate, consider the number of hours required to develop expertise in the recall of strings of numbers. Chase and Ericsson (1981) reported that after only 250 hours of training their subject (SF) was able to recall up to 80 digits. However, studies of experts in sport indicate that it can take more than 10,000 hours of training to achieve expertise. As the range and number of skills required for expert performance increases, the amount of training and the possession of specific genes may become more important.

A related area is the level of skill refinement necessary for expert performance. As a field develops and evolves, the skills required for proficiency become more and more refined and the role of direct influences increases. Consider the domains of sport and music. As reported earlier, experts in these domains spent similar amounts of time in deliberate practice. However, due to problems identifying sport activities that met the criteria for deliberate practice, all sport training was included as deliberate practice. For the musicians studied by Ericsson *et al.* (1993), only the hours spent practicing alone constituted deliberate practice. If all practice activities were considered, the number of training hours for the musicians

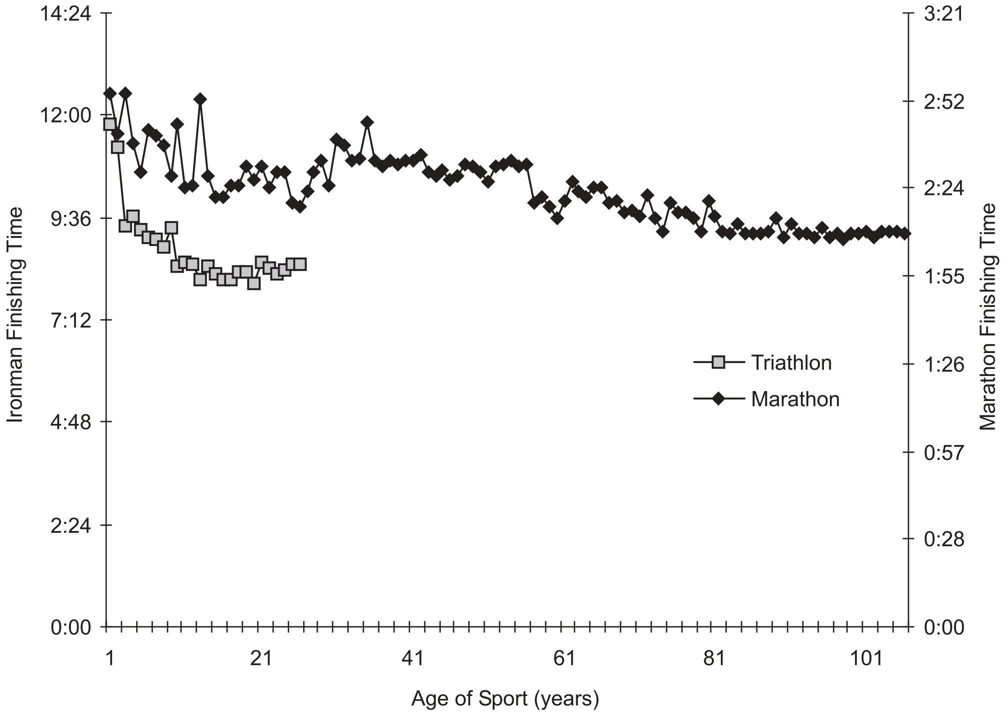

Figure 2. Finishing times for each year of the Boston Marathon and the Ironman Triathlon World Championship since their inceptions in 1897 and 1978 respectively

would be considerably greater than that reported for the expert athletes (>50 hours per week for the musicians compared to < 30 hours for the athletes). This may reflect a greater level of skill refinement required for musical expertise as compared to sport expertise. Indeed, methods to facilitate the acquisition of musical skill have been developed over hundreds of years. In comparison, modern organized sport is a relatively recent invention.

Figure 2 presents a comparison between two similar sports, the marathon and the Ironman triathlon. While both test physical and mental endurance over extended periods of time, a key difference between the two events is how long they have been in existence. The figure presents the winning times for the Boston marathon, established in 1897 and the Ironman Triathlon World Championship held each year in Hawaii since 1978. Both events represent the premier competitions in their respective sports. In both endeavours there is a relatively rapid increase in performance during the first decade or so of involvement but then improvements slowly taper off. In fact, there has been a gradual yet consistent decrease in performance times in the Boston Marathon over the 100+ years of its existence as training methods and capabilities improved. The same type of relationship should be expected in the sport of Ironman triathlon. It is reasonable to suggest that if one aspired to elite status in either of these sports, the more difficult path would be in the marathon where performance has evolved over 100 years rather than the Ironman where performance has evolved over a mere 25 years.

Depth of competition. The number of active competitors in a sport and the depth of competition also influence the ease with which one can realize elite performance. Undoubtedly, it will be more difficult to achieve elite performance in sports such as soccer, which have a worldwide base of competitors than, for example, trampolining. Simply put, it is easier to become an Olympic medallist from a competitor pool of 100 compared to a pool of 10,000. In a study of the development of expertise in decision-making sports, Baker *et al.* (2003a) found that it took significantly more hours of sport-specific training to attain expertise in basketball than in netball or field hockey.

Concluding remarks and directions for future research

The primary purpose of this paper has been to review the various factors contributing to exceptional performance in sport. To this end, a range of primary and secondary factors was considered. However, even the most advantageous genetic composition combined with training in the most favorable environments is not a guarantee of success. Complex and dynamic relationships, such as the development of expert performance, are dramatically affected by any uncertainty (or chaos) in the behaviour of the variables. According to Gollub and Solomon (1996), 'any uncertainty [in a complex system]… no matter how small, will lead to rapidly growing errors in any effort to predict the future behavior' (pp. 282–283). The behaviour of complex systems is only completely predictable when the components of performance are known to an infinite degree of accuracy. Given these limitations, prediction of expert performance will always be limited by uncertainty.

One path forward in expertise research is to consider the interaction of various influences on performance. As previously discussed, twins and adopted children provide an exceptional resource for considering the interaction of genetic and environmental factors, but despite their widespread use in mainstream psychology, twin and adoption research in sports science has been limited. Researchers should also consider multidisciplinary approaches that combine current understanding from biology, psychology and sociology. Although the small samples characteristic of expertise studies limit the statistical power available for examining interactive effects, advances in the level of sophistication in commercially available statistical analysis packages have provided methods for examining complex moderating and mediating relationships; but this would require moving beyond the main effects paradigm of nature versus nurture. Further, due to the complexity of the relationships suggested and the difficulties associated with identifying interactive relationships of this nature (for a review see Wahlsten, 1990) establishing the validity of moderating and mediating relationships will be a long-term process. Cronbach (1991) stated, 'serious interaction research ought to be a program of several years' duration, although there are few examples in behavioral science' (p. 87). Examinations of this nature, howsever, may provide answers to questions that have been elusive to sport researchers using current models.

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