Gobet. F. & Campitelli, G. (2007). The role of domain-specific practice, handedness and starting age in chess. *Developmental Psychology*, 43, 159-172.

The Role of Domain-Specific Practice, Handedness and Starting Age in Chess

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Authors' note

We thank Neil Charness, Philippe Chassy, Merim Bilalić, and anonymous referees for comments on this paper.

Running head: Talent and Practice

Abstract

The respective roles of the environment and innate talent have been a recurrent question for research into expertise. This paper investigates markers of talent, environment, and critical period for the acquisition of expert performance in chess. Argentinian chessplayers (*N* = 104), ranging from weak amateurs to grandmasters, filled in a questionnaire measuring variables including individual and group practice, starting age, and handedness. The study reaffirms the importance of practice for reaching high levels of performance, but also indicates a large variability, the slower player needing eight times more practice to reach master level than the faster. Additional results show a correlation between skill and starting age, and indicate that players are more likely to be mixed-handed than individuals in the general population; however, there was no correlation between handedness and skill within the chess sample. Together, these results suggest that practice is a necessary but not sufficient condition for the acquisition of expertise, that some additional factors may differentiate between chessplayers and non-chessplayers, and that the starting age of practice is important.

Keywords

chess, critical period, domain-specific practice, expertise, handedness, talent

The Role of Domain-Specific Practice, Handedness and Starting Age in Chess

Several theories of expertise have been developed to explain the differences in performance between experts and non-experts in domains such as music, mathematics, games and sports. One strand of research has tried to find out whether expertise is due mainly to domain-specific practice within the task environment (Ericsson, Krampe, & Tesch-Romer, 1993; Howe, Davidson, & Sloboda, 1998; Starkes, Deakin, Allard, Hodges, & Hayes, 1996) or to some talent underpinned by genetic factors (Fein & Obler, 1988; Schneiderman & Desmarais, 1988; Winner, 1996). Another strand has aimed to explain cognitive processes underlying expert performance and its acquisition (Ericsson & Kintsch, 1995; Gobet & Simon, 1996a; Simon & Chase, 1973).

This article focuses on the talent vs. practice question, the philosophical roots of which go back to the nature vs. nurture debate. As can be seen in a recent target article in *Behavioral and Brain Sciences* (Howe et al., 1998) and in the commentaries following it, there is currently insufficient evidence to unambiguously support any of these two extreme positions. Continuing the efforts of others (e.g., Bronfenbrenner & Ceci, 1998; Csikszentmihalyi, 1998), we wish to present empirical data to show that this debate is based on a false opposition, and that both talent and practice have an important role in the acquisition of expert performance.

We first outline the "innate talent vs. practice" debate generally, and the hypothesis of a critical period for the development of expertise. We then focus on the relevance of these topics to chess expertise. When presenting the innate-talent position, we discuss Cranberg and Albert's (1988) hypothesis, based on Geschwind and Galaburda's theory (1985), that non-righthanders should be more represented in several fields, such as mathematics, music, and chess, than in the general population.

When presenting the other extreme emphasizing the primary role of learning from the environment, we summarize Ericsson et al.'s (1993) framework of deliberate practice, which proposes that the amount of deliberate practice is the key to top-level performance. We also discuss hypotheses based on the presence of a critical period in the development of expertise. Following this, we test hypotheses derived from these three approaches with data based on a questionnaire given to Argentinian chessplayers of varying skill levels, and we draw the implications of these data for theory.

The "Innate Talent vs. Practice" Debate

As documented in the literature (e.g., Howe et al., 1998), there is a consensus that individual differences in performance exist in most, if not all, domains of expertise. The debate arises when researchers try to explain the source of these individual differences: some authors, continuing the tradition initiated by Galton (1869/1979), propose that innate talent accounts for most individual differences, while others argue that these differences are better explained with the extended period of intense practice that most experts have to go through. Support for innate talent theories is offered by the study of precocious attainments such as those of Mozart (music), Ramanujan Srinivasa (mathematics), and more recently, Bobby Fischer (chess). Several studies in behavioural genetics also suggest a strong inherited component for intelligence (see Plomin, De Fries, McClearn, & Rutte, 1997, for a review; but see Grigorenko, 2000, for critiques of this line of research). Candidate mechanisms for explaining general intelligence include speed of processing, velocity of the nervous system, and reaction time, among others (Mackintosh, 1998). Since these abilities (paradoxically, not cognitive) are very basic, it is thought that they are genetically determined and not modifiable with practice.

Geschwind and Galaburda (1985) proposed an influential neuropsychological theory describing the relationship between brain development, immune disorders, and cognitive abilities. Great exposure or high sensitivity to intrauterine testosterone in the developing male foetus would lead to a less developed left hemisphere and thus a more developed right hemisphere than in the general population, a state of affairs that they called "anomalous dominance." This would result in a higher probability of being non-righthanded and being gifted in visuo-spatial abilities, and as a consequence, in domains such as mathematics, music, and chess. Geschwind and Galaburda's (1985) theory has motivated a large number of studies (e.g., Krommydas, Gourgoulianis, Andreou, & Molyvdas, 2003; Tan & Tan; 2001; Winner, 1996, 2000), although the results did not always support its predictions. For example, Bryden, McManus, and Bulman-Fleming (1994) argue that there are serious theoretical and methodological difficulties with the concept of anomalous dominance, and that the data on the relationship between handedness and immune disorders show a mixed pattern, with some conditions (allergies, asthma, and ulcerative colitis) showing positive associations with left-handedness, as predicted by the theory, but others (myasthenia gravis and arthritis) showing negative associations. (For further discussion of Geschwind and Galaburda's theory, see the section on innate talent and chess, below.)

At the other extreme of the continuum talent/practice, one finds Ericsson et al.'s (1993) framework of deliberate practice, which was influenced by Simon and Chase's (1973) earlier work on chess expertise. The main assumption is that the differences observed in performance in a number of domains are due to differences in the amount of deliberate practice. Deliberate practice consists of activities deliberately designed to improve performance, which are typically effortful and not enjoyable. Moreover, these activities cannot be extended throughout long periods and must therefore be limited to a few hours a day. High attainments are possible only if there is strong family support and a favourable environment—essentially being in the right place at the right time. Ericsson et al. (1993) report results from music expertise showing that the higher skilled engage more in deliberate practice. The same pattern was found in karate (Hodge & Deakin, 1998), soccer and hockey (Helsen et al., 1998), as well as skating and wrestling (Starkes et al., 1996).

Ericsson et al. (1993) do not rule out the participation of inherited factors, but they limit their role to motivation and general activity levels, explicitly excluding cognitive abilities. Evidence supporting the role of deliberate practice and questioning the role of talent includes a series of longitudinal experiments in the digit-memory span task. The results show that, with sufficient practice, average college students could achieve higher levels than those attained by individuals previously thought to have inherited skills (Chase & Ericsson, 1981).

Critical Period

A third explanation for expert performance, besides innate abilities and practice, is that there exists a critical (or sensitive) period for starting practice in a given domain. A number of studies have addressed the question of critical period in domains such as first language acquisition (Lenneberg, 1967), second language acquisition (Johnson & Newport, 1989; but see also Hakuta, Bialystok, & Wiley, 2003), American sign language (Newman et al., 2001), bird singing (Doupe & Kuhl, 1999), visual system development (Hubel & Wiesel, 1970), and auditory system development (Knudsen, 1998).

The critical period hypothesis implies that certain phenotypes are more likely to appear if particular interactions with the environment occur within a given time interval. For example, normal vision depends on exposition to light in an early period of life, and the mastery of language in humans depends on being exposed to a language early in life. Hensch (2003) analyzed evidence for two possible sources of this phenomenon: neural plasticity and neuroanatomy. He concluded that both a reduction of neural plasticity (hence, a reduction in the possibility of creating new synapses) and a structural consolidation of anatomical circuits are responsible for the existence of a critical period.

In cognitive tasks such as second language acquisition, the early stimulation in a critical period may enormously facilitate the acquisition of the skill, but it may not be a necessary condition for attaining a high-level performance. For example, although there is substantial evidence for a critical period in second language acquisition (e.g., Johnson & Newport, 1989), there is also evidence of high performance in late starters (Birdsong, 1992).

The deliberate practice framework recognizes that there are skills, most notably absolute pitch (Takeuchi & Hulse, 1993), that can be acquired *effortlessly* only during a specific and limited phase of development, perhaps because of biological maturation. However, the most important aspect of the starting age for the deliberate practice framework is that the earlier one starts practicing, the more hours of deliberate practice one accumulates (Ericsson et al., 1993, p. 388).

Research on Chess Expertise

Chess has been an important research domain in the study of expertise (for reviews, see Saariluoma, 1995, and Gobet, De Voogt, & Retschitzki, 2004), and, more recently, in the study of individual differences (Frydman & Lynn, 1992; Gobet, Campitelli & Waters, 2002; Howard, 1999, 2001, 2005; Waters, Gobet, & Leyden, 2002; see Holding, 1985, for earlier research). One invaluable feature of chess is the presence of a rating scale used internationally (Elo, 1978), which measures ability from world-class players down to novices. The World Chess Federation (FIDE, *Fédération Internationale des Echecs*) publishes rating lists of its members every three months and awards the titles of grandmaster, international master and FIDE master. Grandmasters (GMs) are usually rated above 2500 Elo, international masters (IMs) above 2400, masters between 2200 and 2400 (players above 2300 are often called FIDE masters), Experts between 2000 and 2200, class A players between 1800 and 2000, class B players between 1600 and 1800, and so on. In spite of the presence of these titles, it is important to realise that the Elo scale makes it possible to continuously measure the level of expertise, instead of separating individuals in arbitrary categories such as experts, intermediates, and novices. The existence of a continuous variable of chess skill, as opposed to a discrete variable, makes the use of some powerful statistical analysis, such as regression and correlation analysis, more advantageous.

Innate Talent

Based upon Geschwind and Galaburda's (1985) theory, Cranberg and Albert (1988) hypothesize that the primary neurological components of chess skill are located in the right hemisphere of the brain, and that chess skill develops more in males and non-righthanders than in females and righthanders, respectively. They argue that individuals with enhanced right-hemisphere development might have an advantage at chess, because the right hemisphere is known to engage spatial reasoning and pattern recognition, which both directly relate to chess skill (e.g., Simon & Chase, 1973). Cranberg and Albert's (1988) reasoning runs as follows: chess is a visuo-spatial task, visuo-spatial tasks are performed by the right hemisphere, non-righthanded individuals have the right hemisphere more developed, so non-righthanders should be more represented in the chess population.

There is extensive literature suggesting that visuo-spatial tasks are mainly performed by the right hemisphere, although it should be recognized that the left hemisphere is often engaged in these tasks. The involvement of the right hemisphere seems particularly strong for tasks engaging coordinate or metric relations, recognition of patterns as wholes, and spatial reasoning (e.g., Benton, 1985; Bever, 1975; Corballis, 2003; Kogure, 2001).

The link between visuo-spatial abilities and chess is more tenuous (see Gobet, de Voogt, & Retschitzki, 2004, for a review). On the one hand, Charness (1976), Robbins et al. (1996), and Saariluoma (1991) showed that when chessplayers were presented with a visuo-spatial secondary task, their performance in a chess task decreased, but when the secondary task was verbal, the performance remained unchanged. On the other hand, the relationship between visuo-spatial abilities and chess skill has turned out to be more difficult to document than expected, with studies such as Waters et al. (2002) failing to find such a link with adults, and other studies, such as Frydman and Lynn (1992), finding a link between chess and performance IQ with a sample of young chessplayers. Waters et al. (2002) attempted to reconcile these results by suggesting that visuo-spatial skills may be important in the early development of chess skill, but other skills become important over time.

There is some empirical support for the role of the right hemisphere in chess skill. Cranberg and Albert (1988) found that extended lesions of the left hemisphere hardly affect chess performance; however, they did not present evidence with extended right-hemisphere lesions, which would offer a more direct test of their hypothesis. In addition, they recorded the EEG of a chessplayer while he was playing blindfold chess. The player presented normal left-hemisphere activity, but abnormally high right-hemisphere activity. Chabris and Hamilton (1992) performed a divided-visual-field experiment with male chessplayers. They showed that the right hemisphere performs better than the left hemisphere at parsing according to the default rules of chess chunking, but that the left hemisphere performs better than the right at grouping pieces together in violation of these rules. Onofrj et al. (1995) performed an experiment with single photon emission computerized technology (SPECT) while chessplayers were solving a chess problem. They found a non-dominant dorso-prefrontal activation and also a lower non-dominant activation on the middle temporal cortex. The four righthanders presented activation on the right hemisphere, and contrary to the predictions of Geschwind and Galaburda's (1985) theory, the left-hander presented activation on the left-hemisphere. Finally, Atherton, Zhuang, Bart, Hu, and He (2003) found that brain activity was either bilateral or larger in the left hemisphere. In summary, although there is some evidence in favour of the use of the right hemisphere in chess, the results of the last two experiments are problematic for Geschwind and Galaburda's theory.

Sending an informal questionnaire to 396 US chessplayers, Cranberg and Albert (1988) collected data on handedness to test another prediction derived from Geschwind and Galaburda's (1985) theory—that there should be proportionally more non-righthanders in the chess population than in the general population. They found that there were 18% of non-righthanders in the chess population, which is significantly different from the rate in the general population (10 to 13.5%; Bryden, 1982; Geschwind, 1983; Gilbert & Wysocki, 1992). However, they could not find differences between a group of high-level players and a group of low-level players. The higher prevalence of non-righthanded individuals in the chess population as compared to the normal population can be seen as a marker of the role of right-hemisphere processing.

<u>Domain-Specific Practice</u>

In their seminal study of perception in chess, Simon and Chase (1973) pointed out that a decade of intense commitment with the game is necessary in order to reach grandmaster level. They estimated that a master has spent roughly from 10,000 to 50,000 hours playing or studying chess, and that a class A player has spent from 1,000 to 5,000 hours. Thus, it takes about 10 years of study and practice to become an expert. As we have seen, Ericsson et al. (1993) have taken these results to their extreme by stating that levels of performance are not limited by factors related to innate individual differences, but that they can be further increased by deliberate efforts. Note that Simon and Chase (1973) themselves were open to the possibility of individual differences due to genetic factors.

The proponents of deliberate practice (e.g., Ericsson et al., 1993; Ericsson & Charness, 1994; Howe et al., 1998) reject the existence of innate cognitive talent, arguing that there is no evidence for it and that expert performance is directly related to the amount of deliberate practice. Charness, Krampe and Mayr (1996) tested this theory in the field of chess by asking players to report the number of hours spent both studying chess alone and playing or analyzing games with others. The results showed a strong correlation between chess skill—measured by the Elo rating—and the number of hours spent studying alone. Charness et al. also found a strong but less important correlation between chess skill and the number of hours spent studying or practicing with others. Thus, they proposed that the number of hours of study alone, rather than the number of hours of studying and practicing with others, best measures the concept of deliberate practice.

Biographies of world chess champions and other strong grandmasters (e.g., Botvinnik, 2000; Brady, 1973; Forbes, 1992) show that intense dedication to chess is needed to attain high levels of performance. Krogius (1976) presents data showing that former world champion Bobby Fischer—the case mostly discussed by the proponents of the innate talent hypothesis—is almost within the bounds of the 10-year practice rule. Fischer attained his first grandmaster (GM) result 9 years after he started playing chess. Even Judith Polgar, GM at 15 years and 4 months 28 days (15,4,28), started intensive practice at 4 (Forbes, 1992). However, there are more recent cases that do not seem to respect the 10-year rule. World champion Ruslan Ponomariov attained the GM title at the age of 14,0,17 and Peter Leko at 14,4,22. In interviews, both of them reported that they had started playing chess at the age of 7. Also, Ponomariov attained 2550 Elo points (considered GM level) at the age of 12,8,0 and Leko at the age of 13,9,0. More recently, Teimour Radjabov obtained the GM title at the age of 14,0,14. More impressively, Sergey Karjakin obtained the GM title at the age of 12,7,0 and he was recruited at the age of 11 to help Ponomariov in his World Championship match. Finally, Magnus Carlsen obtained the GM title at the age of 13,3,27 and reported: "I learned the moves when I was 5 or 6 but hardly played until I turned 8. I played my first (children's) tournament in July 99 at the age of 8.5" (Friedman, 2003). Hence, although there is substantial evidence suggesting that domain-specific practice is essential for the acquisition of high-level expert performance, it may be the case that inter-individual variability has been underestimated in previous research.

<u>Critical Period</u>

A number of studies have investigated the role of a critical period in chess. Elo (1978) suggested that early introduction to the game and to organized competition is a prerequisite to the attainment of mastery. He presented data of 60 contemporary masters, whose mean starting age was 9.6 (range: from 5 to 16) and whose mean age of starting organized competition was 14.8 (range: from 10 to 18). Krogius (1976) presented data of grandmasters and international masters whose mean starting age was 10.5 years. He found that a group of "early starters" (mean starting age, 6.5) obtained the first GM result earlier (mean age 22.8) than a group of "late starters" (mean starting age, 13.6; mean age of first GM result, 25.3). However, the first group required more time to reach the GM result (16.3 years and 11.7 years, respectively). In Charness et al.'s (1996) study, the mean starting age was 10 ± 4.8 and the mean age of becoming serious at chess was 16.7 ± 8.8. The correlation between these variables and chess rating was -.35 and -.36, respectively. However, when entered into a multiple regression, these variables did not account for more variance than what was already accounted for by the cumulative number of hours of serious study alone; hence, Charness et al. concluded that younger starting age in their sample was not associated with greater achievement when hours of cumulative practice were taken into account (Charness et al., 1996, p. 71). Doll and Mayr (1987) found a nonsignificant correlation between starting age and rating ($r = -.27$). The starting age of the national players of their sample was 10.3 years and that of international players was 7.25 years. The same trend was obtained in the age at which players joined a chess club (13.8 and 10.5 years, respectively). Ericsson et al. (1993) used some of these data to support their hypothesis of deliberate practice: basically, the younger the players start playing chess, the more hours they spend studying it.

Overview of the Study

We submitted a large sample of players both to the Edinburgh Handedness Inventory (Oldfield, 1971) and a questionnaire similar to that used by Charness et al. (1996).

The results allowed us to systematically address the issues identified in the introduction. First, we tested Cranberg and Albert's (1988) hypothesis that handedness is a marker for chess ability. Second, we tested Ericsson's et al. (1993) hypothesis that individuals' current performance is directly related to the amount of deliberate practice. Third, we tested Simon and Chase's (1973) hypothesis that it takes at least 10,000 hours of study and practice to reach master level. Our fourth hypotheses relates to the possibility—verified in our study—that deliberate practice fails to account for all of the variance, beyond limits in measurement. We tested the possibility that starting age may be crucial for the later development of expertise, as suggested by Elo (1978). (We discuss the detail of the practice activities and the dynamics of the co-evolution of practice and performance in a separate paper.)

Methods

Participants

The participants were 104 Argentinian chessplayers (101 males and 3 females). They filled in a three-section questionnaire that was left visible on a desk in the *Círculo de Ajedrez Torre Blanca,* one of the most important chess clubs in Buenos Aires (Argentina). Posters asking for volunteers were also put on the notice board of the club. One of the authors went to several tournaments, both in the *Círculo de Ajedrez Torre Blanca* and other chess clubs in Buenos Aires, and distributed the questionnaires to the players participating in these tournaments. Three grandmasters (mean age = 31 years, standard deviation (±) 3.5), 10 international masters (29.1 ± 10.7), 13 FIDE masters (27.1 ± 8.9), 39 untitled players with international rating (30.2 ± 13.9), and 39 players without international rating (33.2 ± 17.8) filled in the questionnaire. The mean age of the sample was 30.8 ± 14.6 (range: from 10 to 78 years, median = 28 years). Since not all players had international rating, we used the national rating in order to measure chess skill. Note that the two ratings were closely related: for the 65 players having both international and national rating, the correlation between the two scales was .89.[1] The range of the sample was 983 points (from 1490 to 2473), with a mean of 1990.8 and a standard deviation of 221.5. Since the Elo rating has a normal distribution with a theoretical standard deviation of 200, our sample had a range of nearly 5 standard deviations.

Materials

The questionnaire was divided into three sections. (Not all players answered all questions, with the result that the number of data points varies across our measures.) The first section (see appendix 1 for an English translation) contained questions about date of birth, age, profession, international rating, national rating, speed chess rating (rating of the *Círculo de Ajedrez Torre Blanca*),[2] chess title, chess category, age when starting to play chess (henceforth, starting age), age when starting to play chess seriously (henceforth, serious age),[3] age at joining a chess club (club age), years of coaching, number of chess books owned, number of speed games played, and type of training (blindfold chess, reading games without seeing the board, use of chess databases, and use of chess programs). The second section contained a grid in which the participants had to fill out the number of hours per week they spent studying chess alone in each year (henceforth, individual practice). They also had to fill out a second row with the number of hours per week they spent studying or practicing with other players, including tournament games (henceforth, group practice). We estimated the number of hours studied per year by multiplying the figures reported by 52, and then we calculated the sum of the total hours spent with individual and group practice in the whole chess career. In some analyses, we added the values of these two variables to obtain a single variable called *total practice*. The unit of analysis for individual practice, group practice, and total practice was the cumulative number of hours.

The third section contained a Spanish translation of a modified version (Ransil & Schachter, 1994) of the Edinburgh handedness inventory (Oldfield, 1971). The questionnaire had 10 items enquiring about hand preference for a variety of activities such as writing, drawing, or using a knife. For each item, the possible responses were “always left,” “sometimes left,” “no preference,” “sometimes right,” and “always right,” which were coded as 1, 2, 3, 4, and 5, respectively. Moreover, we asked the participants whether they considered themselves righthanded, lefthanded, or ambidextrous. When computing the prevalence of righthandedness, we used self-reported handedness in order to compare our results to Cranberg and Albert’s (1988). When computing the correlation with other variables, the total score of the Edinburgh inventory was used as a measure of the *direction* of handedness (the minimum of 10 indicating extreme left-handedness, and the maximum of 50 indicating extreme right-handedness). In line with current literature (Barnett & Corballis, 2002; Niebauer & Garvey, 2004; Propper & Christman, 2004), we also computed an index of *degree* of handedness. We first re-centred the data around zero, extreme left-handedness being now denoted by –100, and extreme right-handedness being denoted by +100, and we then took the absolute value of the scores.

The individual and group practice variables warrant some comments. Charness et al. (1996) as well as Charness, Tuffiash, Krampe, Reingold, and Vasyukova (2005) argue that individual practice is better than group practice as a measure of deliberate practice, which means that competition should be excluded as a deliberate practice activity leading to expert performance (see also Ericsson et al., 1993, p. 368). However, in Charness et al.’s study (1996, Table 2.4), players considered that active participation in chess tournaments is the most important activity to improve performance. In addition, competitive chess enables interaction with stronger players, in particular during the post-mortem analysis of the game, where valuable information can be gained. (See Helsen et al., 1998, and Janelle & Hillman, 2003, for the role of competition in sport). As a result, we used three measures of deliberate practice: individual practice, group practice (which includes tournament games), and total practice. In order not to confuse these measures with Ericsson et al.'s (1993) definition of deliberate practice, we did not use the label "deliberate practice" for them.

Results

Table 1 shows the descriptive statistics of all variables as a function of level of expertise. Table 2 displays the correlation matrix for all variables. Note that, for the variables submitted to a log-transformation in Table 2, Table 1 shows the value of these variables before transformation.

INSERT TABLE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

Handedness

The three women were excluded from this analysis since the trend in handedness is different for women and men (Cranberg & Albert, 1988; Gilbert & Wysocki, 1992). Six men did not fill out the inventory; therefore, the following analyses were carried out on 95 participants. We found that 17.9% in our male sample, which is close to the 18% found by Cranberg and Albert, were self-defined as either lefthanders or ambidextrous (from now on, we use Cranberg & Albert's terminology and call this group "non-righthanders"). We also asked a male control sample (*N* = 98), matched for age and education level, to fill in the Edinburgh questionnaire and to report their pattern of handedness. In this control sample, 10.2% self-defined as non-righthanders, which was consistent with what had been found in the general population in other studies (10 to 13.5% of non-righthanders; Bryden, 1982; Geschwind, 1983; Gilbert & Wysocki, 1992). The mean of the inventory raw scores, a measure of direction of handedness, was 41.2 (*SD* = 11.3) for the chess sample and 43.9 (*SD* = 9.7) for the control sample. A t-test showed that the difference was statistically significant (t (191) = 1.78, $p < .05$, one-tailed). However, a test of proportion between two independent samples showed that the difference in proportion between the chess sample and the control sample is only marginally significant (z = 1.54, $p = .06$, one-tailed). The mean scores for degree of handedness were 76.7 (*SD* = 21.1) for the chess sample and 83.1 (*SD* = 17.6) for the control sample. A t-test showed that the difference was statistically significant (t (191) = 2.28, $p < .025$, two-tailed). (A two-tailed test was used as Cranberg and Albert, 1988, do not make any prediction about degree of handedness.) Within the chess sample, there were no reliable differences in the percentage of non-righthandedness between titled players (n = 24; 8.3%) and untitled players (n = 71, 21.1%; χ^2 (1) = 1.98, $p = .16$), and the trend was even opposite to the prediction. Titled and untitled players did not differ with respect to the degree of handedness (t (96) = .56, ns). Finally, there was no reliable correlation between the degree or direction of handedness and national rating or speed rating (see Table 2).

Our results show the same pattern as that found by Cranberg and Albert (1988): chessplayers are more likely to be non-righthanded in comparison to the general population, but, within chessplayers, handedness does not correlate with chess skill. To explain the latter result, Cranberg and Albert hypothesized that the group of weaker chessplayers contained young non-righthanded players who could become masters in the future; this may lead to an under-estimate of the proportion of non-righthanders in the group of stronger chessplayers, and thus to a weaker correlation than the real one. In our sample, the age gap between the two groups was not as wide as in Cranberg and Albert's sample, so this explanation does not seem to apply. We will present alternative explanations in the discussion.

Amount of Variance Explained by Deliberate Practice

In order to compare our results with Charness et al.'s (1996), we followed their procedure. We entered the eight variables they used into a multiple-regression analysis (see Table 3). In Charness et al.'s study, the eight variables together accounted for 55% of the variance, with individual practice and log number of books being the significant predictors. When they entered only the significant predictors into the regression analysis, the amount of Elo rating variance accounted for was 59%. (Charness et al., 2005, using a slightly different set of predictors, found that the regression analysis accounted for 39% and 28% of the variance in their two samples.)

INSERT TABLE 3 ABOUT HERE

In our data, the eight variables jointly accounted for 34% of the variance of national rating. The significant predictors were log group practice and coaching (0,1). The regression equation including only the significant predictors was:

$$\text{national rating} = 946 + 243 * \log(\text{group practice}) + 168 * \text{coaching } (0,1)$$

with an adjusted R^2 of .364 ($F(2,85) = 25.9$, $p < .001$); the 95% confidence intervals were 162.1 - 324.1 for log group practice, and 79.1 - 257.1 for coaching (0,1). This means that there was an increase of 243 points in national rating for each log unit of group practice (e.g., from 100 hours of group practice—2 log units—to 1,000 hours of group practice—3 log units) and an increase of 168 points in national rating for the players that had received coaching at some point of their chess career.

INSERT FIGURE 1 ABOUT HERE

The bivariate correlations (see Figure 1) suggest that national rating and speed chess rating are better predicted by group practice than by individual practice. Both variables are significantly correlated with national rating, but individual practice is not correlated with speed chess rating at the .01 level. However, a *t* test for the difference between two non-independent correlation coefficients did not show reliable differences between the correlations involving individual practice and those involving group practice (national rating: $t(86) = 1.42$, ns; speed rating: $t(60) = 1.55$, ns).

Test of Simon and Chase's (1973) Hypothesis

Simon and Chase (1973) estimated that it was necessary to dedicate between 10,000 and 50,000 hours to chess for achieving master level. We tested this hypothesis by calculating the cumulative number of hours spent in group and individual practice until players reached 2200 Elo points (i.e., master level). As we had access to archives containing the Elo lists with the rating of Argentinian players, we were able to find out at which age the rated players of our sample achieved 2200 Elo points.

Based on 34 players, the mean number of hours of total practice accumulated when players attained master level was 11,053, with a standard deviation of 5,538, and a range of 20,592 (from 3,016 to 23,608). Thus, the lower bound of Simon and Chase's estimate roughly coincides with the mean of our data. However, we should also highlight the variability of our data. One player attained master level with just 3,016 hours, while another needed 23,608 hours (a 1:8 ratio). Furthermore, some players in our sample had spent more than 25,000 hours of total practice (i.e., more hours than the "slowest" master) without attaining the master level.

From these data, we can draw two main conclusions. First, the mean number of hours of total practice supports Simon and Chase's claim that a long period of practice and study is required to reach master level. Second, as shown by the measures of variability in the number of hours practicing and studying chess, total practice is not a sufficient condition for becoming a master. The second part of this conclusion might raise the objections that (a) by combining individual and group practice we may have artificially inflated the variability of the data, and (b) individual practice, and not total practice, is the closest marker of deliberate practice, as indicated by Charness et al. (1996). To meet these objections, we also report the data of group and individual practice separately. The mean number of hours of group practice until reaching master level was 6,727, with a standard deviation of 3,298 hours, and a range of 12,584 hours (from 1,612 hours to 14,196 hours). The ratio between the slowest and the fastest player was thus 1:9. With individual practice, the mean was 4,325 hours, with a standard deviation of 3,266 hours and a range of 15,392 hours (from 728 hours to 16,120 hours). Thus, the slowest player spent 22 times more hours than the fastest player! The variability in the number of hours of individual practice to reach master level is so great that it supports our conclusion, based on hours of total practice, that domain-specific practice is not a sufficient condition for expert performance.

Critical Period

In order to disentangle total practice and onset ages, we performed partial correlations between the onset variables (starting age, serious age, and club age) and ratings (national and speed rating), controlling for total practice. In all the analyses below, ages were log-transformed, because of the non-normality of the data and the non-linear relationship between age and rating. The partial correlations between national rating and starting age, serious age, and club age were -.23 ($p < .02$), -.40 ($p < .001$) and -.36 ($p < .001$), respectively. In all cases, the correlations were calculated with over 80 players; missing values were discarded pairwise and, since it was predicted that starting earlier would lead to better performance, the test of significance was one-tailed. Without controlling for hours of total practice, the bivariate correlations were -.28 ($p < .003$), -.37 ($p < .001$), -.34 ($p < .001$), respectively (calculated over 100 players) (see Figure 2). Similar partial correlations were found with speed chess rating, where the correlations were computed with 60 players: starting age = -.18 ($p < .08$), serious age = -.47 ($p < .001$) and club age = -.41 ($p < .002$). Without controlling for hours of total practice, the bivariate correlations (calculated with over 70 players) were -.23 ($p < .03$), -.46 ($p < .001$), and -.40 ($p < .001$), respectively.[4] The partial correlations were similar when current age is partialled out in addition to total practice, with the difference that the correlation between starting age and speed chess rating is now only -.09 ($p > .20$). A test of the difference between two non-independent correlations with listwise deletion shows that the correlations were significantly higher for speed than for normal chess with serious age, t (67) = 4.01, $p < .05$, and club age, t (67) = 4.09, $p < .05$.

INSERT FIGURE 2 ABOUT HERE

The scatterplots in Figure 2 may give the impression that the results reported above can be explained by only a few participants that started playing seriously or joined a chess club late in life. We computed the partial correlations removing the players that started playing seriously or joined a chess club after the age of 30 (respectively $n = 4$ and $n = 6$). The correlations, although smaller, were still statistically significant (serious age: -.23, $p < .03$, and club age: -.21, $p < .04$ for national rating, and -.38, $p < .003$ and -.32, $p < .009$ for speed rating, respectively).

In summary, both for national and speed ratings, the age at which players start playing chess seriously and enter a club correlates with current rating, even when the amount of practice has been partialled out. Therefore, our data are consistent with Elo's (1978) proposal of the presence of a critical period. This conclusion is further supported by an analysis of the absolute age at which the strong players start playing chess seriously. The means and standard deviations (±) for the different levels were the following: grandmasters: 11.3 years ± 1.1 ($n = 3$), international masters: 10.3 ± 3.6 ($n = 9$), FIDE masters: 11.6 ± 3.1 ($n = 13$), rated players: 14.2 ± 3.9 ($n = 39$), and non-rated players: 18.6 ± 11.5 ($n = 36$). Almost all players with title started playing chess seriously no later than the age of 12. In our sample, the probabilities to become an international level player (grandmaster or international master) are about 1 in 4 (.24) for players starting to play seriously at the age of 12 or before, and only 1 in 55 (.018) for players starting after the age of 12 (χ^2 (1) = 12; $p < .002$), suggesting that one is very unlikely to achieve international level when serious play begins after the age of 12. On the other hand, a cut-off age of 12 is not apparent in our sample with respect to achieving a national level (2000 Elo points), since 54.5% of the players who started to play seriously after the age of 12 reached the national level. This is not far, but still statistically different, from 75.6% with the players who started to play seriously at the age of 12 or before (χ^2 (1) = 4.7; $p < .03$).

Discussion

This paper has investigated different variables in order to uncover which ones predict chess skill best. The results shed new light on the practice vs. talent debate, in particular on the roles of handedness, domain-specific practice, and starting age in the development of skill.

Handedness

As a possible source of individual differences not related to the expertise environment, we focused on handedness. Using a well-validated measure (the Edinburgh Inventory), we found that handedness and chess were related (non-righthanders tended to be more represented in our chess sample than in the general population, and chessplayers' degree of handedness was less strong than for the control group). However, there was no relation between handedness and skill level within our sample of moderately to highly skilled chess players. In general, these results replicate Cranberg and Albert's (1988), but also add new information by showing evidence of reduced degree of handedness with chessplayers.

One possible explanation for the relation between chess and handedness, but the lack of relation between handedness and skill level, is that having a more developed right hemisphere does not necessarily mean that one is not righthanded (Geschwind & Behan, 1984). In other words, there may be chessplayers with more developed right hemisphere who are righthanders. Indeed, there is evidence that only one third of the people with more developed right hemisphere are not righthanded

(Geschwind & Behan, 1984). If this is the case, our failure to identify a correlation between skill and handedness does not mean that brain asymmetry is irrelevant, but that other measures of brain asymmetry, including measures of structural differences using MRI, are needed to test this hypothesis. Another possibility is that non-righthanders are more likely to consider and choose a visuospatial discipline such as chess, and then easily improve during the earlier stages (that is why there are more non-righthanders in the chess population), but thereafter the commitment to the discipline is the factor that causes the largest improvement (that is why there are no differences in handedness between skill levels). A third possibility, in line with research into mathematical talent, is that the link between non-righthandedness and visuospatial ability is underpinned more by enhanced inter-hemispheric interaction than by an enhanced right hemisphere (Benbow, 1987; Singh & O'Boyle, 2004). This explanation receives direct supported from our data on degree of handedness showing that chessplayers tended to be more mixed-handed than the control group. Finally, although our sample spanned five standard deviations of skill, it did not cover the full range from absolute beginners to world champion. Therefore, it is not impossible that restriction of range may have affected our results and that a correlation might emerge with the full range of chess skill.

Domain-Specific Practice

While the role of practice has been emphasized for a long time (e.g., by De Groot, 1946/1978), Ericsson et al. (1993) have taken the extreme position that domain-specific practice is a sufficient, not merely necessary, condition for expertise. Our data are not consistent with this position. Although the overall correlation between individual and group practice and chess skill shows a reliable pattern, this variable on its own explained less than 50% of the variance. Thus, our data indicate that domain-specific practice is necessary, but not sufficient, to acquire master level.

According to Simon and Chase (1973), one has to spend between 10,000 to 50,000 hours of practice and study to become a chess master, which would take at least 10 years. In our sample, the mean of total practice (11,053 hours) coincided with the lower bound of Simon and Chase's range. However, there was also a remarkable amount of variability, which was apparent in the scatter-plots of Figure 1 and in the numerical estimates of variability we have provided. Some players with relatively few hours of total practice (even as low as 3,016 hours) achieved master level, while others needed much more time (up to 23,608 hours). This 1:8 ratio is so large as it is very unlikely that it can be explained by errors in measurement alone. In addition, some players with a huge amount of practice (more than 25,000 hours) did not reach the master level. Thus, while our data support Simon and Chase's claim that a long period of practice and study is required to become a master, the substantial variability in the number of practice hours is not consistent with the view that practice alone is sufficient for becoming a master. This result must count against Ericsson et al.'s (1993) theory of deliberate practice, and in particular the "monotonic benefits assumption" that "the amount of time an individual is engaged in deliberate practice activities is monotonically related with that individual's acquired performance (p. 368)."

Interestingly, our estimates are much below the upper bound of Simon and Chase's range (50,000 hours). This result is consistent with other measures (e.g., the number of years needed to reach grandmaster level, which we have discussed in the introduction; see also Howard, 1999, 2001), which show that there has been recently a speeding-up in the time to reach high levels of expertise. Whether this speeding-up can be best explained by a rise in the general level of intelligence (Howard, 1999, 2001) or by changes in training methods (e.g., apparition of computerized databases) and in the structure of the chess environment (e.g., increased opportunity to play in tournaments) is still debated (e.g., Gobet et al., 2004; Howard, 2005).

Starting Age

The final goal of our study was to explore the possibility that there was a critical period in the acquisition of chess expertise. In order to disentangle measures of onset age (starting age, age of becoming serious, and age of joining a chess club) and practice, we carried out a partial correlation between these measures and current rating (national and speed rating, respectively), controlling for the number of hours of individual practice.

The results indicated that the correlation between current rating and the age at which players started playing chess seriously or joined a club was significant even when controlling for the number of hours of practice. This correlation was even stronger with speed chess, although not significantly different. Moreover, almost all players who obtained a title started studying seriously or joined a chess club when they were 12 years old or before. Interestingly, the only two exceptions—a FIDE master and an international master who were taught the rules at 14 years of age and joined a club at 15 years of age—were non-righthanders (self-defined ambidextrous and left-handed, respectively). Thus, being actively exposed to a chess environment at an early age (i.e., not just playing chess with friends or relatives, but reading chess books, solving problems, and receiving feedback from advanced players) is important for developing skills. These results support Elo's (1978) proposal of a critical period in skill development.

To explain how differences in starting age may lead to individual differences, independently of the amount of practice, we suggest two explanations. First, it is known that young children pay attention to different features than teenagers or adults (e.g., Siegler, 1986), including that they are more tuned to concrete patterns than adults, who direct their attention to more abstract patterns (Piaget & Inhelder, 1955). Thus, starting at different ages may lead to differences in what is learned and how knowledge is organized. This is consistent with the well-established role of chunking and pattern recognition in chess and other domains (De Groot, 1946/1978; Gobet, 1998; Gobet et al., 2001; Gobet & Simon, 1996b; Simon & Chase, 1973). Chunking offers a well-specified mechanism for explaining the acquisition of implicit knowledge (see Gobet et al., 2001, for details), and differences in the efficiency of chunking mechanisms or in what is being learnt could explain individual differences in skill. Calderwood, Klein and Crandall (1988) as well as Gobet and Simon (1996b) have proposed that knowledge-based pattern recognition is essential to play high-quality games in speed chess, because there is little time to carry out look-ahead search. Indeed, this hypothesis, combined with Elo's hypothesis of a critical period, leads to two predictions that can be tested in our data: (a) there should be a high correlation between normal ratings and speed chess ratings, because these two forms of chess require essentially the same type of procedural, recognition-based knowledge; and (b) starting age should correlate higher with speed chess than with normal chess, because reduced thinking time in speed chess enhances the role of pattern recognition skills, which should be easier to learn when young. Consistent with Burns (2004), who found that speed chess accounts for 81% of the variance of slow chess, the first hypothesis was supported by our data, which showed a high correlation between national and speed rating (r (72) = .83, $p < .001$). The second hypothesis was also supported by our results, as serious age and club age correlated higher with speed chess than with normal chess.

The second explanation, which is not inconsistent with the first one, is that starting to interact with a specific environment at earlier ages may facilitate the acquisition of knowledge later used in pattern recognition because the brain shows more plasticity to environmental stimulation at young ages. There is substantial, but not always uncontroversial, evidence for the idea that young peoples' brains show more plasticity in learning than those of adults (Elman et al., 1996; Hensch, 2003; Johnson & Newport, 1989). For example, Hensch (2003) proposed that both a reduction of neural plasticity outside a critical period and a structural consolidation of neuroanatomical circuits during the critical period explain why several skills are much more easily acquired during the critical period.

Conclusions and Future Directions

In summary, starting to play seriously not later than the age of twelve, carrying out individual practice such as reading books, playing with others, and receiving feedback from a coach seem to be all important factors to attain a high level of expertise in chess. There was some evidence that individual differences in abilities not related to the chess environment differentiate between players and non-chessplayers (direction and degree of handedness). Together, these results suggest that the talent/practice debate is based on a false opposition, and hint at the need to promote developmental theories of expertise which provide mechanisms reconciling these two radical positions.

In comparison to Charness et al. (1996) and Charness et al. (2005), we used a measure of handedness and designed a few additional questions about the amount of practice (e.g., use of computer databases and computer programs). A further improvement was that, in addition to the dependent variable of Elo rating for standard games, we also used the rating for speed chess. This allowed us to address questions related to the skills required by this special modality of chess, in particular pattern recognition (Gobet & Simon, 1996b).

We acknowledge three limits of our study. First, although often used within the framework of deliberate practice, retrospective questionnaires do not possess ideal reliability. This being said, empirical research has shown that they correlated reasonably well with independent measures (Ericsson et al., 1993, p. 380). In addition, this methodology leads to replicable results. For example, one key result in our study—the correlation between cumulative hours of individual practice and skill level (r = .42)—is reasonably similar to that estimated by Charness et al. (1996; r = .60), and Charness et al. (2005; r = .54 for the extended sample from their 1996 study, and r = .48 for an independent sample), in spite of the fact that the data were collected in three continents.

Second, being a correlational study, this investigation cannot establish causation. Even if a correlation of 1 is obtained between the number of hours of practice and chess rating, this does not necessarily mean that practice is the cause of high-level performance; it may well be the case that good players practice more than weak players because they are rewarded by their victories. However, correlational studies have the advantage that they provide key information in order to carry out further studies which require more time and resources (e.g., longitudinal studies). Third, although our sample was a fair representation of the population of chessplayers in Argentina with respect to gender and ethnicity, this population underrepresents women and some ethnic groups compared to the general population. This may affect the generalizability of our findings

Traditional research on expertise has mainly relied upon standard experiments, aptitude tests, and questionnaires. The next step requires novel approaches. A first possibility is to submit a few experts to a large variety of measures, addressing both issues related to talent and to practice, and to analyze these data individually in order to provide computational theories of these individuals (Gobet & Ritter, 2000). We are currently collecting such data in our laboratory, subjecting chessplayers from novice to grandmasters to a number of measures, including brain activation, eye movements, visuospatial memory, reaction times, and domain-specific memory tasks. A second approach—actually an extension of the first one—is to carry out longitudinal studies following the development of novices over many years until they hopefully become experts, again collecting a variety of data aimed both at identifying individual differences and the role of practice, and at developing computational models of these data. The use of computational modelling is inescapable, due to the complexity of the processes under study, the complexity of the environments being assimilated by the experts, and the amount and dynamic character of the data being collected.

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APPENDIX 1: CHESS QUESTIONNAIRE

(English translation from Spanish)

Answer all the questions, please. Leave a blank space only if you do not possess the ratings requested. If you do not know your rating/ratings, you can ask the secretary for it/them. Alternatively, you can write down your name to allow us to look up your ratings. Moreover, fill out the form of hours of study and practice in chess following the instructions. Thank you for your participation.

1) How old are you?____

2) What is your profession? ____

3) What is your national Elo rating?_____________________________________

4) What is your speed chess rating?_____________________________________

5) What is your category?____

6) What is your international Elo rating? __________________________________

7) Do you have any title (GM, IM, FM)? Which one?__________________________

8) At what age did you learn how to play chess?______________________________

9) At what age did you start playing chess seriously?__________________________

10) How many hours per week (on average) have you studied alone during the current year? __

11) How many hours per week (on average) have you studied or practiced chess with other chess players (including tournament games) during the current year?________

12) Have you ever joined a chess club?______________________________________

If yes, at what age for the first time?_______________________________________

13) Have you ever received formal chess instruction from a chess coach?__________

Individual coaching: from (age)______to (age)_______________________________

Group coaching: from (age)________to (age)________________________________

14) How many books do you have? (excluding chess journals)___________________

15) Do you play blindfold chess?____

16) Do you reproduce chess games from journals without using the chessboard?__________________

17) Do you use any computer database to study chess?__________________________

18) Do you play games against chess software?________________________________

19) Do you play speed chess games?____

How many per week?____

Table 1. Descriptive statistics of all the variables measured in this study, as a function of skill.

		TOTAL		Non-rated		Rated		FIDE		IM		GM	
	N	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
National rating	104	1991	221	1780	125	2030	103	2165	136	2300	82	2445	39
Speed rating	72	1958	208	1787	124	2003	134	2194	122	2315	50	2403	0
Dir. of handedness[a]	98	41.3	11.2	41.7	11.1	40.6	12.2	44.6	4	41.0	11.6	31.7	19
Deg. of handedness[a]	98	76.4	21.1	76.0	25.2	78.2	18.4	73.1	19.9	76.1	16.7	75.0	25.0
Total practice	89	13,325	11,527	8,303	7,900	11,715	9,029	19,618	10,917	27,929	15,804	[d]	[d]
Individual practice[b]	90	5,375	5,788	3,744	5,236	4,567	4,767	8,012	6,484	10,602	7,000	[d]	[d]
Group practice[b]	89	7,921	6,827	4,557	3,586	7,101	5,044	11,605	5,942	17,326	10,736	[d]	[d]
Age	104	30.8	14.6	33.18	17.8	30.2	13.9	27.1	8.9	29.1	10.7	31	3.5
Starting age	104	8.8	4.3	10.3	5.1	8.7	3.8	7.5	2.9	6.5	3.1	5.7	1.1
Serious age	100	15	8	18.6	11.5	14.2	3.9	11.6	3.1	10.3	3.6	11.3	1.1
Club age	102	15	8.2	18.9	11.1	14.2	4.8	10.8	3.6	9.9	3	11.7	2.1
Number of books	99	66.3	98.2	24.4	23.1	81.4	113.3	125.9	150.2	78.4	88.7	116.7	85
Coaching (0,1)	103	0.81	0.4	0.67	0.5	0.85	0.4	0.92	0.3	1	0	1	0
Chess bases (0,1)	104	0.67	0.5	0.51	0.5	0.72	0.4	0.85	0.4	0.8	0.4	1	0
Chess program (0,1)	104	0.66	0.5	0.59	0.5	0.67	0.5	0.85	0.4	0.6	0.5	1	0
Blindfold reading (0,1)	104	0.56	0.5	0.46	0.5	0.54	0.5	0.77	0.4	0.7	0.5	0.67	0.6
Blindfold chess (0,1)	104	0.23	0.4	0.15	0.4	0.26	0.4	0.23	0.4	0.5	0.5	0	0
Speed games (0,1)[c]	104	0.84	0.4	0.67	0.5	0.9	0.3	1	0	1	0	1	0
Speed games[c]	102	17.3	33.7	8.7	10	18.4	21	19	26.1	13.3	15.1	121.7	156.8

Note. [a]For the direction of handedness, the scale ranges from 10 (extreme left-handedness) to 50 (extreme right-handedness); for the degree of handedness, the scale ranges from 0 (mixed handedness) to 100 (strong handedness). [b]Group and individual practice were measured as the cumulative number of hours studying or practicing with others (group practice) or practicing alone (individual practice). [c]Speed games (0,1) measures whether or not the participants play speed games, and speed games is the average number of speed games played per week. [d]No GM answered these questions.

Table 2. Correlations and descriptive statistics for chess ratings, handedness, practice variables, activities, and age variables.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. National rating		.83**	-.05	.04	.57**	.42**	.54**	.08	-.28**	-.37**	-.34**	.44**	.35**	.33**	.11	.24*	.16	.27**	.28**
2. Speed rating			.10	-.01	.38**	.25*	.43**	-.04	-.23	-.46**	-.40**	.39**	.35**	.13	-.05	.05	.04	.25*	.30*
3. Direction of handedness				.26**	.13	.11	.16	.18	-.18	.00	.00	.17	-.17	-.04	-.23*	-.12	-.08	-.04	-.17
4. Degree of handedness					.17	.10	.12	.26**	.13	.13	.17	.25*	-.14	-.12	-.13	-.15	-.01	-.13	-.11
5. Log total practice						.70**	.94**	.43**	-.17	-.08	-.07	.59**	.10	.26*	.18	.31**	.10	.08	.03
6. Log individual practice							.51**	.17	-.14	-.16	-.15	.41**	.19	.15	.15	.30**	.15	.07	.05
7. Log group practice								.41**	-.19	-.14	-.11	.60**	.05	.26*	.14	.27*	.04	.07	-.02
8. Log Age									.30**	.54**	.62**	.32**	-.45**	-.13	.03	-.06	-.17	-.34**	-.23*
9. Log starting age										.59**	.59**	-.11	-.33**	-.21*	.18	-.12	-.05	-.33**	-.19*
10. Log serious age											.87**	-.12	-.42**	-.24*	-.11	-.09	-.15	-.35**	-.18
11. Log club age												-.10	-.48**	-.21*	-.03	-.08	-.11	-.38**	-.20*
12. Log number of books													.10	.28**	.06	.17	.09	.16	.11
13. Coaching (0,1)														.29**	.07	.15	.14	.31**	.19
14. Use of chess databases (0,1)															.37**	.37**	.09	.47**	.34**
15. Use of chess programs (0,1)																.39**	.05	.07	.02
16. Blindfold reading (0,1)																	.40**	.23*	.21*
17. Blindfold chess (0,1)																		.12	.14
18. Playing speed chess (0,1)																			.72**
19. Log number of speed games																			
Mean	1991	1958	41.3	76.4	3.9	3.1	3.7	1.4	0.9	1.1	1.1	1.5	0.8	0.7	0.7	0.6	0.2	0.8	0.8
sd	221	208	11.2	21.1	0.4	1.3	0.4	0.2	0.2	0.2	0.2	0.5	0.4	0.5	0.5	0.5	0.4	0.4	0.7

Note. Correlations with * are statistically significant at $p < .05$, and those with ** are significant at $p < .01$ (two-tailed).

Table 3. Multiple regression predicting national rating (using the same variables as Charness et al., 1996).

Variable	B	SE	Beta	t	p	95% CI
Constant	1233.3	269.7	0	4.57	< .001	695.5 - 1771.2
Coaching (0,1)	137.6	58.5	0.264	2.35	< .03	21.0 - 254.2
Log group practice	136.8	66.4	0.272	2.06	< .05	4.4 - 269.2
Log age	327.3	167.3	0.312	1.96	> .05	-6.5 - 661.1
Log serious age	-318.6	204.8	-0.288	-1.55	> .1	-727.2 - 89.9
Log starting age	136.1	129.4	0.123	1.05	> .2	-122 - 394.1
Log individual practice	17.8	18.2	0.110	0.97	> .3	-18.5 - 54.1
Log club age	-147.5	215.6	-0.141	-0.68	> .4	-577.4 - 282.4
Log number of books	3.3	42.8	0.009	0.07	> .9	-82.1 - 88.7

Note. $R = .642$, $R^2 = .412$, Adjusted $R^2 = .345$, $F(8,70) = 6.14$, $p < .001$. Missing values were handled by excluding cases list-wise.

Figure captions

Figure 1. Scatter plots of national rating and speed rating as a function of log individual practice and group practice. The unit of analysis of individual and group practice is the cumulative number of hours. With group practice, there are 89 data points for national rating and 63 for speed chess rating; with individual practice, there are 81 data points for national rating and 55 for speed chess rating. (The plots for individual practice have excluded nine players who reported zero hours of practice. With these players included, the equations are 1754.508 + 73.490x ($r^2 = 0.175$; $N = 90$) for national rating, and 1817.242 + 43.808x ($r^2 = 0.063$; $N = 64$) for speed rating.)

Figure 2: Scatter-plots of national rating as a function of log starting age, log serious age, and log club age.

Figure 1

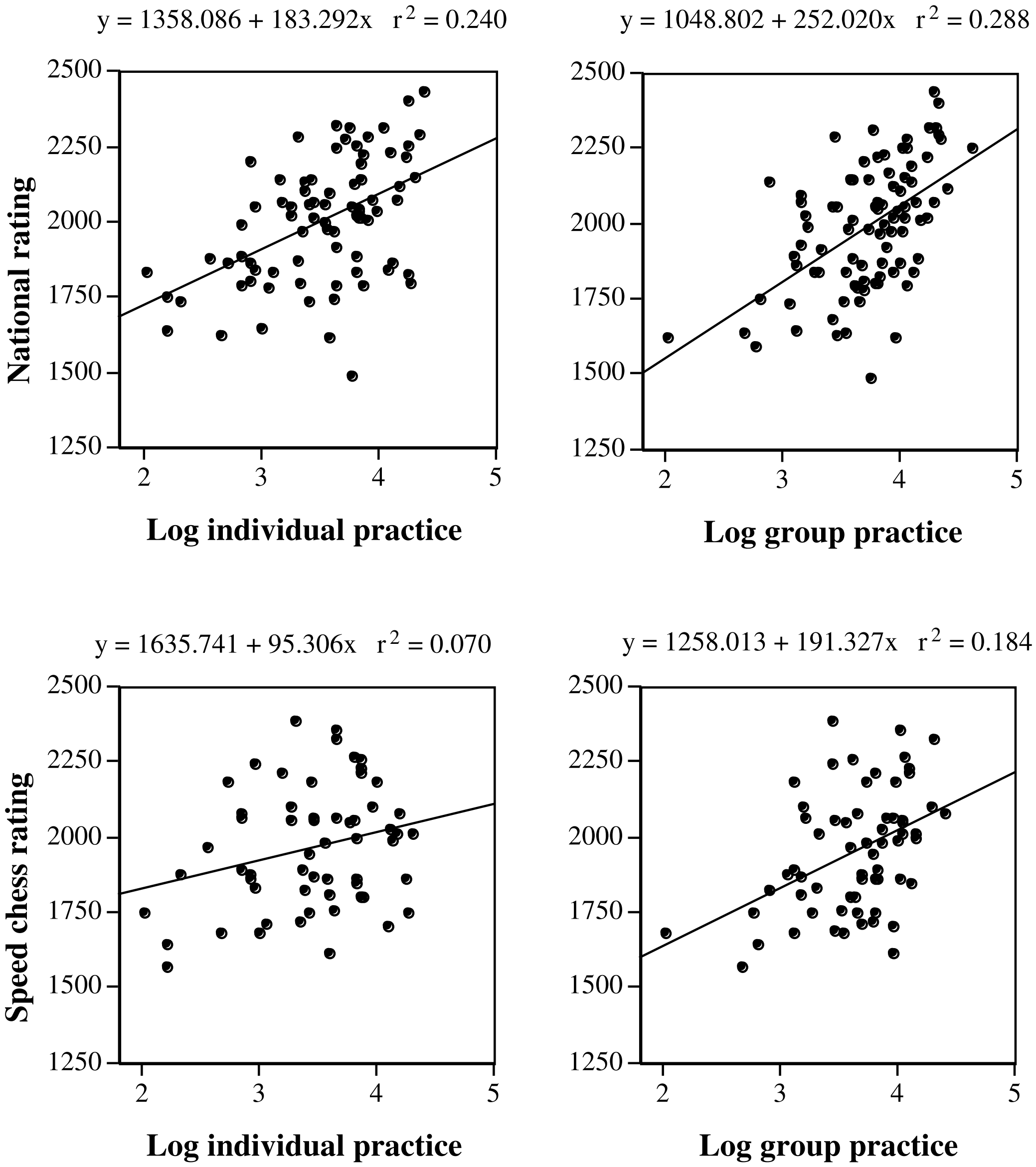
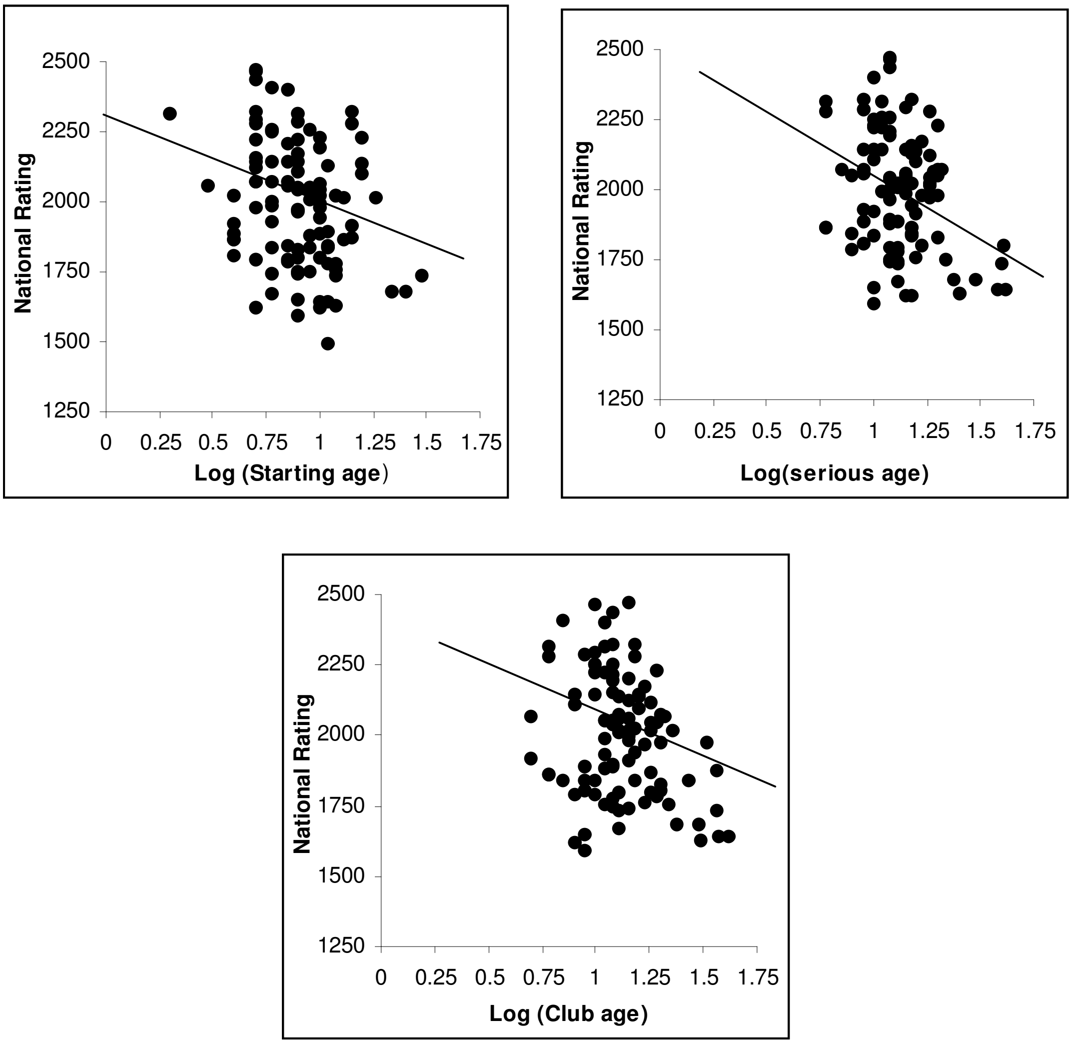

y = 1358.086 + 183.292x   r 2 = 0.240
y = 1048.802 + 252.020x   r 2 = 0.288
National rating
2500
2250
2000
1750
1500
1250
2
3
4
5
Log individual practice
Log group practice
y = 1635.741 + 95.306x   r 2 = 0.070
y = 1258.013 + 191.327x   r 2 = 0.184
Speed chess rating
Log individual practice
Log group practice

Figure 2


2500
2250
2000
1750
1500
1250
National Rating
0 0.25 0.5 0.75 1 1.25 1.5 1.75
Log (Starting age)
Log(serious age)
Log (Club age)

Footnotes

[1]The scores were somewhat lower in the national rating, due to differences in the results taken into account. For instance, the four best players had 2520, 2491, 2490 and 2488 in the international rating and 2438, 2473, 2400 and 2463 in the national rating, respectively.

[2] Standard games are played with an average of three minutes per move; in speed chess, each player has only five minutes for the entire game. The speed chess rating is computed independently from the national rating. In some cases, the calculation for the former rating is based on more than one thousand games.

[3] What did the players consider as "seriously"? Apparently, they assumed that this term referred to the time they joined a chess club. The question about starting to play seriously yielded similar results to the question about the age of joining a chess club (serious age: $M = 15.0$, $SD = 8.0$; club age: $M = 15.0$, $SD = 8.2$; $r = .87$, $p < .001$).

[4] The results are fairly similar when listwise deletion and 2-tailed tests are used. The respective partial correlations for national rating (80 players) are: starting age, -.14; ns; serious age, -.39, $p < .001$; and club age, -.31, $p < .005$. The respective correlations for speed rating (56 players) are: starting age, -.28, $p < .05$; serious age, -.55, $p < .001$, and club age, -.49, $p < .001$.