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It Takes More Than Practice and Experience to Become a Chess Master:
Evidence from a Child Prodigy and from Adult Tournament Players

by

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Abstract

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Ericsson’s theory of deliberate practice and Chase and Simon’s recognition-action theory both hold that the key to reaching master level performances at chess is to engage at least 10,000 hours of deliberate practice. In addition, Ericsson claims that the primary source of individual differences in chess skill is deliberate practice time. In this dissertation, two studies were conducted to investigate whether deliberate practice or other chess-related experience is sufficient to explain individual differences. Study 1 investigated the amount of time a young and exceptional chess player, CS, had studied alone and engaged in other chess-related experiences. CS spent little time studying alone and little time engaging in other chess-related experiences. Nonetheless, she achieved an exceptional chess level. CS’s achievement is difficult to reconcile with Ericsson’s 10-year/10,000-hour practice rule. Study 2 investigated factors contributing to the chess skills of 77 adult chess subjects, showing that time spent studying alone and time spent engaging in other chess-related activities are strongly related to chess skill. However, contrary to the theory of deliberate practice and recognition-action theory, other factors including domain-general fluid intelligence, domain-specific fluid intelligence, and domain-specific crystallized intelligence all contributed to chess skill even after controlling for practice and other chess-related activities. These findings support the view that spending time studying
alone and playing chess is necessary, but not sufficient to achieve a high chess performance level.
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Psychologists have investigated how people become experts for decades. Although it is evident that there are substantial individual differences in performance across a wide variety of tasks (see Howard, 2009; Howe, Davidson, & Sloboda, 1998), there is disagreement about the relative importance of various sources of individual differences. Some researchers argue that the primary source of individual difference is natural ability, whereas others argue that the primary source is practice, with natural ability making little to no difference. This current dissertation presents evidence from a case study of a young and exceptional chess player and from a separate study of chess players that, taken together, support the view that there is more to expertise than practice.

Many researchers (e.g., Charness, Tuffiash, Krampe, Reingold, & Vasyukova, 2005; Ericsson, 2004; Ericsson, Krampe, & Tesch-Romer, 1993; Ericsson & Lehmann, 1996; Howe et al., 1998; Sloboda, Davidson, Howe, & Moore, 1996) have studied and emphasized the importance of deliberate practice in achieving expert performance. Other researchers (e.g., Bower & Hilgard, 1981; Ericsson & Lehmann, 1996; Ericsson, 2002; Ericsson et al., 1993; Gagne & Medsker, 1996) have revealed several characteristics of activities and factors important for learning and improving performance. These include, (a) providing immediate informative feedback, (b) allowing learners to have ample opportunities to gradually refine their performance and correct any errors by repetition, and (c) provide an appropriate level of difficulty for learners of different skill levels. Also important are the learners’ efforts to improve their performance and motivation to attain a high performance level on the task. When these activities and factors are present, speed and accuracy of performance on cognitive, perceptual, and motor tasks improve greatly with practice (e.g., Chase & Ericsson, 1982; Fitts & Posner, 1967). Ericsson et al. (1993)
argued that since these activities are very effortful and require a high level of concentration, they can only be engaged in for a limited amount of time per day.

**Definition of Deliberate Practice**

Before proceeding further, it is important to discuss the definitions and measures of deliberate practice. Ericsson and his colleagues (Ericsson, 2014c; Ericsson & Lehmann, 1996; Ericsson et al., 1993) define deliberate practice as “the individualized training activities specially designed by a coach or teacher to improve specific aspects of an individual’s performance through repetition and successive refinement” (Ericsson & Lehmann, 1996, p. 278 - 279). However, the definition in their empirical work is inconsistent with this definition. For example, Ericsson, Krampe, and Tesch-Romer (1993) estimated participants’ deliberate practice time by asking them how many hours per week they had practiced alone.

Ericsson and Charness (1994) considered two types of activities to be deliberate practice when learning chess. The first concerns studying chess with an “individualized study guided by a skilled teacher” (p. 739). This chess activity that involves coaching meets the criteria of Ericsson et al.’s (1993) definition of deliberate practice. It is unclear from the definition, however, what types of individualized study should be employed to improve chess skills. The second type of activity is self-directed study. For example, Ericsson and Lehmann (1996) interviewed elite chess players, concluding that chess players “created optimal learning situations by studying published chess games for several hours every day and attempting to predict—one by one—the moves chosen by chess masters” (p. 279). Ericsson and Charness (1994) described this chess activity as deliberate practice even though it does not meet Ericsson et al.’s (1993) deliberate
practice criteria. Similarly, Charness, Krampe, and Mayr (1996) argued that serious study alone has the same characteristics of deliberate practice. According to Ericsson’s conception of deliberate practice, coaches and teachers are important because they can provide immediate feedback about move choices, and help the players to identify their weaknesses and strengths. Charness et al. (1996) argued that when chess players study chess alone, knowledge and feedback potentially provided by coaches is available in books and computer programs. Thus, studying chess alone allows a player to control the amount of study, receive immediate feedback, and try out different approaches.

Therefore, they argued that serious study alone in chess is probably closest in meaning to Ericsson et al.’s (1993) deliberate practice theory. Charness and his colleagues (Charness, Krampe, & Mayr, 1996; Charness et al., 2005) estimated deliberate practice time by asking their participants to report on how many hours per week they had seriously studied chess alone. Studies by Charness and his colleagues (1996; 2005) that used time studying alone as their measure of practice have been frequently cited as evidence for the primacy of deliberate practice (e.g., Ericsson, 2006), even though these studies would not be relevant to the role of deliberate practice if deliberate practice had been defined in the way Ericsson has defined it more recently (see Ericsson, 2014c).

Researchers have differed on whether or not playing chess should be considered deliberate practice. Charness et al. (2005) argued that playing chess is not deliberate practice for two reasons. First, unlike playing chess, when a chess player studies chess problems, these problems are deliberately chosen at an appropriate challenging level, which generally cannot be provided in a tournament environment. Second, the characteristics of serious study activities cannot generally be satisfied during tournament
play. These activities include (a) selected problems to address specific weaknesses, (b) allowing for multiple repetitions of similar problems, and (c) having opportunities to test multiple solutions for the same problems. Therefore, Charness et al. (2005) concluded that “opportunities for skill improvement are severely restricted during tournament play” (p. 153). However, some studies (e.g., Charness et al., 1996; Gobet & Campitelli, 2007) considered playing chess with opponents to be deliberate practice. They argued first that chess players reported one of the most important activities to improve their skills to be playing chess in tournaments (see Charness et al., 1996). Second, playing chess with stronger players allows players to obtain valuable information, especially analyzing the positions after games (see Helsen, Starkes, & Hodges, 1998; Janelle & Hillman, 2003). This however, involves a bit of circular reasoning. If the question is the importance of deliberate practice, then it is circular to decide whether an activity involves deliberate practice based on whether the activity increases chess skill.
Study 1

There are two main approaches for investigating the role of practice, and especially deliberate practice, in the development of expertise. The first approach is case-study oriented in which a small number of talented people are compared to more typical controls with regard to how the talented people obtained their skills and whether practice can account for their extraordinary performance. The second approach is to investigate how much variance can be accounted for by practice time. These two approaches will be reviewed and discussed in two sections of this dissertation separately, namely in sections titled Study 1 and Study 2.

One of the most striking examples of practice leading to exceptional performance is provided by Ericsson, Chase, and Faloon (1980). In this study, a student, SF, was asked to practice extensively on the forward digit span task in which the task is to repeat a list of random digits immediately after their presentation. According to Ericsson et al. (1980), SF had average memory ability and average intelligence, and initially had an average digit span of seven. After 230 hours of extensive practice (one hour a day, three to five days a week, for more than one and half years), SF’s digit span increased from 7 to 79 digits. Chase and Ericsson (1982) explained that SF’s exceptional performance after practice was accomplished by three main components. First, SF was able to associate the new materials with information in long-term memory. For example, if he was presented with the digits “3594,” he would associate these digits with Bannister’s world-record time for running the mile (3 minutes 59.4 seconds). Then, these four digits would be stored as a single unit or chunk. In other words, SF was able to develop a strategy to chunk the digits into a unit and associate this unit with his prior knowledge of Bannister’s
running time. Second, SF increased his digit span by storing information in a hierarchical retrieval structure, which organizes meaningful encoding cues (e.g., running times) and allows these cues to be accessed in the correct order. Third, SF was able to increase his encoding and retrieving information speed. Therefore, based on SF’s exceptional performance, Ericsson and his colleagues (1980; 1982) argued that through practice, even ordinary people can achieve extraordinary performance.

The importance of deliberate practice has been studied in the domain of chess as well as the domain of music. Chase and Simon (1973) discussed the importance of practice in the acquisition of chess skill, summarizing their view as follows: “the overriding factor in chess skill is practice. The organization of the Master's elaborate repertoire of information takes thousands of hours to build up, and the same is true of any skilled task (e.g., football, music). That is why practice is the major independent variable in the acquisition of skill” (Chase & Simon, 1973, p. 279). Furthermore, Ericsson and Smith (1991) concluded that at least of ten years of full-time practice is a requirement for attaining an international level of performance in the chess domain.

More recently, a test of whether extensive deliberate practice can lead to a high level of expertise in golf was undertaken by Dan McLaughlin. Inspired by Ericsson et al.’s (1993) theory and his 10,000-hour rule, McLaughlin quit his job as a commercial photographer with the goal of becoming a professional golfer. McLaughlin was not a competitive athlete and had never played a full 18 holes of golf prior to starting his experiment, which he refers to as “the Dan Plan.” Ericsson commented that “I was impressed right away, I found Dan to be committed to and focused on what he wanted to accomplish – the right astronaut for the mission” (Healey, 2011). Before undertaking his
“journey,” McLaughlin consulted K. Anders Ericsson and Len Hill, who gave him detailed information about deliberate practice, and helped him learn how to obtain the maxim effect of deliberate practice. In April 2010, McLaughlin started engaging in deliberate practice and hired a coach to get maximal improvement for each hour of practice, meeting Ericsson’s deliberate practice criteria. In August 2011, McLaughlin played his first full round of golf, and starting in May 2012, he recorded detailed statistics about his performance (http://thedanplan.com/). His story has been widely reported, with many people excited to see how it would turn out. However, in April 2015, after completing 6,003 hours of deliberate practice, he called off his experiment due, in part, to back injuries and financial frustrations. His performance in golf is discussed in term of the handicap index. The handicap index is calculated by using the average of a golfer’s best 10 handicap differentials in the last 20 rounds, and multiplying it by 0.96. The handicap index is calculated based on the score that golfer obtained in each round and it is adjusted to account for differences golf courses. Smaller handicaps indicate better performance. His last handicap index was 5.5, placing him in the 85th percentile of the men’s population of the United States Golf Association (USGA). His best handicap index was 2.6, which placed him in the 93rd percentile. However, he was unable to maintain that level of performance very long (see Figure 1). As Figure 1 shows, it took McLaughlin about 2,500 hours of deliberate practice to reach the 70th percentile of USGA. When he reached the 83rd percentile, he had engaged in an additional 1,500 hours of deliberate practice without improving much. Similarly, when he was in the 90th percentile, his ranking did not improve much after another 1,500 hours of deliberate practice, with his final percentile below the 90th. Based on his rate of profiting from
deliberate practice, it seems unlikely that McLaughlin would have become a professional golfer even if he had completed 10,000 hours of deliberate practice. It is worth stressing again that McLaughlin’s practice met the criteria for Ericsson’s deliberate practice definition by having a coach design the individualized practice plan to specifically improve his golfing skills.

![Figure 1](image.png)

Figure 1. McLaughlin’s USGA rating history and percentiles as a function of the number of hours of deliberate practice. The percentile was calculated based on men’s population in USGA.

Can anyone become an expert with enough deliberate practice? After engaging in about 6,000 hours of intensive deliberate practice, McLaughlin reached around the 90th percentile of the USGA population, but was still far away from the level required to be a professional golfer. Based on McLaughlin’s performance, it appears that not everyone can become an expert even with sufficient deliberate practice. As Sternberg and Ben-Zeev (2001, p. 73) skeptically asked, “Is one to believe that anyone could become a Mozart if only he or she put in the time? …Or that becoming an Einstein is just a matter of deliberate practice?” It would appear that many people have devoted sufficient time to
practice to reach exceptional levels of accomplishment in a given domain, but the number that can reach the level of Wolfgang Amadeus Mozart or Albert Einstein is extremely small.

Many researchers have investigated the role of natural ability in the development of expertise (e.g., Bloom, 1985; Gagné, 2004; Shiffrin, 1996; Simonton, 1999; Winner, 1996). Before considering this literature, it is important to provide a clear definition of natural ability. Natural ability has been defined in terms of the ability to profit from domain specific experience. Epstein (2014) stated, “no two people respond to training in exactly the same way because of their genes. A very important kind of talent is the ability to profit more rapidly, from one hour of practice, than the next guy does, and that's very much mediated by your genes.” In this dissertation, natural ability is defined as the ability to profit from domain-specific experience, which may be a result of genes and/or early experience. In this definition, domain-specific experience includes not only deliberate practice (e.g., studying chess positions, training, coaching) as defined by Ericsson et al. (1993), but also other activities that the individual has been experienced in the given domain (e.g., playing chess with opponents). Accordingly, the view that natural ability is important holds that people have different cognitive and physical abilities, and, regardless of whether these abilities are environmentally or genetically determined, these abilities contribute to individual differences in the speed and level of acquisition of skill in a given domain. It is important to note that this view of natural ability does not discount the importance of domain-specific practice and training in the acquisition of skills, but emphasizes the importance of individual differences in domain-general cognitive or physical abilities in the ability to profit from training, practice, and experience.
One of most influential natural-ability models is Gagné’s (2003) Differentiated Model of Giftedness and Talent (DMGT). This model distinguishes the domains of natural abilities (giftedness) and performance (talent). According to Gagné (2003), “giftedness” describes individuals who have the natural potential to become among the top 10 percent for their age group in one or more domains. There are four basic potentials that can exist as natural abilities: intellectual, creative, socio-affective, and sensori-motor (Gagné, 2004). Intellectual potentials are the abilities to read, speak, and understand concepts, and include the potentials of fluid reasoning, thinking abstractly, memory, sense of observation, judgment, and metacognition. Creative potentials are those abilities that produce original work, and include inventiveness, imagination, originality, and retrieval fluency. Socio-affective potentials concern those abilities that help communicate with others, and include intelligence, communication, and influence. Sensori-motor potentials are those physical abilities that help perform a specific task, and include vision, audition, strength, endurance, and coordination.

Gagné (2004) described an individual with “talent” as someone who “designates the outstanding mastery of systematically developed abilities (or skills) and knowledge in at least one field of human activity to a degree that places an individual at least among the top 10 percent of age peers who are or have been active in that field or fields” (p. 120). He also described it as something that can “progressively emerge from the transformation of high aptitudes into the well-trained skills characteristic of a particular field of human activity” (Gagné, 2004, p. 123). According to Gagné (2004, p. 124), “talent is a developmental construct. That statement means that soon after youngsters have begun learning a new set of skills, it becomes possible to assess their performances
normatively, comparing them with others who have been learning for an approximately equal amount of time.” Talent can be found in diverse fields including cooking, craftsmanship, music, sports, chess, dance and so on.

In the music field, there are eight possible developed talents: performing, improvising, composing, arranging, analysis, appraising, conducting, and teaching (McPherson & Williamon, 2006). Therefore, based on DMGT, musical performers are required to have both the intellectual and sensori-motor potentials to reach exceptional achievement, which means that they are required to have physical and mental dexterity, motor memory, and auditory memory to become talented performers (McPherson & Williamon, 2006). Musical composers are required to have the intellectual and creative potentials, meaning that they are required to have mental dexterity, inventiveness, and originality to become exceptional composers. Based on DMGT, chess players might be required to have both the intellectual and creative potentials to reach an exceptional achievement, meaning that they are required to have mental dexterity, fluid reasoning, thinking abstractly, memory, judgment, and originality to become exceptional chess experts.

One of the most important sources of evidence supporting the importance of natural ability is the study of precocious children. The very existence of prodigies would seem to contradict the argument for the universal primacy of deliberate practice and support the view that natural ability plays a critical role. Child prodigies have been defined as children under 10 years old whose performance is at a level that is rare even in highly skilled adults (Feldman, 1993; Ruthsatz & Detterman, 2003). As Winner (2000) stated, “gifted children, those with unusually high ability in one or more domain, not only
develop more rapidly than typical children, but also appear to be qualitatively different” (p. 153). Generally, their extraordinary talents are domain specific, such as music, chess, math, sports and visual arts.

Child prodigies have been found most frequently in the domain of music (Jenkins, 2005), and these prodigies developing their skills to reach an extraordinarily high level during early age, usually before adolescence (Morelock & Feldman, 2003). One of the most famous musical prodigies is Wolfgang Amadeus Mozart (1756 – 1791). Mozart was able to tell when violins were only very slightly out of tune when he was four (Schonberg, 1970), and began showing his talent by playing the harpsichord when he was just three years old. At age four, he began composing his own music and at age six gave his first public concert. By age twelve, he had written ten symphonies, a cantata, and an opera. Mozart’s early sign of perfect pitch indicates that he had the sensory potentials to identify and recreate the given notes. At age four, Mozart “could play it faultlessly and with the greatest delicacy, and keeping exactly in time” (Zaslaw & Cowdery, 1990, p. 276), indicating that he had intellectual and motor potentials to read, understand, and perform the given music. Most important, Mozart’s compositional abilities during early age indicates that he had the creative potential to produce original work.

Although it is generally accepted that Mozart was a musical prodigy, Lehmann and Ericsson (1997; 1998) argued that his achievement was the result of extended deliberate practice. Lehmann and Ericsson (1998) investigated the correlation between the dates of piano sonatas composed by Haydn, Clementi, Mozart, Beethoven, and Schubert’s and their complexity ratings. They found that the complexity of the sonatas increased as a function of dates, suggesting the sonatas from later periods of time tended
be rated more complex than those from earlier ones. They also compared the prodigies’ ages and the difficulty of pieces that they could play from the last three centuries. They found that the more recent prodigies were able to play more difficult pieces at a younger age than the prodigies from earlier. They concluded that these findings suggest that more recent prodigies were able to achieve higher levels of performances faster than previous historical prodigies, which could be attributed to the change in training. They stated that “these previous levels of expert performance do not appear to require special innate talents, at least by today's standards, but they are viewed as predictable consequences of appropriate instruction and extended deliberate practice” (Lehmann & Ericsson, 1997, p. 46). Although these arguments seem reasonable at face value, they fail to consider two major variables (Arthur Gottschalk, personal communication, April 22, 2016). First, they neglect the incremental increases in instrumental technology over time. For instance, the action of the modern piano is much faster and more responsive than the fortepiano which Haydn, Mozart and the early Beethoven used to writing their piano music. Secondly, they also neglected the fact that the earlier pieces they examined were meant to be played with improvised ornamentation, often of a highly technical nature. As keyboard improvisation players, Mozart, Clementi, and Beethoven competed at least once in improvisatory battles (Abert 2007; Solomon, 1998). Although it is true that the methods of practice and training have improved over the years in the field of music, it is not the only factor responsible for the increased complexity of music pieces over years.

Contrary to Lehmann and Ericsson’s (1997; 1998) study, Simonton’s (1991) study of 120 classical composers supports the role of natural ability in musical talent. He found that the most exceptional composers had less formal music training before they
began to compose than many of the less exceptional composers did. In addition, these most eminent composers had less practice composing before they made lasting contributions to the classical repertoire.

A more recent case study of a musical prodigy conducted by Ruthsatz and Detterman (2003) investigated the role deliberate practice played in a prodigy’s exceptional performance. The subject of the case study was a six-year old musical prodigy, Derek, who had played in numerous concerts and released two musical CD’s in which he sang in two languages and played several musical instruments. According to Ruthsatz and Detterman’s (2003), Derek’s exceptional musical performance was not a result of structured musical lessons and extended deliberate practice. He learned and mastered his musical skills by simply listening to other performers and improvising his own pieces (Ruthsatz & Detterman, 2003, p. 514). Therefore, Ruthsatz and Detterman concluded that “Derek has not received formal training and therefore has not engaged in what Ericsson and Charness (1994) have described as deliberate practice. … Derek spends a great deal of time in playful imitation of other musicians but improvement in his performance is a by-product, not the driving force behind his practice activity” (2003, p. 516). Contrary to the assertions of Ericsson and his colleagues’, the existence of Derek provides evidence that a prodigy’s exceptional achievements in music do not necessarily result from deliberate practice.

Child prodigies have also been found in the field of mathematics. One of the most exceptional math prodigies on record is Srinivasa Ramanujan (1887-1920). Ramanujan was an Indian mathematician and contributed extraordinarily to several fields of mathematics including mathematical analysis, number theory, infinite series and
continued fractions. Although it is not known how he turned out to be an extraordinary mathematician, it is clear that he received little or no formal training in advanced mathematics and learned mathematics on his own.

Ramanujan learned advanced trigonometry and proved sophisticated theorems by himself at age 13 (Berndt & Rankin, 2001). At age 14, he learned geometry and infinite series. By age 15, he was able to solve cubic equations. At age 16, he developed and investigated the Bernoulli number and calculated the Euler-Mascheroni constant up to 15 decimal places (Kanigel, 1991, p. 90). Despite his talent in mathematics, he performed poorly in other subjects in school and, as a result, was not able to finish his college education. After he dropped out of college, Ramanujan continued to pursue independent research in mathematics. At age 26, Ramanujan wrote a letter containing nine pages of mathematics to the famous British mathematician, G. H. Hardy. Hardy commented that “they [theorems] defeated me completely; I had never seen anything in the least like them before…and [these theorems] must be true, because, if they were not true, no one would have the imagination to invent them” (Kanigel, 1991, p. 168). Normally, excelling at mathematics requires several years of training and exposure to current theory. The basis of Ramanujan’s extraordinary achievements in math remains unknown.

Child prodigies have also been found in chess. Chess has been referred to as the drosophila of cognitive science (Simon & Chase, 1973), because playing it successfully requires the elaborate interaction of several cognitive functions including perception, memory, knowledge, searching, and others. Moreover, many phenomena and theories of chess expertise have been shown to be generalizable to other domains of expertise.
Therefore, the study of chess prodigies may provide the best and most effective way to study human cognition.

Bobby Fischer was one of the greatest chess players of all time and has often been cited as a prime example of a prodigy because he learned how to play chess at the age of six and became a grandmaster at the age of 15 (Brady, 2011). However, Ericsson et al., (1993) based on Brady’s (1973) book, *Bobby Fischer: Profiler of a Prodigy*, suggested that Fischer dedicated sufficient time to practice so that his performance could be explained in terms of deliberate practice: Fischer was only a year shy of the bounds of the 10-year practice rule when he became a grandmaster and he dedicated a great deal of time to practice, perhaps even approaching 10,000 hours (Ericsson et al., 1993). Therefore, according to Ericsson et al., Fischer’s early accomplishments could be explained by practice and without appealing to natural ability. However, it is unlikely that Fischer’s practice would meet Ericsson’s recent criteria for deliberate practice. Nonetheless, Ericsson and colleagues argued that nearly anyone can become an expert with enough deliberate practice and discounted the importance of natural ability by stating that “in well-established domains of expertise even the most “talented” cannot reach an international level in less than around a decade of experience and intense preparation” (Ericsson, 2007, p. 11). Ericsson (1993, 1994, 1998, 2002, 2004, 2007, Ericsson & Ward, 2007) has repeatedly emphasized the importance of this statement and the importance of deliberate practice played in skill acquisition. This argument has been popularized by Malcolm Gladwell’s (2008) *Outliers*, which debuted at number one in the New York Times Best Seller list and maintained that position for 11 consecutive weeks. Gladwell (2008) repeatedly mentioned and claimed that the key to success in any field is
Ericsson and colleagues’ research has been cited and discussed in many other popular books, including Talent is Overrated (Colvin, 2010) and The Genius in All of Us (Shenk, 2010). It also has been cited extensively in scholarly journals and books to emphasize the importance of deliberate practice for the acquisition of expertise.

Although the explanation of Fischer’s chess expertise in term of deliberate practice appears dubious because his performance was far better than that of many other chess players who have studied thousands of hours, it cannot be decisively refuted. However, there are other examples of chess prodigies whose achievements are even more difficult to explain by deliberate practice. These include Paul Morphy (1837-1884), José Raúl Capablanca (1888-1942), and Samuel Reshevsky (1911-1992). According to Lawson (2010), Morphy was never taught to play chess, learning it on his own when he was six simply from watching others play. After Morphy’s family recognized his precocious talent, he was encouraged to play at family gatherings and local chess milieus. By the age of nine, he was the best player in his hometown, New Orleans. When Morphy turned 12, he stopped playing chess and did not begin again until he was 20. Within two years, he became the best chess player in the world.

Capablanca (1888-1942) learned chess at the age of four by simply watching his father play (Capablanca, 1916). When he was eight, Capablanca’s father took him to a doctor who recommended that he should be prohibited from playing chess. As a result, the amount of time he practiced chess was very limited. Nonetheless, by age 13, he beat the Cuban Chess Champion, Juan Corzo. When he was seventeen, Capablanca passed the entrance examinations of Columbia University and then played baseball on the freshman
team. While in college and aged 18, he defeated World Chess Champion, Emanuel Lasker. Capablanca did not concentrate on chess again until he was 20. He became world champion within two years after he quit school and started playing chess seriously. He was world champion from 1920 to 1927 and went 8 years (from 1916 to 1924) without losing a single game when competing actively in tournaments. During Capablanca’s entire chess career, he only lost 35 of 567 tournament games.

Reshevsky (1911 – 1992) learned chess at the age of four. At age eight, he was able to beat many accomplished players and gave simultaneous exhibitions. When he was ten, he defeated a grandmaster and former French champion, David Janowski. Although Reshevsky has been recognized as a chess prodigy, he never became a truly professional chess player. He quit chess and gave up most competitive chess matches for seven years, from 1924 to 1931. The year he started playing chess again he won the U.S. Open Chess Championship. After graduating from the University of Chicago in 1934, he won the U.S. Chess Championship in 1936, 1938, 1940, 1941, 1942, 1946, and 1969.

Ruslan Ponomariov (born in 1983), Peter Leko (born in 1979) and Magnus Carlsen (born in 1990) are contemporary prodigies. Gobet and Campitelli (2007) interviewed Ponomariov and Leko and found that both of them reported that they had started playing chess at the age of 7. Ponomariov attained a grandmaster (GM) title at age of 14 (obtained 2,550 Elo points, considered as GM level, at the age of 12 years and 8 months), and Leko was at age of 14 years and 4 months (obtained 2,550 Elo points at the age of 13 years and 9 months). The final and most impressive example is Carlsen who learned chess at the age of 5, but he was not initially interested in chess (Max, 2011). He stated that “I learned the moves when I was 5 or 6 but hardly played until I turned 8. I
played my first [children] tournament in July 99 at the age of 8.5” (Friedmann, 2003). He finished in 13th place at the Norwegian Chess Championship for children under the age of 11. Based on these prodigies’ ages when they started playing chess and ages they obtained the GM title, Gobet and Campitelli (2007) concluded that “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 interindividual variability has been underestimated in previous research” (p. 162). Hence, Morphy, Capablanca, Reshevsky, and more recently Ponomariov and Leko and Carlsen’s exceptional achievements are all difficult to be accounted for from a purely deliberate practice perspective.

Currently, the world record holders for being the youngest to defeat a grandmaster are Awonder Liang (born in 2003) in standard time control chess and David Howell (born in 1990) in blitz chess. The youngest player to obtain the grandmaster title is Sergey Karjakin (born in 1990). Liang became the youngest player to have defeated a grandmaster, Larry Kaufman, in chess at standard time control at the age of 9 years and 3 months. Howell broke the world record to become the youngest player to beat a grandmaster, John Nunn, in an official blitz chess at the age of 8 years and 10 months. Karjakin obtained the GM title at the age of 12 years and 7 months, and learned to play chess when he was 5. Their exceptional achievements in chess seem contradictory to the statements made by advocates of the primacy of deliberate practice. Even though the historical accounts of these chess players are credible and, for the most part contemporaneously documented, these players were not scientifically investigated and therefore do not conclusively refute the 10-year/10,000-hour rule. The contemporary
prodigies, in particular Karjakin, certainly violate the 10-year practice rule, and probably the 10,000-hour rule too.
**Introduction to the Case Study of a Young Chess Player**

One aim of this study was to investigate whether the chess skill of a young chess player, CS, is consistent with the views of those asserting the primacy of deliberate practice. A second aim was to investigate whether she has any exceptional cognitive abilities that could be associated with her chess ability.

As discussed previously, the definitions and measures of deliberate practice were inconsistent across different studies in different fields. Ericsson and Charness (Ericsson et al., 1993; Charness et al., 1996; Charness et al., 2005) measured deliberate practice by asking the participants to estimate how many hours they practiced or studied alone. However, players studying chess alone were not necessarily engaging in Ericsson et al.’s deliberate practice. Ericsson’s deliberate practice may be equivalent to practice alone in the domain of music because violinists and pianists may improve their skills by repeatedly performing the same or similar pieces of music. However, in chess, the amount of time studying alone does not equal the amount of time spent practicing because studying chess alone does not necessarily mean an improvement in skills by doing something again and again (Merriam-Webster Online Dictionary). There are several other chess-related activities that can be engaged when studying alone. For instance, chess players may study and learn chess principles and learn other aspects of chess theory during study alone. They may also study specific opening positions and prepare moves to play against opponents whose opening preferences are known. Therefore, deliberate practice may be part of what occurs when players study alone but there are also other chess-related experiences involved. Furthermore, one characteristic of deliberate practice that Ericsson et al. (1993, p. 391) stressed is that deliberate practice itself is not inherently motivating and enjoyable. Ericsson et al. (1993) stated that “the
lack of inherent reward or enjoyment in practice as distinct from the enjoyment of the result (improvement) is consistent with the fact that individuals in a domain rarely initiate practice spontaneously” (p. 368 – 369). This unenjoyable characteristic restricts the amount of time spent studying alone even more that can be considered deliberate practice. Therefore, in this current research, the measure of time studying alone does not purport to measure “deliberate practice.” This similar logic can be used to argue that playing chess with opponents does not fit into the definition of deliberate practice. In addition, players playing chess with opponents and in tournaments generally do not play against equally skilled opponents. Thus, it provides little to no opportunity to engage in Ericsson et al.’s deliberate practice. However, players are still able to learn something from it, especially during post-game analysis. For instance, post-game analysis allows a player to learn where things went wrong and learn more strategies for the future.

Therefore, playing chess with opponents and in tournaments are both considered part of chess-related experience in the present study. In summary, it is clear that there are individual differences in attaining specific skills, with it being possible that some individuals are able to profit more from domain-specific experience (not necessarily restricted to deliberate practice) than others. Thus, in this study, studying chess alone and playing chess with opponents are all considered as chess-related experience.

In order to examine whether the young chess player’s exceptional performance in chess can be attributed to chess-related experience, I provide a detailed history of her chess related activities, including how and when she started and learned chess, how many hours she spent studying chess alone, how many hours she spent playing chess with
opponents, how her chess rating changed over time as function of chess experience, and what her attitude was towards studying and playing chess.

Another purpose of this study is to investigate the cognitive abilities that can be potentially associated with chess ability. The following will first review the literature regarding the correlation between general intelligence and chess skills, followed by a literature review of potential cognitive abilities associated with chess abilities.

If the existence of prodigies provides evidence for the view that natural ability plays a critical role in the acquisition of expertise, then an obvious follow up question is whether it is necessary to have a high level of general intelligence (IQ) to become a prodigy. Older studies (e.g., Hollingworth, 1942) considered a prodigy to be someone of exceptional intelligence. For example, Hollingworth (1942) suggested that a child prodigy should have an IQ exceeding 180. However, the evidence supporting this notion is lacking. More recent researchers have proposed that prodigies’ outstanding performances can be attributed to their exceptional skills in specific domains, and that an extremely high IQ is not a prerequisite for outstanding precocious achievement. This hypothesis is consistent with recent results presented in several studies. These studies can be categorized into two different approaches: case studies of prodigies (e.g., Ruthsatz & Detterman, 2003; Ruthsatz & Urbach, 2012) and case studies of savants (e.g., Sloboda, Hermelin, & O’Connor, 1985; Young & Nettelbeck, 1995).

Case Studies of Prodigies.

As discussed previously, Ruthsatz and Detterman’s (2003) study of Derek showed that his exceptional performance in music was not the result of deliberate practice. As a result, key questions remain about what cognitive abilities facilitated his acquisition of
music abilities. Ruthsatz and Detterman (2003) assessed Derek’s IQ and found that his full-scale IQ score was 132 (98.4 percentile). Among the four cognitive abilities (verbal reasoning, abstract reasoning, quantitative reasoning and short-term memory), the most striking skill was his extraordinary memory (percentile = 99.99). Therefore, Ruthsatz and Detterman argued that Derek’s exceptional performance in music can be attributed to his extraordinary memory which compensates for his lack of formal training and deliberate practice. More recently, Ruthsatz and Urbach (2012) assessed the IQs of eight prodigies: four musical prodigies, one art prodigy, one math prodigy, one prodigy who switched from music to astronomy, and one prodigy who switched from music to art. They found that the IQ scores varied widely among eight prodigies, ranging from 108 (70th percentile) to 147 (99.6th percentile). These two studies of a total of nine prodigies show that the prodigies’ exceptional performances in specific domains cannot not be explained by general intelligence alone.

Case Studies of Savants.

Another source of evidence demonstrating exceptional performance in specific domains that is unrelated to general intelligence is the occurrence of savants. For example, Sloboda et al. (1985) assessed a musical savant’s IQ, domain-specific memory, and verbal working memory (digit spans). They found that he had a verbal IQ of 62 and a performance IQ of 60. His digit spans were 5 for forward and 4 for backward recall. However, his ability to listen and play unfamiliar musical pieces was exceptional. Therefore, Sloboda et al. (1985) concluded that his talent can be attributed to his exceptional musical memory but not to general intelligence. Similar results have been reported by Young and Nettelbeck (1995). A musical savant with autism, TR, had a
verbal IQ of 100 and a performance IQ of 111. TR had perfect pitch, which is a rare ability even among talented musicians. In addition, TR’s domain-specific memory for music pieces was superior to a professional pianist. Therefore, these two case studies of musical savants support the view that “general intelligence is not a prerequisite for structure-based skill” (Sloboda et al., 1985, p. 155).

**Cognitive Abilities and Chess.**

If general intelligence is not a prerequisite for outstanding precocious achievement, then what contributes to the prodigies being so exceptional? In this section, I first review the research on the relationships between general intelligence and chess expertise. Next, I review the cognitive abilities that could reasonably be expected to show associations with chess expertise: working memory, visuo-spatial short-term memory, and approximate number system.

**General intelligence and chess.** Several studies have investigated whether chess expertise is associated with general intelligence (IQ) by either comparing chess players’ IQ scores with the general population or by examining the relationships between IQ scores and skill levels. The results are mixed. Some studies have shown that chess players tend to have higher IQ scores than the general population (e.g., Bilalic, McLeod, & Gobet, 2007; Frydman & Lynn, 1992; Grabner, Neubauer, & Stern, 2006; Grabner, Stern, & Neubauer, 2007), while others have shown positive relationships between IQ score and skill level, ranging from \( r = .35 \) to \( r = .55 \) (e.g., Bilalic et al., 2007; Frydman & Lynn, 1992; Grabner et al., 2007). However, one study reported no evidence that IQ correlated with chess skills, \( r = -.08 \) (Unterrainer, Kaller, Halsband, & Rahm, 2006).
Frydman and Lynn (1992) administered the Wechsler Intelligence Scale for Children (WISC) to 33 young gifted Belgian chess players and found that these young chess players’ full-scale ($M = 121$), verbal ($M = 109$), and performance IQs ($M = 129$) were all well above population mean ($\mu = 100$). In addition, they found that the stronger players ($M_{(f)} = 122$, $M_{(v)} = 110$; $M_{(p)} = 131$) were slightly higher in full-scale(f), verbal(v), and performance(p) IQs than the weaker ones ($M_{(f)} = 117$, $M_{(v)} = 107$; $M_{(p)} = 124$). Based on these findings, Frydman and Lynn (1992) concluded that a high level of general intelligence is important for achieving a high level of chess skill. However, the relationship between general intelligence and chess achievement that Frydman and Lynn (1992) found does not rule out other plausible explanations. For example, it does not rule out the possibility that the high intelligence children were more likely to be encouraged to play chess.

Grabner et al., (2006) administered the revised German intelligence structure test 2000 (Intelligenz-Struktur-Test 2000 R, I-S-T 2000R) to 90 Austrian tournament-rated chess players to assess their IQ. They found that the chess players’ mean IQ score was well above the population mean, although there was a wide range of IQs.

Later, Grabner et al. (2007) investigated the correlation between tournament-rated chess players’ IQ scores and their skill levels across a wide range of chess skill. They found that the chess players’ mean IQ was well above the mean for the general population and their chess skill correlated with their IQ scores ($r = .35$).

In the same year, Bilalic, McLeod, and Gobet assessed the general intelligence and chess skills of 57 children who play chess. The children’s IQ was assessed by using WISC-III, and their chess skills were measured by administrating three different chess-
related tests: a chess test, a recall test, and the knight’s row test (KRT). The chess test consists of two parts: rules of games (e.g., moves, castling), and chess problems that featured different chess motifs. In the recall test, adopted from de Groot (1965), the participants were required to reconstruct a position previously presented for 10 second. In KRT, adopted from Holding (1990), the participants were required to transfer the knight from one corner of the board to the other on the same horizontal as quickly as possible. These three chess-related tests have high validity as measures of chess skill as determined by correlating these three tests with the scores in the tournaments organized in schools and coaches’ estimates of the children’s chess abilities. The authors found that these young chess players’ mean IQ score ($M = 122; SD = 17$) was substantially above the population mean, and that the IQ scores correlated with the chess skills (Chess test: $r = .55$; Recall: $r = .54$; KRT: $r = -.49$). In the same study, the authors compared the mean IQ of a subsample of elite young chess players ($n = 23$) with the mean for the remainder of the sample ($n = 34$), and found that elite young chess players’ mean IQ score of 133 was substantially higher than the mean IQ score of 114 for the other players.

On the other hand, one study failed to find an association between fluid intelligence scores and chess skills. In 2006, Unterrainer and colleagues administered the Standard Progressive Matrices (SPM) to both 25 chess players (Elo ratings ranged from 1250 to 2100; $M = 1683$) and 25 non-chess players to assess their fluid intelligence. They found that the chess players’ mean fluid intelligence score ($M = 28.56; SD = 2.33$) was essentially equal to the mean of the non-chess players ($M = 28.60; SD = 1.22$). In addition, no evidence was presented suggesting fluid intelligence is correlated with chess skills ($r = -.08$).
In summary, several studies have shown that chess players have a higher mean IQ score than the general population and there is a positive association between chess skill and IQ. However, the variance of these IQ scores was rather wide. In addition, the chess prodigies’ IQ scores were unreported. Therefore, the questions of whether general intelligence is a prerequisite for being a chess prodigy and whether it is associated with chess expertise have not been answered conclusively.

**Working memory and chess.** Working memory is not simply the capacity used to memorize a string of digits; instead, it is the ability to maintain access to goal-relevant information while concurrently manipulating and processing other incoming information or distractions.

The evidence for the association between working memory and chess expertise is mixed. Bilalic et al. (2007) measured the working memory and chess skills of 57 children who played chess. Working memory was measured by using forward and backward digit spans. They also measured these children’s chess skill levels using the three tests described in an earlier section. They found that working memory was correlated with each of the measures of chess skill (Chess test: $r = .58$; Recall: $r = .48$; KRT: $r = -.57$).

Unterrainer et al. (2006) used both forward and backward digit spans and Corsi block-tapping tasks to measure 25 chess players’ and 25 non-chess players’ verbal and visuo-spatial working memory, respectively. In the forward Corsi block-tapping task, the participants were asked to copy a sequence of moves made by the experimenter tapping an array of blocks. The backward Corsi block-tapping task is similar to the backward digit span, except that the participants are asked to recall the sequence of moves in the reverse of the presented order. They found chess players scored slightly higher in verbal
working memory (chess players: $M = 19.12, SD = 3.8$; non-chess players: $M = 18.52, SD = 3.45$), as well as in visuo-spatial working memory (chess players: $M = 20.12, SD = 3.64$; non-chess players: $M = 18.64, SD = 2.78$).

Jastrzembski et al. (2006) compared the working memory of chess players at three different chess skill levels (novice, intermediate, and expert). They measured the chess players’ working memory by using the 2-back lag task. In the 2-back lag task, the participants were presented with a list of numbers, and they were required to judge whether the current number is the same or different from the number in two before it. For example, the participants were presented with the digits of 2, 5, and 3 in a sequence, and when they saw the digit 3, they had to decide whether the digit 3 was same or different from digit 2. The authors did not find evidence for a difference in working memory task across skill levels.

**Visuo-spatial short term memory and chess.** Visuo-spatial short-term memory is the capacity for holding a small amount of visual and spatial information in mind in an active, readily available state for a short period of time. A common theoretical view is that playing chess requires a high level of visuo-spatial abilities (Chase & Simon, 1973; Frydman & Lynn, 1992). When playing chess, players are required to calculate moves, while maintaining the potential moves in their mind. This type of ability requires chess players to temporarily store and maintain visual and spatial information for a short period of time. This theoretical view is consistent with Frydman and Lynn (1992) who found that the mean performance IQ score for a sample of young chess players ($M = 129$) was higher than their mean verbal IQ score ($M = 109$). In addition, they found that the stronger players had a higher mean performance IQ score ($M = 131$) than the weaker ones.
These results led the authors to conclude that visuo-spatial abilities are important for chess playing.

Unterrainer et al. (2006) measured chess players’ and non-chess players’ visuo-spatial short-term memory by using the forward Corsi block-tapping task and found a moderately large difference in the favor of chess players (chess players: $M = 10.48$, $SD = 2.2$; non-chess players: $M = 9.36$, $SD = 1.91$; $p = .06$). However, since the difference was not significant at conventional levels, the data do not rule out the possibility of no true differences.

**Approximate number system and chess.** The approximate number system (ANS) is a cognitive system that produces an intuitive “number sense” and supports the numerical estimation of the magnitude of a group without relying on any languages or symbols. This type of intuitive number sense has been shown to exist in human (Feigenson, Dehaene, & Spelke, 2004; Libertus & Brannon, 2009) and other non-human animal species (Brannon, Jordan, & Jones, 2010). In humans, the ANS is active across the entire lifespan.

Despite the absence of direct evidence of an association between ANS acuity and chess skills, there is indirect evidence that there may be an association. Research has shown that chess skill is correlated with math ability (Grabner et al., 2006; 2007), and math ability is correlated with ANS (Feigenson, Libertus, & Halberda, 2013; Halberda, Mazzocco, & Feigenson, 2008). In this section, I first review research on the associations between chess skills and math abilities. Next, I review research on the associations between math ability and ANS.
Grabner et al. (2006; 2007) measured tournament-rated chess players’ different intelligence components: verbal, numerical and figural, and investigated their associations with expertise levels. They found that chess players’ displayed a slight advantage in numerical IQ (2006: $M = 119$, $SD = 14$; 2007: $M = 116$, $SD = 14$) over both verbal (2006: $M = 112$, $SD = 12$; 2007: $M = 108$, $SD = 13$) and figural IQs (2006: $M = 110$, $SD = 16$; 2007: $M = 106$, $SD = 15$). Among these types of IQ, the strongest relationship was with numerical IQ, which correlated, but not significantly, .46 with chess ratings (Verbal: $r = .38$; Figural: $r = .02$).

The links between the ANS and math ability in both group and individual differences have been well-established. For example, Halberda et al. (2008) examined and tested 64 children’ mathematical abilities and their ANS. The children were very rapidly presented with two spatially intermixed colored dots so as to prohibit them from counting the number of the dots. They were then asked to determine which color was more numerous. Halberda et al. (2008) found that individual differences in achievement in school mathematics were related to individual differences in ANS (Test of early mathematical ability: $r = -.57$; Woodcock-Johnson revised calculation subtest: $r = -.53$).

Moreover, studies also have shown that children who have dyscalculia (as known as mathematical learning disability) have worse ANS than typically developing children of the same age (e.g., Andersson & Östergren, 2012; Mazzocco, Feigenson, & Halberda, 2011).

Therefore, even though there is no direct evidence of an association between ANS and chess skills, the ANS was correlated with mathematical achievements, which was correlated with chess skills.
Based on the literature discussed above, seven cognitive ability tasks were investigated in this study.
Method

Participants

Young chess player. At the time of testing, CS was a 10-year-old female chess player who had obtained a United States Chess Federation (USCF) rating of 2141 (at the 96.6th percentile of the entire USCF population: based on the database in USCF in 2015: 64,069 members).

Children. A total of 34 healthy 10-year-old children were recruited from different elementary schools from Houston in Texas and Taipei City in Taiwan. Sixteen of the children are boys and eighteen girls.

Procedures

Young chess player. Data was collected from one day of informal face-to-face interviews with CS and her parents and two days of testing seven cognitive tasks, one chess memory task, and one chess knowledge task. This study was approved by the institutional review board at Rice University. This testing lasted nearly six hours in total. During the interview, CS and her family were encouraged to talk about her experience playing chess, her friendship with other chess players, her hobbies, her entry into playing chess, and her general beliefs about chess. Information was sought in three important areas. First, I was interested in learning how she had become interested in chess. Second, I wanted to learn more about informal learning experiences that occurred before her first formal engagement with chess activities. Finally, I wanted to learn about her involvement in any formal or informal training and practice experience after she started playing chess seriously, including her coaching experience, how many hours she had seriously studied alone, and how many hours she had seriously played chess with opponents.
**Children.** To be eligible to participate in this study, the children had to be 10 years old and have had little or no experience playing chess. This study was approved by the institutional review board at Rice University. Two methods were used to recruit the children participants. First, they were recruited via school newspapers and flyers handed out in elementary schools, local libraries, and shops. Contact information was included in the flyer, with interested parents asked to contact the researcher for detailed information. Data collection was held in the primary schools, Rice University, the participants’ home, and local libraries. On the data collection day, parents and children were asked to review and sign consent forms that provided them with study information, including experimental procedures, risks, benefits, and confidentiality procedures. In the second method, the schools that had agreed to participate in this study were asked to distribute a flyer with a parental consent form to Grade 5 children. Interested parents returned a signed parental consent form, and then the children were explained and signing the consent form on the data collection day. Data collection was held in the primary school. At the end of session, the children received a $10 gift card. The time needed to complete the tasks ranged from 45 to 60 minutes.

**Materials**

**Cognitive abilities tasks.** A total of seven cognitive tasks were used and were based on the reviewed literature. All the participants performed the tasks in the same order: forward digit span, backward digit span, approximate number system, visuo-spatial forward span, visuo-spatial backward span, automated symmetry span, and visual short-term memory.
Forward and backward digit spans. Digit span is the most commonly used task to measure verbal short-term memory and verbal working memory, and its reliability and validity has been well-documented (see Conway, Kane, & Engle, 2003; Coway, Kane, Bunting, Hambrick, Wilhelm, & Engle. 2005). In a forward digit span, a list of pseudo-random numbers was presented auditorily from a computer at the rate of one per second. There were two different number lists of the same length. The presentation began with two numbers, increasing until the participant committed two errors in the same length of list. The participants were asked to repeat them back in the correct order immediately after the presentation of the list. In a backward digit span, the procedure was similar. The participants were asked to recall the digits in reverse of the presented order. For example, if the participant was presented with the list of digits of “1-3-9-7,” they would be asked to recall the digit in a reverse order, with the correct response in this case being “7-9-3-1.” The longest length that the participant recalled correctly one at least one of two lists was the participant’s score. Each participant obtained one score for the forward digit span and one score for the backward digit span.

Approximate number system (ANS) task. The participants’ ANS was assessed by using a 10-minute computerized task. On each trial of this task, the participants were simultaneously presented with two side-by-side arrays of blue and yellow dots on a gray background (see Figure 2). The participants were asked to judge whether there were more numbers of blue dots or more numbers of yellow dots. In this task, there are a total of 4 blocks, and each block had 40 trials. Before the actual trials, the participants received 4 practice trials with immediately feedback to make sure that the participants understood the rules of this task. For each block, the participants pressed the space bar to initiate the
task, with each trial appearing for 200 ms and followed by a mask with blue and yellow noises. After the 200 ms blue and yellow dots arrays had disappeared, the participants had an unlimited amount of time to indicate their response by pressing the buttons on the keyboard. The array of blue dots always appeared on the right-hand side of the screen and the array of yellow dots always on the left-hand side of the screen. The participants indicated their responses by pressing either the “M” (blue dots are more than yellow dots) or “Z” (yellow dots are more than blue dots) key on the keyboard. The numerical size of the dots in each array ranged from 5 to 22, and the ratio between two color dots varied among 1:2, 2:3, 3:4, 4:5, 5:6, 6:7, 7:8, 8:9, 9:10, and 10:11. Each ratio had 10 trials. Half of the trials in each ratio had more blue dots than yellow dots, and half of the trials were more yellow dots than blue dots. Half of the trials were “dot-size controlled” and half of the trials were “area-controlled.” In the “dot-size controlled” trials, the size of the average blue dots was equal to the size of the average yellow dots. In other words, the array with more dots had a larger total area on screen. In the “area controlled” trials, the total area of blue dots on the screen was equal to the total area of yellow dots. In other words, the array with more dots had smaller sized dots on average. On both dot-size and area controlled trials, the individual dot size varied randomly by up to ±20% of the average dot sizes to avoid the participants use individual dot size as a proxy for number.

Each participant’s ANS was measured as the Weber fraction \( (w) \), which is an estimation of each participant’s discrimination sensitivity and internal noise by modeling individual participant’s performances in accordance with Weber’s law. The individual participant’s Weber fraction was calculated based on the method described by Halberda, Mazzocco, and Feigenson (2008), which assumes that numerosity for blue and yellow
arrays are distributed as Gaussian random variables with means $n_2$ (larger set) and $n_1$ (smaller set) and standard deviations ($w \times n_2; w \times n_1$). This model (see Equation 1) uses the complementary error function $erfc$ to estimate the correct proportion at each ratio (larger set / smaller set: $n_2 / n_1$) and models these correct proportions as a smooth function of increasing ratio.

$$Proportion\ Correct = 1 - \frac{1}{2} \text{erfc} \left( \frac{n_1 - n_2}{\sqrt{2w} \sqrt{n_1^2 + n_2^2}} \right)$$

(1)

In this model, there is only one single free parameter, $w$, for one participant in each ratio bin. To determine a single $w$ value that minimizes the last squared error across each ratio bin, the Levenberg-Marquardt algorithm was applied. This obtained $w$ value indicates the standard deviations of the Gaussian representations of the ANS for the participant. Therefore, an individual who has a larger $w$ value indicates more noises in his/her ANS.

Figure 2. Approximate number system task.

**Forward and backward visuo-spatial memory spans.** A computerized version of Corsi’s (1972) block-tapping task was used to measure the participants’ visuo-spatial
short-term memory (forward span) and visuo-spatial working memory (backward span). This task was used because of its high reliability and validity (Orsini, 1994). The validity of this task has been shown by the fact that it correlated with other tasks (Orsini, 1994). For example, this task was correlated with arithmetic operations ($r$ ranged from .19 to .38), digit span ($r$ ranged from .28 to .39), block design ($r$ ranged from .30 to .53), verbal IQ ($r$ ranged from .19 to .36), performance IQ ($r$ ranged from .31 to .49), and full-scale IQ ($r$ ranged from .28 to .45).

In the forward visuo-spatial memory span, the participants were presented with a pseudo-random sequence of colored blocks in different locations on the computer screen at a rate of one per second, and then the screen became blank for 3 seconds. At the recall phase, the participants were asked to recall the sequence of colored block locations in the order in which they had appeared by clicking on the blocks and given unlimited time to do so (see Figure 3). The presentation began with two blocks, increasing until the participant committed two errors in the same length of list. In the backward visuo-spatial memory span, the procedure was similar. The participants were asked to recall the locations in reverse of the presented order. The longest length that the participant recalled correctly at least one of two lists was the participant’s score. Each participant has two scores: one score for the forward visuo-spatial span and one score for the backward visuo-spatial span.
Automated symmetry span. Unsworth, Heitz, Schrock, and Engle's (2005) automated symmetry span task (see Figure 4) was applied to measure the participants’ dynamic working memory, involving both the storage and processing of information. The automated symmetry span task has high test-retest reliability ($r = .77$, Unsworth, Redick, Heitz, Broadway, & Engle, 2009) and high internal consistency (Cronbach’s $\alpha = .86$, Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle, 2004; Cronbach’s $\alpha = .86$, Unsworth, Brewer, & Spillers, 2009). In addition, the validity of this task has repeatedly been demonstrated by the fact that it tended to correlated with other working memory tasks, and higher-order and lower-order cognitive processes. For example, this task has been correlated with other working memory tasks, such as automated operation span (e.g., Unsworth, Brewer, et al., 2009: $r = .48$; Unsworth, Redick, et al., 2009: $r = .66$; Unsworth & Spillers, 2010: $r = .46$) and automated reading span (e.g., Unsworth, Brewer, et al., 2009: $r = .38$; Unsworth, Redick, et al., 2009: $r = .7$; Unsworth & Spillers, 2010: $r = .42$). It also correlated with lower-order cognitive processes, such as antisaccade (e.g., Unsworth & Spillers, 2010: $r = .22$) and the Stroop task (e.g., Unsworth & Spillers, 2010: . . . )
Moreover, it correlated with higher-order cognitive processes, such as the Raven progressive matrices (e.g., Unsworth, Brewer, et al., 2009: $r = .34$; Unsworth, Redick, et al., 2009: $r = .51$), number series (e.g., Unsworth, Brewer, et al., 2009: $r = .29$; Unsworth, Redick, et al., 2009: $r = .45$), and necessary arithmetic operation (e.g., Unsworth, Redick, et al., 2009: $r = .53$). In the automated symmetry span task, the participants were asked to recall the sequences of red squares within a $4 \times 4$ matrix, while performing a symmetry judgment task. During the symmetry judgment trials, the participants were presented with geometric patterns in an $8 \times 8$ block ($6 \text{ cm} \times 6 \text{ cm}$) matrix of white and black squares, and they were asked to judge whether this presented pattern was symmetrical along the vertical axis. All the participants started the task with 15 symmetry judgment practice trials, and the mean response time across the 15 trials was calculated. This calculated mean time plus 2.5 standard deviations served as the maximum time for presenting the symmetry pattern to each participant. Immediately after a symmetry pattern presentation, a 500 ms blank screen was shown, followed by the $4 \times 4$ white matrix filled with one red colored square presented for 650 ms. The length of the pseudo-random sequence of red square was from two to five, and three trials of each set length presented. At the recall phase, the participants were asked to recall the sequence of red square locations in the order in which they appeared by clicking on the cells of an empty matrix (see Figure 4). Accuracy was scored overall on the basis of correct serial locations within the response matrix. The symmetry span task took an average of approximately 15 minutes to complete.
**Visual short-term memory task.** The participants’ visual short-term memory was assessed by using a 5-minute computerized task with sequential comparison paradigm. In this task, there were a total of 2 blocks, and each block had 30 trials. Before the actual trials, each participant undertook 4 practice trials with immediate feedback to ensure that they understood the rules of the task. For each block, the participants pressed the space bar to initiate the task. Each trial starts with a 1000 ms fixation followed by an array. After 500 ms, the array disappeared and the screen went blank for 900 ms. The same number of colored squares reappeared in the same location, but with one of the colors of the squares having either changed to one of the remaining colors or maintaining the same color (see Figure 5). The participants were instructed to detect whether or not there were any color changes. The participants had an unlimited amount of time to make their responses by pressing either “A” (two arrays are the same) or “L” (two arrays are different) in the keyboard.
Figure 5. Visual short-term memory task.

The number of squares presented on screen, also called set size, in each trial ranged from 2 to 7. Each set size had 10 trials. Half of the trials in each set size were the “same” and half were “different.” The fixation was presented in the center of the screen. The colored squares were presented in pseudo-random selected positions in the following twelve positions: [-8, -2], [-6, 2], [-5, -4.5], [-3, 3.5], [-3, -1], [0, -3], [1, 5], [2, 2], [4, -4], [6, 2.5], [7, -2.5], and [8, 5]. The values in the x and y coordinators were in the units of centimeter distance from the center of the screen. The screen size was the same for all the participants. The colored squares were randomly selected from a set of 8 colors with the following HEX codes: red [#FF0000], green [#008000], black [#000000], blue [#0000FF], yellow [#FFFF00], white [#FFFFFF], pink [#FFC0CB], and purple [#800080].

Each participant’s visual short-term memory was calculated based on single detection methods (Green & Swets, 1966, 1974), which estimated each participant’s sensitivity ($d$-prime, $d'$) in discriminating color-change trials from no-color-change trials. This estimate was derived from the measurements of hit rate and false-alarm rate. Since
signal detection analyses require that neither the hit rate nor the false alarm be 0 nor 1, an adjustment recommended by Stanislaw and Todorov (1999) was adopted (see Equation 2). I used the log linear approach to add 0.5 to both the number of hits (\(n_{\text{Hit}}\)) and the number of false alarms (\(n_{\text{FA}}\)) and added 1 to both the number of signal trails (\(n_{\text{Signal}}\)) and the number of noise trials (\(n_{\text{Noise}}\)). Then, the hit rate and false-alarm rate were calculated. This adjustment was applied to all the participants regardless of whether or not extreme rates were obtained.

\[
d' = Z\left(\frac{n_{\text{Hit}} + 0.5}{n_{\text{Signal}} + 1}\right) - Z\left(\frac{n_{\text{FA}} + 0.5}{n_{\text{Noise}} + 1}\right) \tag{2}
\]

One single \(d'\) value for each participant in each set size was calculated, and a mean d-prime was calculated across six set sizes. A higher \(d'\) means a higher sensitivity to detect signal change and a higher visual short-term memory capacity.

**Chess knowledge task.** van der Maas and Wagenmakers’ (2005) Verbal Knowledge Test from the Amsterdam Chess Test (ACT), which was adapted in part from Pfau and Murphy (1988), was used to investigate CS’s chess knowledge. This task consisted of a total of 18 four-alternative multiple-choice questions varying in difficulty: five questions refer to opening knowledge, four questions to strategical knowledge or positional knowledge, five questions to endgame knowledge, one question to chess knowledge definition, and three questions measure the capacity to visualize chess moves. This task has fairly acceptable reliability, Cronbach’s \(\alpha = .67\) (van der Mass & Wagenmakers, 2005). The complete chess knowledge test is reproduced in Appendix A. CS was required to perform this task using pencil and paper without any time limitation.

**Chess memory task.** CS’s ability to reconstruct positions was assessed by administering the Memory Test from van der Maas and Wagenmakers’ (2005) ACT.
This task demonstrated fairly acceptable reliability, Cronbach’s $\alpha = .43$ (van der Maas & Wagenmakers, 2005). In the results of the present study, this task had high item reliability, Cronbach’s $\alpha = .93$. This task consisted of 6 typical positions varying in memory load (three levels: 0-16 pieces, 17-24 pieces, and 25-32 pieces). Each position was presented for 10 seconds, followed by a blank screen for 2 seconds. Then, the participants were asked to reconstruct the briefly shown positions on an actual chess board. The percentage of accuracy of the reconstructed pieces was calculated. The six positions are reproduced in Appendix B.

**Chess-related background survey.** To be consistent with previous research, Charness, Tuffiash, Krampe, Reingold, and Vasyukova’s (2005) simplified version of the survey was adopted to obtain CS’s (1) demographics; (2) chess-related developmental milestones; (3) general chess belief; and (4) cumulative and current chess activities. In order to understand CS’s enjoyment of chess-related activities, the assessment of her enjoyment of on each of the various chess activities were asked in the questionnaires. She was asked to respond using a 7-point Likert scale, with 1 indicating “not at all enjoyable” and a rating of 7 indicating “very enjoyable.” CS was also asked to estimate her time investment in two categories: (1) serious analysis of position she did alone (e.g., using chess books, magazines, data bases) and (2) the amount of time she spent seriously playing opponents. The survey questions were delivered orally, with the responses written down by the author of this dissertation on the questionnaire. During the interview, CS and her parents were encouraged to share and talk about anything besides the survey questions, including her experience with other chess players, her initially interest in
chess, and her other activities besides playing chess. The complete survey is reproduced in Appendix C.

**Number of games played in tournaments.** CS’s number of games played in FIDE and USCF were obtained from each official website: https://www.fide.com/ and http://www.uschess.org/.
Results and Discussion

Defining and Preprocessing Variables

**Approximate Number System.** In order to be easily compare with other tasks, the results of this task were rescaled to make the larger number indicate a better performance. The individual player’s $w$ value was rescaled using the maximum $w$ value among all the participants to minus the original $w$ value obtained by individual player. The maximum value among 34 children was 1.43, and this new value called “rescaled $w$.”

**Studying alone.** In order to obtain the total number of study alone hours, CS was asked to estimate how many hours she had studied alone for a typical week at a given age. The total number of study alone hours was calculated by multiplying the weekly estimated average number of hours by the number of weeks in a year, and adding the yearly estimates at and below that age.

**Playing with opponents.** In order to obtain the total number of hours that CS had played seriously with opponents, CS was asked to estimate how many hours she had spent playing with opponents for a typical week at a given age. The total number of hours playing with opponents was calculated by multiplying the weekly estimated average number of hours by the number of weeks in a year, and adding the yearly estimates at and below that age.

**Playing in tournaments.** CS’s number of games played in tournaments were obtained from both USCF and FIDE’s official website, which are not estimated numbers. However, since the duration varies game-by-game, each game in USCF tournaments was estimated as 4 hours and each game in FIDE tournaments was estimated as 5 hours. The
total of number of hours played in USCF and FIDE was used as the total number of hours playing in tournaments.

**Chess experience.** Studying alone, playing chess with opponents, and playing chess in tournaments are all considered chess experience. Thus, the total time for chess experience is the sum of the number of hours of these three chess-related activities. Since the original distribution of chess-related experience was positively skewed, the square root of this variable was used to decrease skew. Previous studies used log transformations to reduce skew but because the distribution of log-transferred number of hours of chess experience was negatively skewed, the square root of transformation was chosen. This new variable is called “square root of experience.”

**CS’s Chess-Related Background**

CS is an only child. Her father has played chess, and had a United States Chess Federation (USCF) rating about 1550 (79th percentile) at the time of this study. The first time CS showed an interest in learning chess was at age of 6, and her father had a USCF rating about 1050 at that time. She asked her father to teach her the basic rules of chess so that she could join the chess club at school. Her interest in chess appeared to be self-motivated. CS did not join the USCF and start playing chess seriously until she was 7. Even after she started playing chess seriously, she still enjoyed and spent time on other indoor and outdoor activities. Parts of her interview history are documented in Appendix E.

At the time of this study, CS had received chess instructions both in a group and individually. When she was 7, she participated in a chess club and received training for three months during the summer. From the age of 8 to the interview date (age of 10), she
met occasionally with a grandmaster over a two to three months period for consultation. In general, CS’s chess training has been relatively unstructured, not very intensive, and irregular.

**CS’s Chess Rating History**

Figure 6 shows CS’s USCF rating history as a function of the number of months that she has played chess seriously. Within 19 months of the time she had started playing chess seriously, CS’s rating was at the 88th percentile of the USCF population, at the 95th percentile of the junior group (under age 21), and at the 98th percentile of the U12 group (age 12 and under). At the time of this study, which was 43 months after she had started playing chess seriously, CS’s rating was at the 96th percentile of the UCSF population, the 99th percentile of the junior group, and the 99th percentile of the U12 group. A few days after the interview, CS defeated a grandmaster. As of the current writing, which is 61 months after she started playing, CS’s rating is in the 98th percentile of the USCF population, the 99.6th percentile of the junior group, and the 100th percentile in the U12 group. CS has defeated two grandmasters and finished eighth in an international competition. At present, it might be too early to claim that CS is a chess prodigy, but her exceptional achievements and performances in chess at her age call into question the claim that “in well-established domains of expertise even the most ‘talented’ cannot reach an international level in less than around a decade of experience and intense preparation” (Ericsson, 2007, p. 14).
Figure 6. CS’s rating history as a function of the number of months since she started playing chess seriously. The vertical dashed line indicates the interview date. She started playing chess seriously when she was 7 years and 5 months old, and at the time of writing, she was 12 years and 5 months old. Three types of percentiles are labeled on the right hand-sided y-axis. “All” indicates the percentiles were calculated based on the entire population of USCF. “Junior” indicates the percentiles were calculated based on all junior members whose ages were under 21. “U12” indicates the percentiles were calculated based on all the child members whose ages were 12 and below.

**CS’s Chess-Related Experience History**

CS’s rating history (shown in Figure 6) presents her incredibly fast chess skill acquisition rate. The years of chess-related experience she had had before she defeated a grandmaster substantially less than decade (from the age of 6 to the age of 10).

Nevertheless, the advocates of deliberate practice argued that a child with early achievement might dedicate “sufficient time” to practice, so her performance could be still explained in terms of the amount of deliberate practice hours.

According to Ericsson et al.’s (1993) description of deliberate practice, deliberate practice activities are not inherently enjoyable and motivating, but aim at improving one’s level of performance. During the interview, CS was asked to rate her enjoyment of various chess-related activities. She rated her experience in analyzing positions (7 out of
7 on 7-point Likert scale, with 1 indicating “not at all enjoyable and 7 indicating very enjoyable), participating in chess tournaments (7 out of 7), receiving formal instruction (6 out of 7), and solving chess problems (7 out of 7) as enjoyable. Moreover, she reported that even if she goes a long time without improving her rating, she still enjoyed studying chess. She also reported that she enjoyed chess because of the opportunities for friendships that it provides and also the opportunities to compete at a high level. Overall, CS’s engagement in chess-related activities was deemed enjoyable. Among these chess-related activities, it seems analyzing position, solving chess problem, and receiving formal instruction may meet Ericsson’s definition of deliberate practice. However, since Ericsson et al. (1993) claimed that “deliberate practice requires effort and is not inherently enjoyable” (p. 368), CS has engaged in little-to-no deliberate practice as described by Ericsson et al. (1993).

Although CS’s studying alone measure was adopted from Charness et al.’s method (1996; 2005), as discussed previously, the amount of time CS spent studying alone does not equal the amount of time she spent on deliberate practice. Therefore, studying alone has been considered to be part of chess experience, and the term of deliberate practice is avoided. Even though “the opportunities for skill improvement are severely restricted during tournament play” (Charness et al. 2005, p. 153), it is possible that the individual differences in skill acquisition can lead the individuals have different responses to different types of chess-related activities. Thus, it is possible that CS has improved her chess skill by playing with others and during tournament play. Therefore, playing chess was considered to be part of chess-related experience in this present study. As mentioned previously, the amount of time playing chess was assessed using two
methods. The first method was adopted from Charness et al.’s (2005) survey, which required CS to retrospective report the number of hours that she has seriously played with opponents. The second method was collecting data from the USCF and FIDE websites to obtain the numbers of games that CS has played in USCF and FIDE tournaments, and the number of hours CS had played in tournaments estimated accordingly. The amount of chess-related experience CS has engaged in were calculated by adding up the amount of time CS has spent studying chess alone, self-reported chess playing, and playing in tournaments.

Figure 7 shows CS’s weekly statistics studying alone, reported playing, tournament play, and overall chess-related experience as a function of her age until the interview date. The cumulative number of hours studying alone and reported playing at a given age were calculated by multiplying the weekly estimated average number of hours by the number of weeks in a year, and adding the yearly estimates at and below that age. The total cumulative number of chess-related experience at each given age is the sum of the number of studying alone hours, the number of self-report chess playing hours, and the number of tournament play hours. Figure 8 shows CS’s cumulative number of hours for these variables listed above as a function of her age until the interview date. As Figure 8 shows, at the age of 10, CS had engaged in 156 hours of studying alone, 1,196 hours playing chess, and 2,417 hours playing in tournaments. Overall, at the age of 10, CS had engaged in a total of 3,769 hours of chess-related experience.
Figure 7. CS’s estimated weekly amount of time engaging in chess-related experience by age. “Total” indicates the overall chess-related experience.

Figure 8. CS’s estimated accumulated amount of time engaging in chess-related experience by age. “Total” indicates overall chess-related experience.

CS’s rating history and the percentiles as functions of her amount of chess-related experience are plotted in Figure 9. CS had engaged in approximately 156 hours of studying alone and engaged in a total of approximately 3,769 hours of chess experience when she defeated a grandmaster and achieved a rating that placed her in the 96th
percentile of the entire USCF population. Thus, CS’s engagement in chess-related experience was substantially less than 10,000 hours or 10 years of deliberate practice. These findings call into question the assertion that the primary source of individual differences in the development of expertise is deliberate practice.

![Figure 9. CS’s rating history and percentile as a function of the number of chess-related experience hours. The dashed circle indicates CS’s rating reached the 96th percentile in the entire USCF population.](image)

Although CS and McLaughlin acquired different types of skills, it is still informative to compare their skill acquisition rates. Figure 10 presents McLaughlin’s percentile as a function of the number of deliberate practice hours and CS’s percentile as a function of the number of studying alone hours and chess-related experience. As argued previously, if there is any deliberate practice involved in CS’s chess experience, it would be involved in the studying alone time. This figure illustrates that CS and McLaughlin had substantially different profiting rates from one hour of studying alone and one hour of deliberate practice, respectively. CS was able to reach the 80th percentile without engaging in any deliberate practice, compared to McLaughlin, who engaged in
approximately 3,000 hours of deliberate practice to reach the same percentile. To be 
conservative and account for all the chess-related experience, CS reached the 80th 
percentile after approximately 900 hours of chess-related experience. Similarly, to reach 
the 90th percentile, CS had studied chess alone for approximately 43 hours, or had 
engaged in approximately 2,198 hours of chess experience, while McLaughlin had 
engaged in approximately 4,664 hours of deliberate practice. After CS had studied chess 
alone for approximately 156 hours, or had 3,749 hours of chess experience, she was in 
the 96th percentile of the USCF population and defeated a grandmaster. McLaughlin was 
unable to reach the same percentile in the USGA even after he had engaged in 5,960 
hours of practice. Moreover, his best score never came anywhere near the level of the 
lower end performance of the golfing equivalent of a grandmaster. Two main conclusions 
can be drawn from these data. First, because CS beat a grandmaster 3 years and 7 months 
after she started seriously playing chess, her exceptional chess performance is not 
consistent with Ericsson’s 10-year rule. Second, CS’s number of hours of engaging in 
studying and playing chess and her total hours of engaging in domain-specific experience 
do not sufficient explain her exceptional performance in chess and how she became a 
master.
Figure 10. CS’s percentiles as a function of hours spent study alone and chess experience, and McLaughlin’s percentile as a function of hours of deliberate practice. This is graphically presented using a smoothing spline with lambda, $\lambda = 0.07$.

**CS’s Domain-Specific Abilities**

Two domain-specific tasks were used to measure and access CS’s and other chess players’ ($n = 77$) chess memory and chess knowledge. These chess players were all adults with a wide range of chess skills ($M = 1683$, $SD = 574$, Min = 381, Max = 2651). See Study 2 in this dissertation for detailed information on the recruitment and methods used by the adult chess players. In the chess memory task, the item reliability (Cronbach’s $\alpha$) of the six positions was 0.93. CS was able to reconstruct 81% of the positions of the pieces (see Figure 11). In the chess knowledge task, CS obtained 78% accuracy (see Figure 12). As Figure 11 and Figure 12 show, CS’s chess memory and chess knowledge scores were both higher than most other chess players, with only four chess players scoring higher than CS on the chess knowledge task. Both chess memory, $r(75) = .73, p < .001$, 95% CI [.60, .82], and chess knowledge, $r(75) = .67, p < .001$, 95% CI [.52, .78] highly correlated
with chess rating. In the chess knowledge task, CS missed 4 (question 9, 10, 12, and 13) questions out of 18. Question 9 was an obscure endgame question, question 10 was an obscure opening question, and question 13 was an outdated opening question (see Appendix A for these questions). CS got all the four strategic knowledge questions correct (Question 1, 2, 3, and 14), and also got all three imagery questions correct (Question 16, 17, and 18). The chess players’ accuracy on the chess knowledge test and its relations with hours spent studying alone and hours of chess experience are presented in Figure 13. As Figure 13 shows, the relationships among rating and number of hours studying alone, and the number of hours of chess experience were positive but small. Several players, including CS, were able to obtain high scores on chess knowledge task with minimal amount of time spent studying chess or engaging in chess-related experience. At the time of testing, CS had studied chess alone for only 156 hours. As Figure 12 and Figure 13 show, very few chess players who studied chess as little as CS had, or had as little chess experience as CS, performed as well in the chess knowledge test. It is unclear how CS and other the few chess players were able to obtain so much chess knowledge with their limited amount of studying time. The lack of relationship between either studying alone time or chess-related experience with chess knowledge was unexpected.
Figure 11. The scatterplot of CS and other chess players’ USCF ratings and their accuracy in chess memory task. CS’s data is indicated by a red triangle mark.

Figure 12. The scatterplot of CS and other chess players’ USCF ratings and their accuracy in chess knowledge task. CS’s data is indicated by a red triangle mark.
Figure 13. The scatterplots of CS and other chess players’ accuracy in chess knowledge and the number of hours studying alone and chess-related experience. CS’s data is indicated by a red triangle mark.

**CS’s Domain-General Cognitive Abilities**

The rank for each cognitive task that CS obtained out of the 35 subjects including CS are listed as follows: 1st in visual short-term memory, 3rd in backward visuo-spatial memory span, 4th in backward digit span, 6th in forward visuo-spatial memory span, 9th in approximate number system, 23rd in automated symmetry span, and 26th in forward digit span (see Table D-1 in Appendix D for details of the six cognitive abilities, except for visual short-term memory). Among these seven cognitive ability tasks, her performance in the visual short-term memory (VSTM) task was the highest (mean d-prime = 2.41) among all the other children ($M = 1.38$, $SD = 0.43$, Min = 0.27, Max = 2.10) (see Children Group 1 in Figure 14). A follow up study was conducted to investigate whether her exceptional performance in this task was a true effect because with so many tasks she could be the highest performer on one task due to chance.
Another 28 10-year-old children were recruited with the same criteria and the same method discussed in the method section. These children were recruited from different elementary schools from Houston in Texas. Thirteen of the children are boys and fifteen girls, with none of them having played chess. It took approximately 10 minutes to complete this task, and the children received a $5 gift card to compensate them for their time and effort. In this follow up study, CS’s performance in the VSTM task maintained the highest among all the children ($M = 1.06$, $SD = 0.55$, $\text{Min} = 0.08$, $\text{Max} = 2.06$) (see Children Group 2 in Figure 14). These two child studies suggested that CS had exceptional performance in her visual short-term memory when compared to other age-matched children. In Study 2 in this dissertation, 77 adult chess players with a wide range of USCF ratings ($M = 1683$, $SD = 574$, $\text{Min} = 381$, $\text{Max} = 2651$) were also recruited to perform the same task. CS’s performance in this task was at the rank of 4th among all the adult chess players (see Adult Chess Player in Figure 14). Overall, CS’s performance in the visual short-term memory task was very exceptional.
Figure 14: The performance of the three groups in the visual short-term memory test. The horizontal dashed line indicates CS’s performance.

The association between visual short-term memory and chess skill were examined by using two different analytic approaches with the data in Study 2. The first analysis examined the correlation between chess ratings and VSTM scores and found no evidence of a relationship, \( r(75) = .07, p = .55 \) (see Figure 15).
Since previous studies showed that chess-related experience is a strong predictor of chess skills, the second analysis concerned performing a multiple regression to assess whether the ratings are associated with VSTM, after controlling for the effect of the degree of chess-related experience. In this regression model, chess player’s rating was treated as a dependent variable, and VSTM and the total number of experience hours were treated as independent variables. A square root transformation was used for the number of experience hours to reduce the skewness of the original positively skewed distribution. There was a low and non-significant correlation between the square root of chess experience and visual short-term memory, $r(75) = -.18, p = .12$. Figure 16 shows the relation between chess rating and visual short-term memory after controlling for the
number of hours of chess experience (square root of experience). The results of the multiple regression showed that after controlling the number of experience hours, there is a weak but non-zero relationship between VSTM and rating (incremental $r^2 = .03$, $F(1, 74) = 4.26$, $p = .043$) (see Table D-2 in Appendix D for full model results). Even though this weak but non-zero relationship has been detected, no conclusions can be drawn from these data with respect to the causal relationship that may exist between visual short-term memory and chess abilities. This study leaves one unexplained puzzle: The correlation between VSTM and rating is weak.

![Figure 16. The relation plot between rating and visual short-term memory after both variables have been controlled by the square roots of the number of hours of experience.](image)

This case study is important for two reasons. First, CS is, to my knowledge, the first young high-achieving chess player to be investigated contemporaneously with thorough experiments and interviews. Second, previous studies found that chess prodigies reached master level in substantially less than 10 years, but provided little-to-no
information on the number of hours of deliberate practice or studying alone they had 
engaged in. This case study provides detailed quantitative estimates of this and also 
includes the number of hours of her chess-related experience.

**Can Cognitive Ability Explain CS’s Chess Skill?**

CS’s performance on the seven cognitive ability tasks were all well above 
average, and among these tasks, her performance in the visual short-term memory task 
was exceptional. In the visual short-term memory task, CS performed better than all of 
the 62 age-matched children and better than all but three of the 77 adult chess players. In 
Ruthsatz & Detterman’s (2003) case study of a musical prodigy, Derek, they also found 
that the most striking cognitive ability that Derek possessed is his extraordinary short-
term memory. This present study also found that CS has an exceptional visual short-term 
memory performance. However, due to the weak relationship between VSTM and chess 
skill in the study of chess players, this extraordinary performance may not be directly 
associated with her chess skills. It is possible that there are other cognitive abilities that 
mediate between her visual short-term memory and her chess skills.

**Can Study Alone and/or Other Chess Experience Explain CS’s Chess Skill?**

Ericsson (2007) claimed that “in well-established domains of expertise even the 
most ‘talented’ cannot reach an international level in less than around a decade of 
experience and intense preparation” (p. 14). However, CS defeated a grandmaster after 
she had been seriously playing chess for only 3 years and 7 months. CS had studied chess 
alone for approximately 156 hours, or had had 3,749 hours of chess experience. The 
amount of time she spent on deliberate practice was less than these reported numbers and 
it is unclear whether any of her chess-related experience would meet Ericsson’s definition
of deliberate practice. The little time she spent studying alone, along with her exceptional achievement in chess is particularly difficult to reconcile with Ericsson’s 10-year/10,000-hour practice rule. It is informative to compare CS’s performance with McLaughlin’s golf performance even though they were conducted in different domains. CS and McLaughlin’s skill acquisition rates differ significantly. These results contradict the argument that pure deliberate practice is sufficient to explain the individual differences in skill acquisition.

A limitation of this study is that it relied on self-report measures of the amount of time spent studying chess alone and playing chess with opponents. However, self-reporting is a standard method used to measure the amount of time spent on deliberate practice (e.g., Ericsson et al., 1993; Charness et al. 1996; Charness et al. 2005, Gobet & Campitelli, 2007). Even though Charness et al.’s (2005) survey has been adopted in this study, and has been used frequently in the study of chess expertise, it is always possible that these types of retrospective self-reports are inaccurate. However, as this experiment was conducted when CS had only been playing chess seriously for 3 years and 7 months, her retrospective estimates may be more accurate than others.
Study 2

In the previous section of this dissertation, I reviewed the literature and discussed the disagreements about the relative importance of various sources of individual differences in the development of expertise. I also reviewed the definitions and measures of deliberate practice that Ericsson et al. (1993), Charness et al., (1996; 2005) and other researchers (e.g., Gobet & Campitelli, 2007; Howard, 2012) have used in their research of chess expertise. In addition, I presented a case study as evidence that there is more to expertise than deliberate practice, and called into question the claim of the primacy of deliberate practice. In this study, I first discuss and review a debate concerning whether deliberate practice itself is sufficient to explain the individual differences in the skill acquisition. Next, I present a study of adult chess players which sought to identify other factors that affect individual differences in chess skill.

A widely cited and influential source of evidence for the primacy of deliberate practice is the study of violinists and pianists conducted by Ericsson et al. (1993). In this study of violinists, the authors studied violinists who had achieved three different levels of accomplishment: “best students,” “good students,” and “future teachers.” The students considered the “best students” to be students judged exceptional musicians with the potential for careers as international soloists. The “good students” were good musicians but not as outstanding as the “best students,” with the “future teachers” considered the least exceptional. The authors interviewed and compared estimates of the amount of time the violinists in these three groups devoted to practice. They estimated the amount of deliberate practice the participants had engaged in by asking them to report the number of hours per week they had practiced alone. They found that the mean time the “best
students” practiced alone was approximately 10,000 hours whereas for the good students the mean was approximately 8,000 hours and for the future teachers it was about 5,000 hours. In a similar study, these authors investigated pianists who had achieved two levels of accomplishment: “expert” and “amateur.” The amount of deliberate practice that they had engaged in was assessed using the same method as in the study of violinists: asking subjects to report the number of hours they had practiced alone. The mean time for the “experts” was approximately 10,000 hours whereas the mean time for the amateurs was approximately 2,000 hours. These results were the basis of the authors’ conclusion that the key activity in the acquisition of expertise is deliberate practice. To emphasize the primacy of deliberate practice, Ericsson et al. (1993) claimed that “individual differences in ultimate performance can largely be accounted for by differential amounts of past and current levels of practice” (p. 392), and denied the role that natural abilities played in the skill acquisition with the following strong statement:

We agree that expert performance is qualitatively different from normal performance and even that expert performers have characteristics and abilities that are qualitatively different from or at least outside the range of those of normal adults. However, we deny that these differences are immutable, that is, due to innate talent. Only a few exceptions, most notably height, are genetically prescribed (p. 400).

In spite of many critiques (e.g., Anderson, 2000; Detterman, Gabriel, & Ruthsatz, 1998; Gardner, 1998; Schneider, 1998; Winner, 2000), Ericsson maintained that “individual differences in genetically determined capacities and fixed structures required for the development of elite performance appear to be quite limited, perhaps even
restricted, to a small number of physical characteristics, such as height and body size” (Ericsson, Nandagopal, & Roring, 2005, p. 305). Ericsson also claimed that no other factors contribute to the development of expertise in the following statement: “New research shows that outstanding performance is the product of years of deliberate practice and coaching, not of any innate talent or skill” (Ericsson, Prietula, & Cokely, 2007, p. 1).

However, Ericsson (2014b) later stated that “I have never claimed that deliberate practice can explain all reliable variance in attained performance (see, Ericsson, 2014b; 2014c, for an extended discussion). On the contrary I have acknowledged for decades that height and body size (Ericsson, 1998) cannot be changed by training, yet influence the attainment of elite performance in some domains of expertise” (p. 5-6). Although it is true that Ericsson had never claimed that deliberate practice can explain “all” reliable variance in attained performance, he did deny other potential factors that might account for the individual differences in skill acquisition. The only factors he hypothesizes might have an effect on skill acquisition are the small number of physical characteristics in some particular domains. These factors do not appear to be present in the domain of chess.

As discussed previously in the study of CS, Ericsson and his colleagues’ (1993) findings and conclusions have been widely cited in popular literature, scholarly peer-reviewed literature, books, and textbooks, as well as being widely reported in newspapers and public media. In general, the idea of 10,000-hour rule has been widely accepted. However, this debate about the primacy source of individual differences in the skill development has never been settled and resolved in scientific literature, and this debate has become increasingly heated in the most recent decade. These criticisms have been
discussed in two different contexts: conceptual and empirical (e.g., Hambrick, Macnamara, Campitelli, Ullen, & Mosing, 2016; Hambrick, Oswald, Altmann, Meinz, Gobet, & Campitelli, 2014; Winner, 2000).

From the perspective of the conceptual context, Marcus (2012) criticized the statements made by Ericsson et al. (2007) by stating that “The psychologist Anders Ericsson went so far as to write, ‘New research shows that outstanding performance is the product of years of deliberate practice and coaching, not of any innate talent or skill.’” He argued that “practice does indeed matter- a lot- and in surprising ways. But it would be a logical error to infer from the importance of practice that talent is somehow irrelevant, as if the two were in mutual opposition” (p. 97). Moreover, Gagne (2007) sharply criticized that Ericsson “readily rejects information, especially of a retrospective nature, when it contradicts his positions, but as readily accepts it when it supports his thesis (e.g., Bloom’s retrospective interviews)” (p. 67). He argued that Ericsson created straw men to attack by stating that the “text accumulates ‘evidence’ that is in fact irrelevant to the core question, for instance a long description of the necessary role of deliberate practice (DP), a role no IT [innate talent] defender denies” (p. 67).

From an empirical perspective, researchers have criticized the lack of statistical information Ericsson et al. (1993) provided (e.g., Gagne, 2007; Tucker & Collins, 2012). For instance, the groups of “best violinists” and “good violinists” in Ericsson et al.’s (1993) study were nominated by professors. Another group of “music teachers” was recruited from a different department in the academy, which had lower admission standards. Although the authors confirmed the skill differences among these three groups by analyzing the mean number of successful entries in violin competition, they did not
provide the standard deviations and ranges of their skills. Secondly, Ericsson et al. (1993) analyzed the mean difference on the cumulative hours of deliberate practice between the groups of the “best” students and the “good” students, but did not provide the standard deviations or range of their practice hours. Without standard deviations or ranges, it is unknown whether the association between practice hours and performance was consistent across every individual violinist. Finally, Ericsson presented no measures of the percentage of variance explained by practice hours, and there was not sufficient data provided to allow other researchers to examine the explanatory power of deliberate practice.

Hambrick, Oswald, Altmann, Meinz, Gobet, and Campitelli (2014) re-analyzed studies of expertise in the domains of music and chess to examine the extent to which deliberate practice can account for individual skill level differences. Re-analyzing six chess studies and eight music studies, they found that the mean proportions of reliable variance explained by deliberate practice in chess and music were 34% and 30% respectively. These leaves about 65% of the variance unexplained and presumably due to other factors. Platz, Kopiez, Lehmann, and Wolf (2014) presented a meta-analysis of 13 studies in the domain of music and found that the correlation between deliberate practice time and musical skills was .61, indicating that deliberate practice explains 36% of the variance. Platz et al. (2014) argued that it would be a problematic interpretation of their findings with $r^2$ value, because “relationship between variables should be interpreted in terms of linear relationship” (p. 10). However, statistically, their results showed that the variance that can be explained by deliberate practice is 36% (see reply by Hambrick, Altmann et al., 2014a).
Ericsson (2014) criticized Hambrick, Oswald et al.’s (2014) study on several grounds. One of Ericsson key criticisms is that Hambrick, Oswald et al.’s (2014) “analysis ignores the effects of forgetting, injuries, and accidents, along with the differential effects of different types of practice at different ages and levels of expert performance” (p. 84). However, Hambrick, Altmann et al. (2014b) replied that the factors they considered were the same as those in the original study conducted by Ericsson et al. (1993) in which skill level in music was predicted by self-reports of the time spent practicing alone. Moreover, Hambrick, Altmann et al. (2014b) pointed out that their re-analyses including the study conducted by Charness et al. (2005) that Ericsson cited as evidence to support his viewpoint.

A more comprehensive meta-analysis of all available studies relating to deliberate practice and expertise was conducted by Macnamara, Hambrick, and Oswald (2014). In this meta-analysis, Macnamara et al. (2014) analyzed a total of 88 studies across the major domains of expertise, including games, music, sports, education and professions. Macnamara et al. (2014) categorized the studies into three groups based on the method used to measure deliberate practice time: retrospective questionnaires, retrospective interviews, and logs. Studies that used retrospective questionnaires or retrospective interviews required their participants to estimate deliberate practice time. Studies that used logs required their participants to record their engagement of deliberate practice either by using a diary or a computer on an ongoing basis. Presumably, the log method provides a more precise estimate of deliberate practice time (Tuffiash, Roring, & Ericsson, 2007). Macnamara et al (2014) found that the variance explained by deliberate practice was 20% for the studies using retrospective interview, 12% for studies using a
retrospective questionnaire, and only 5% for studies using logs. It suggests that the variance explained by deliberate practice is less than the variance presented by Hambrick, Oswald et al. (2014). Since the log method explained the lowest percentage of variance, it is possible that variance explained by deliberate practice is lower than previously estimated.

These results again call into question Ericsson’s assertion of the primacy of deliberate practice. However, Ericsson (2014b; 2014c) argues that only Ericsson et al.’s (1993) study of pianists out of the 88 studies (or one from 157 effect sizes) included in Macnamara et al.’s (2014) meta-analysis both met his criteria for accurately estimating deliberate practice time and did not restrict the range of performance. However, since Ericsson (2014c, p. 4) clearly stated that practice time not involving teachers or coaches does not meet his deliberate practice criteria, and Ericsson et al.’s (1993) study of pianists measured the amount of deliberate practice by measuring how many hours that pianists had practiced alone, it is unclear why Ericsson (2014c) claimed that this study met his deliberate practice criteria.

Ericsson (2014b; 2014c) argued that some other studies such as Macnamara et al. (2014) included in the meta-analysis do not meet his deliberate practice criteria. However, Ericsson previously credited their methods and used their findings as evidence to support his viewpoint of deliberate practice. For example, among these studies, one study in particular was conducted in the domain of chess (Charness et al., 2005). According to Ericsson’s (2014b; 2014c) criteria, Charness et al.’s (2005) study did not meet the criterion of deliberate practice because it measured the amount of time that chess players had studied alone. However, as discussed previously, Ericsson used the
same methods to measure the amount of deliberate practice. He also credited Charness et al.’s (2005) study by stating that it “reports the most compelling and detailed evidence for how designed training (deliberate practice) is the crucial factor in developing expert chess performance” (Ericsson, 2005, p. 237). Moreover, Ericsson has frequently used Charness et al.’s (2005) results to support the primacy of deliberate practice (e.g., Ericsson, Nandagopal, & Roring, 2009, p. 205).

Several studies have investigated the relationship between deliberate practice and skill acquisition in chess domain. In the following section, I review these studies individually.

Charness, Krampe, and Mayr (1996) collected data on the following eight variables on 110 chess players: current age, age when starting to learn chess, age when first played chess seriously, age when first joined a chess club, coaching experience (yes or no), number of hours spent studying or practicing with other players (group practice), number of hours spent studying chess alone (individual practice/study alone), and number of chess books owned. A regression model in which chess rating was regressed on these, and found that these eight variables together accounted for 55% of the variance in chess skills with study alone time ($\beta = 0.56$) and number of books ($\beta = 0.29$) the only two significant predictors. The variable of “time studying alone” accounted for 36% of variance. Using Spearman’s (1904) equation to correct for unreliability of measures with reliability estimates of .8 for deliberate practice and .91 for chess rating, as used by Hambrick, Oswald et al. (2014), the variance explained by time studying alone increased to 50%.
In 2005, Charness and his colleagues used a set of predictors focusing on the relationship between deliberate practice (study alone) and chess skill. They measured the total number of hours that players had seriously studied chess and played in tournaments, the number of years of private instruction and group instruction, and the current hours/week spent seriously studying chess and playing in tournaments. These variables explained 34% of the variance in a sample of 375 players. The correlations between chess rating and the amount of time spent studying alone were .54 and .48 in two subsamples. After correcting for unreliability, the correlations between current skill rating and studying alone were .63 and .56 in samples 1 and 2, respectively. The variance in chess skills explained by deliberate practice (study alone) were therefore 40% and 32%.

Gobet and Campitelli (2007) used Charness et al.’s (1996) method to study 90 chess players, and found that the correlation between cumulative hours of study alone and skill level was .42 (explaining 18% of variance). After correcting for unreliability, the variance explained by individual practice (study alone) was 24%. Importantly both Gobet and Campitelli (2007) and Campitelli and Gobet (2011) found that there was great variability in the amount of practice the players had engaged in before becoming masters. For example, one player required 16,000 hours of individual practice (or study alone), whereas another player required only 728 hours. Similarly, one player required 14,200 hours of group practice, whereas another player required only 1,600 hours. Moreover, Gobet and Campitelli (2007) found that one player was able to become a master with a total of only 3,000 hours of practice which included both individual and group practice. It took another chess player 23,600 hours of practice to reach the same chess level. This variability among chess players strongly supports the proposition that “domain-specific
practice is necessary but not sufficient to acquire master level” (Gobet & Campitelli, 2007, p. 168).

Howard (2012) measured the following seven variables from 533 chess players: age, age when started to study chess seriously, age when started to learn chess, formal coaching experience (yes or no), number of study hours, number of games they played, and number of study hour in the past year. In a regression model, chess rating was regressed on these seven variables which together accounting for 49% of the variance. The number of games, number of study hours, and age beginning serious practice were the only three significant predictors. Number of games was the strongest predictors in the model and correlated .33 with chess rating. After correcting for unreliability, this correlation is .39.

The studies above investigated the importance of study alone or playing chess in acquiring chess skills. There is one potentially important but relatively neglected factor that determines chess skill: chess knowledge. Pfau and Murphy (1988) measured chess players’ chess knowledge, positional judgments, and tactical skills, and they found that chess knowledge was not only significantly related to rating, but also related to positional judgment and tactical skills. Thus, Pfau and Murphy (1988) claimed that chess knowledge is a determinant rather than a byproduct of chess skill.

In summary, a number of studies support the proposition that chess-related experience (studying alone and playing chess) are important but not sufficient to explain the individual difference in skill. This current study adopted the same methods used in the case study of CS to measure adult chess players’ domain-general cognitive abilities, chess memory, chess knowledge, and Charness et al.’s (2005) simplified survey version.
However, CS’s data are not included in this study. In addition to assessing the proportion of variance explained by chess experience, an aim of this study was to identify factors other than chess-related experience that can explain the individual differences in chess abilities.
Method

Participants

A total of 79 chess players were recruited from different chess clubs and chess tournaments from Dallas, Fort Worth, College Station, Beaumont, Galveston, Houston and surrounding areas, in Texas and Taipei City in Taiwan. Two participants were excluded from the final analysis. The first excluded participant did not perform two cognitive tasks and the chess knowledge task. The second excluded participant did not fill out the survey regarding the estimates for the amount of studying alone and playing chess hours. The final sample of 77 chess players consisted of 67 males and 10 females, with a mean age of 35 years and an age range of 18 years to 77 years. Figure 17 presents a histogram of the chess players’ USCF ratings. Figure 17 shows that the chess players had a wide range of chess skills ($M = 1683$, $SD = 574$, $Min = 381$, $Max = 2651$), including several players at grandmaster level.

![Histogram of chess players’ USCF ratings.](image)

Figure 17. Histogram of chess players’ USCF ratings.
Procedure

To be eligible to participate in this study, the chess players had to be at least 18 years old and have a United States Chess Federation (USCF) rating. This study was approved by the institutional review board at Rice University. Two methods were used to recruit participants: First, they were recruited via flyers handed out in local chess clubs and chess tournaments. Second, they were recruited via an invitation email distributed to all members of local chess clubs and to all members of the chess program at the University of Texas – Dallas. Contact information was included in the flyer and email, and interested participants were asked to contact the researcher for detailed information.

Data collection was held at Rice University, University of Texas - Dallas, the participants’ home, or local shops. On the data collection day, participants were first asked to review and sign a consent form that provided them with study information, including the experimental procedures, risks, benefits, and confidentiality procedures. By the end of session, the participants received $20 to compensate them for their time and effort. The time spent completing the experiment was approximately 120 minutes.

Materials

**Cognitive abilities tasks.** A total of seven cognitive tasks were used. All the participants performed the tasks in the same order: forward digit span, backward digit span, approximate number system, visuo-spatial forward span, visuo-spatial backward span, automated symmetry span, and visual short-term memory. Detailed information about these tasks has been described in the case study of CS.

In order to avoid the problem of multiple testing and the associated increase in the Type I error rate or the low power associated with correcting for multiple tests, I planned
*a priori* to do a principal component analysis to reduce the number of variables. The number of factors retained was determined based on the percent of variance explained by each component and, as will be seen, ended up being one.

**Chess knowledge task.** van der Maas and Wagenmakers' (2005) Verbal Knowledge Test from the Amsterdam Chess Test (ACT), which was adapted in part from Pfau and Murphy (1988), was used to investigate the chess players’ chess knowledge. The questions in this task were categorized into two different perspectives of chess-specific knowledge: crystallized and fluid intelligence. Fifteen questions were used to measure the participants’ chess-specific crystallized intelligence. An example item for chess-specific crystallized intelligence is “in the middle game a passed center-pawn should be blocked by _____.” Three questions were used to measure the participants’ chess-specific fluid intelligence, which referred to the chess players’ mental imagery or capacity to visualize chess moves. An example item for chess-specific fluid intelligence is “How many moves do you need at least to play the knight f6 to a1?” Detailed information about this task has been described in the case study of CS, with the complete chess knowledge task reproduced in Appendix A.

**Chess memory task.** The participants’ ability to reconstruct positions was measured by administering the Memory Test from van der Maas and Wagenmakers’ (2005) ACT. Detailed information about this task has also been described in the case study of CS, with the six positions reproduced in Appendix B.

**Chess-related background survey.** The participants were asked to fill out a simplified version of a survey adopted from Charness et al. (2005). This survey collected participants’ (1) demographics; (2) chess-related developmental milestones; (3) general
chess belief; and (4) cumulative and current chess activities. This survey collected two important variables: (1) the amount of time spent seriously analyzing positions alone (e.g., using chess books, magazines, databases) and (2) the amount of time spent seriously playing chess with opponents. The participants were asked to estimate the hours in a typical week they had spent studying alone and playing chess with opponents at a given age. The cumulative times study alone and playing chess with opponents were calculated by multiplying the weekly estimated average number of hours by the number of weeks in a year, and adding the yearly estimates at and below that age. If the distribution of studying alone or playing chess with opponents was positively skewed, log transformation will be applied, which is the method used frequently in previous studies (e.g., Charness et al., 2005; Gobet & Compitelli, 2007; Howard, 2012). The complete survey is reproduced in Appendix C.

**Number of hours played in tournaments.** Chess players’ number of games played in FIDE and USCF were obtained from each official website: https://www.fide.com/ and http://www.uschess.org/.

The aims of this study were to test both Chase and Simon’s (1973) recognition action theory and Ericsson et al.’s (1993) theory of deliberate practice as well to find factors in addition to deliberate practice that contribute to the individual differences in chess skill. According to recognition-action theory, chess expertise is due primarily to the ability to recognize familiar patterns of pieces, and practice allows players to build up the patterns of chess positions required for the recognition-action mechanism. Chase and Simon (1973) explained the recognition-action mechanism by stating that “each familiar pattern serves as the condition part of a production. When this condition is satisfied by
recognition of the pattern, the resulting action is to evoke a move associated with this pattern and to bring the move into short-term memory for consideration” (p. 269). That is, when a chess position is recognized by a player, they group several chess pieces corresponding to chunks stored in the long-term memory. These chunks are associated with plausible moves so that the players can often immediately “see” the best move. Therefore, Simon and Chase (1973) claimed that after at least 10,000 to 50,000 hours of practice, chess players were able to reach a master level because they had stored those thousands of familiar patterns (or chunks) in their long-term memory. Twenty years later, Ericsson et al. (1993) similarly emphasized the importance of practice in acquiring skills and claimed that no other factors have more than trivial effects.

In this present study, three views of the sources of individual difference in chess skills were tested. The first viewpoint is Ericsson’s deliberate practice, which claims that there are no factors other than deliberate practice that have more than trivial effects on chess skill. As discussed previously, the amount of deliberate practice has typically been measured by asking players to report the amount of time they have studied alone, with deliberate practice a subset of studying alone time. Therefore, according to this viewpoint, the only variable that explains chess skills is the amount of time players have studied alone. The second viewpoint emphasizes the importance of chess-related experience. According to this viewpoint, the amount of chess-related experience is the primary source of the individual differences in chess skill, which includes the amount of time chess players spend studying alone, playing chess with opponents and playing chess in tournaments. That is, these three chess-related experiences together account for essentially all of the individual differences in chess skill, and therefore no other factors
have more than trivial effects. The third viewpoint emphasizes that deliberate practice and other chess related experience are not sufficient to explain all individual differences in chess skill. Other factors may include cognitive ability (domain-general fluid intelligence), chess-specific crystallized intelligence, and chess-specific fluid intelligence.

**Planned Analyses**

First, given that cognitive ability and chess experience may interact, a test was planned to assess the existence of an interaction between cognitive ability and chess-related experience to chess skill, and then decide whether interaction terms would be included in the final model. The next step was to assess the degree to which the assumption normality of residuals in the multiple regression model was violated.

The plan was to use a hierarchical multiple regression to test the predictions of the three views of individual differences in chess skill: deliberate practice, chess experience, and natural ability with previous chess experience. In addition, a commonality analysis was planned for use to determine the distinct contributions of variance from possible confounded variables. For example, if two variables (i.e., A and B) were used to predict variable Y, and A and B are confounded, the variance explained for these two predictors could be distinguished into three groups: unique variance of A ($U_A$), unique variance of B ($U_B$), and common variance between A and B ($C_{AB}$). In a hierarchical regression analysis, if A is entered into the model first, it accounts for both the variances associated with A ($U_A$ and $C_{AB}$) in Y. The second entered variable B only accounts for the unique variance of B ($U_B$) in Y. Therefore, if there is no theoretical basis for assuming that common variance should be attributed to one of variables rather than other, I planned to use the commonality analysis to estimate the unique and common variances that contribute to the
model and to report the minimal and maximal variances of the variables that can be attributed to the model. For example, the minimal variance that A can attribute to Y is the unique variance of A, and the maximal variance that A can attribute to Y is the sum of unique variance of A and common variance between A and B.

The theoretical predictions based on each point of view are summarized in Table 1. According to the deliberate practice view, no factors other than deliberate practice should contribute non-trivially to the variance in chess skills. Again, deliberate practice was measured by studying alone in this present study. Therefore, study alone should account for essentially all of the individual differences in chess skills and, therefore, the incremental variance ($\Delta R^2$) of studying alone in chess skills should be positive and the incremental variances of other factors should equal to zero or close to zero (see the “Deliberate Practice” column in Table 1). Playing chess with opponents and playing chess in tournaments were assessed and measured with different methods, despite these two activities being similar and associated in some way. Therefore, these two chess playing activities were grouped into one major category called “playing chess.” The incremental variance of playing chess is the sum of the incremental variances of these two chess playing activities, which provided the maximum variance for these types of activities. Study alone and two chess playing variables have shared variances and there is no theoretical basis for assuming that shared variance should be attributed to one of variables rather than the others. Therefore, the minimum and maximum incremental variances of these variables were also predicted and presented in Table 1. The Venn diagram in Figure 18 illustrates the unique and common variances among these three chess-related experience variables. The minimum incremental variance of study alone is
the unique variance of study alone (area “a” in Figure 18), and the maximum incremental
variance is the sum of unique variance of study alone and its common variances shared
with other variables (areas of “a” + “d” + “g” + “e” in Figure 18). According to
Ericsson’s deliberate practice, the minimum and maximum incremental variance of
deliberate practice (or study alone) are predicted to be positive. Since playing chess does
not meet Ericsson’s criteria for deliberate practice, deliberate practice theory does not
predict a positive incremental variance for this variable. Therefore, the incremental
variance of all chess experience is predicted by deliberate practice theory to have the
same incremental variance as study alone.

The next prediction was based on the viewpoint that both natural ability and chess
experience are important. In the present study, the potential factors to be considered were
domain-specific experience, domain-general cognitive ability (fluid intelligence), chess-
specific fluid intelligence, and chess-specific crystallized intelligence. Since the sequence
of entry in a sequential multiple regression matters, the justification for the sequence is
presented as follows: First, the purpose of this study is to investigate whether there are
other factors in addition to chess experience that contribute to chess skill. Thus, the first
group of variables to be entered consists of the three chess experience components: study
alone, playing chess with opponents, and playing chess in tournaments. This means that if
there are any common variances between chess experience and other factors, the common
variance will be attributed to chess experience. As a result, variance explained by other
factors will be estimated conservatively because some of the confounded (common)
variance may not attributable to experience. The next variable to enter the model is
domain-general fluid intelligence. The number of variables to enter the model was
planned to be determined by the results of the principal components of the seven cognitive abilities, which turned out to be just one. This domain-general fluid intelligence variable was entered before chess-specific fluid intelligence and chess-specific crystallized intelligence because domain-general fluid intelligence was viewed as influencing the other two variables. That is, a player with higher domain-general fluid intelligence may be able to acquire more chess knowledge, but chess knowledge is assumed not to be a causal factor in domain-general fluid intelligence. The next variable to enter the model is chess-specific fluid intelligence, which was assessed by using each chess player’s capacity to visualize chess moves in three questions in the chess knowledge task. This variable was entered before chess-specific crystallized intelligence because fluid intelligence (domain general or chess-related) was viewed as influencing crystallized knowledge. As suggested by Pfau and Murphy (1988), chess knowledge is important to chess skills, but it has been somehow neglected in much of the empirical literature in this field. Therefore, the last variable to enter the model was chess-specific crystallized intelligence, which was assessed and measured by 15 questions in the chess knowledge task.

Figure 18. The illustration of the unique and common variance components among three chess experience variables.
Table 1. The predictions of the incremental variances of several potential relevant variables for the perspective of deliberate practice and chess experience.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Deliberate Practice</th>
<th>Chess Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta R^2$</td>
<td>Min</td>
</tr>
<tr>
<td>Study Alone</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Playing Chess</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>Total Chess Experience</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Domain-General Fluid Intelligence</td>
<td>~0</td>
<td></td>
</tr>
<tr>
<td>Chess-Specific Fluid Intelligence</td>
<td>~0</td>
<td></td>
</tr>
<tr>
<td>Chess-Specific Crystallized Intelligence</td>
<td>~0</td>
<td></td>
</tr>
</tbody>
</table>
Results and Discussion

Defining and Preprocessing Variables

Data for the following variables were defined and examined carefully to ensure the quality of the data prior to further statistical analyses. The analyses were conducted using both raw data and the data after correcting for unreliability (Cohen & Cohen, 1983). The corrected data were analyzed for two reasons: First, it is not possible to accurately test the magnitude of a correlation between two variables without controlling for the potential distorting effect of measurement error variance (see Schmidt & Hunter, 1999, for an excellent review). Second, the analysis based on corrected data avoids potential inaccurate estimation in a multiple regression due to the predictors differing in their reliability.

Chess rating. Chess rating is the dependent variable in the analysis. Regarding the measurement of chess players’ skills, many previous studies used the self-reported current chess rating that might be from different tournament organizations. In this study, all of the participants had a USCF rating, and their current ratings were all obtained from USCF’s website to avoid potential inaccuracies caused by misremembering or due to the rating being from a different organization. The reliability coefficient used for the chess rating was .91, following Hambrick, Oswald et al. (2014).

Study alone. As described previously in the method section, study alone was measured by using a retrospective self-reported estimate of the hours in a typical week a subject had studied alone at a given age. The total cumulative study alone time was calculated by multiplying the weekly estimated average number of hours by the number of weeks in a year, and adding the yearly estimates at and below that age. The distribution of the number of study alone hours was extremely skewed, and one player
had a value of 0. A log(x+1) transformation was used to reduce the skew; (x+1) was used rather than (x) to avoid the problem associated with the log of zero being undefined. This new variable is named “Log Study Alone.” The reliability coefficient used for the self-reported study alone time was .80, following Hambrick, Oswald et al. (2014).

**Playing chess with opponents.** Playing chess with opponents was assessed and measured by using retrospective self-reported estimate of the hours in a typical week they had seriously played with opponents at a given age. The total cumulative playing chess with opponents was calculated by multiplying the weekly estimated average number of hours by the number of weeks in a year, and adding the yearly estimates at and below that age. The distribution of the number of hours playing chess with opponents was also extremely skewed, and one player had no value. Thus, a log(x+1) transformation was used to reduce skew and (x+1) was used rather than (x) to avoid the problem associated with the log of zero being undefined. This new variable is named “Log Playing Opponents.” Since playing chess with opponents was also assessed by using self-report as the measure of study alone, it was estimated to have a reliability of .8.

**Playing in tournaments.** Playing in tournaments was measured by using the number of tournament games that the chess players have played historically. The total number of games is the sum of the number of games played in USCF tournaments and the number of games played in FIDE tournaments. Because the original distribution of this variable was extremely skewed, a log transformation was used to reduce the skew. This new variable is named “Log Tournaments.” Since the number of games played in tournaments was directly obtained from the records of chess official websites, the reliability of this measure was assumed to be 1.
Cognitive ability or domain-general intelligence. Principal component analysis was used to reduce the number of seven cognitive ability variables and to avoid the possibility of type I errors. Table 2 shows the percentages of variance for the first three principal components. The first principal component was chosen for further analysis (see Figure 19) and accounted for 53% of the total variance among the seven cognitive abilities. Table 3 presents the loadings of the seven cognitive abilities on the first principal component. This principal component variable is called “PC cognitive ability” and it is used to represent the general-domain fluid intelligence in this study. Since PC cognitive ability was computed by using the principal component of the seven cognitive abilities, it was assumed to have high reliability and assigned a coefficient of 0.9.

Table 2.
The percent of variance for the first three principal components.

<table>
<thead>
<tr>
<th>Principal Component Number</th>
<th>Percent of Variances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52.75</td>
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<tr>
<td>2</td>
<td>13.34</td>
</tr>
<tr>
<td>3</td>
<td>9.86</td>
</tr>
</tbody>
</table>

Figure 19. The scree plot of the principal component analysis for the cognitive ability data.
Table 3.
Loading values of the seven cognitive abilities in the first principal component.

<table>
<thead>
<tr>
<th></th>
<th>First Principal Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digit Span Forward</td>
<td>.66</td>
</tr>
<tr>
<td>Digit Span Backward</td>
<td>.77</td>
</tr>
<tr>
<td>Approximate N. System</td>
<td>.70</td>
</tr>
<tr>
<td>Block Tapping Forward</td>
<td>.72</td>
</tr>
<tr>
<td>Block Tapping Backward</td>
<td>.75</td>
</tr>
<tr>
<td>Auto Symmetry Span</td>
<td>.81</td>
</tr>
<tr>
<td>Visual STM</td>
<td>.67</td>
</tr>
</tbody>
</table>

Chess-Specific Fluid Intelligence and Crystallized Intelligence. The item

reliability (Cronbach’s α) for the three chess fluid knowledge questions was .45, and the

item reliability for the fifteen chess crystallized knowledge questions was .72.

Table 4 presents a descriptive correlation matrix for all these variables, including

chess rating, seven cognitive abilities, PC cognitive ability, chess-specific memory,

chess-specific fluid intelligence, chess-specific crystallized intelligence, Log study alone,

Log playing with opponents, and Log playing in tournaments.
Table 4.
Descriptive correlation matrix for all the variables.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
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<td>.65</td>
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<td>.39</td>
<td>.65</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<td>-.08</td>
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<td>.32</td>
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<td>.49</td>
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<td>.07</td>
<td>.09</td>
<td>.28</td>
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<tr>
<td>6. Block Tapping Backward</td>
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<td>-.03</td>
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<td>-.07</td>
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<td>10. Chess Memory</td>
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<td>.67</td>
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<td>.59</td>
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<tr>
<td>12. Chess-Specific Crystallized Intelligence</td>
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<td>.30</td>
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<td>.28</td>
<td>.29</td>
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<td>.53</td>
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</tr>
<tr>
<td>13. Log Study Alone</td>
<td>.55</td>
<td>-.15</td>
<td>.03</td>
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<td>.07</td>
<td>-.03</td>
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<td>.43</td>
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<tr>
<td>14. Log Playing with Opponents</td>
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<td>.07</td>
<td>-.02</td>
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<td>-.13</td>
<td>-.03</td>
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<td>15. Log N. of Tournaments</td>
<td>.65</td>
<td>-.08</td>
<td>.04</td>
<td>.03</td>
<td>.28</td>
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<td>.44</td>
<td>.53</td>
<td>.43</td>
<td>.35</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. The approximate number system was rescaled to be positive. The higher scores represent better scores. 

$r < .37, p < .001; r < .29, p < .01; r < .22, p < .05$
Test of Recognition-Action Theory and Claim of Deliberate Practice.

In order to test whether deliberate practice, which was part of studying alone, was the only factor explaining individual difference in attaining chess skills, and to further investigate whether other factors may play a role in chess skill acquisition, a series of analyses were performed.

Before proceeding to test the three views of the sources of individual difference in chess skills, two analyses were performed to assess the appropriateness of the model. The first was to test whether cognitive ability and chess-related experience interacted. Two types of model were generated: completed and reduced. The reduced model consists of one dependent variable (chess rating) and six main effect predictors: Log study alone, Log playing opponents, Log tournaments, PC cognitive ability, chess-specific fluid intelligence, and chess-specific crystallized intelligence. Separate tests of the Log study alone x PC cognitive ability, Log playing opponents x PC cognitive ability, and Log tournaments x PC cognitive ability interactions were tested in terms of the incremental variance added by the interaction. All probability values were tested using a Bonferroni-corrected alpha level of .017. None of the three interactions were significant with the $p$ values for the Log study alone x PC cognitive ability, Log playing opponents x PC cognitive ability, and Log tournaments x PC cognitive ability interactions being .08, .997, and .39, respectively. Although there was a slight hint of a Log study alone x PC cognitive ability interaction, these results are generally consistent with Hambrick and Oswald’s (2005) conclusion that the relationship between domain-general fluid intelligence and amount of time spent on chess-related experience is additive.
The six predictors were used in a multiple regression analysis. As Figure 20 shows, the distribution of the residuals for this regression model does not show great non-normality. Moreover, Lumley, Diehr, Emerson, and Chen (2002) conclude that a multiple regression is robust when the residuals are positively skewed.

Figure 20. The distribution of the residuals in the multiple regression.

Further analyses were conducted for both the actual data and the data after correcting for unreliability (measurement error). Spearman’s (1904) disattenuation formula (Equation 3) was used to adjust for measurement error (unreliability) from a correlation coefficient (Hunter & Schmidt, 1990). In Equation 3, \( r_{xy} \) represents the true correlation between two measures, \( r_{xy} \) represents the observed correlation between the measures, and \( r_{xx} \) and \( r_{yy} \) represents the reliabilities of the two measures. The corrected correlation coefficients between seven variables were presented in Table 5.

\[
r_{xy} = \frac{r_{xy}}{\sqrt{r_{xx}r_{yy}}}
\] (3)
Table 5.
Coefficients of actual data and the data after correcting for unreliability.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td>1. Chess Rating</td>
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<td>.39</td>
<td>.65</td>
<td>.27</td>
<td>.47</td>
<td>.65</td>
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<tr>
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<td>.49</td>
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<td>-.07</td>
<td>.18</td>
<td>.29</td>
</tr>
<tr>
<td>3. Log Playing with Opponents</td>
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<td>.80</td>
<td>.35</td>
<td>-.05</td>
<td>.10</td>
<td>.11</td>
</tr>
<tr>
<td>4. Log Number of Tournaments</td>
<td>.68</td>
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<td>.39</td>
<td>1</td>
<td>.21</td>
<td>.44</td>
<td>.53</td>
</tr>
<tr>
<td>5. PC Cognitive Ability</td>
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<td>-.06</td>
<td>.22</td>
<td>.90</td>
<td>.35</td>
<td>.37</td>
</tr>
<tr>
<td>6. Chess-Specific Fluid Intelligence</td>
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<td>.17</td>
<td>.66</td>
<td>.55</td>
<td>.45</td>
<td>.52</td>
</tr>
<tr>
<td>7. Chess-Specific Crystallized Intelligence</td>
<td>.81</td>
<td>.39</td>
<td>.14</td>
<td>.62</td>
<td>.46</td>
<td>.92</td>
<td>.72</td>
</tr>
</tbody>
</table>

Note. The reliabilities are shown on the diagonal. The lower triangle contains the correlations corrected for unreliability and the upper triangle contains the uncorrected correlations.

As described previously, the multiple regression results showed that these six variables accounted for 66% of variances (adjusted $R^2 = 63\%$) (see Table D-3 in Appendix D). After controlling for the unreliability of measures, these six variables accounted for 82% of variances (adjusted $R^2 = 80\%$). This model accounts for more variance than models in previous studies. For example, Charness et al.’s (2005) model accounted for a total of 38% of chess skill variance. Gobet and Campitelli’s (2007) model accounted for 41% of chess skill variance. The regression model in this current study, which has a similar number of predictors, accounted for more variance than these previous studies. One possible explanation is that this study used a wider range of chess ratings than previous ones. The standard deviations of the participants’ chess rating were 267 in Charness et al.’s (2005) study, 222 in Gobet and Campitelli’s (2007) study, and 574 in the current study. The standard deviation for chess rating is 609 for the entire USCF population. The standard deviation for chess rating in the present study was not quite as high as the population, but it was close.
In order to test the three different theoretical approaches discussed previously and to determine whether the variance of each predictor contributes to chess skill, the second analytic approach concerned conducting a commonality analysis and a hierarchical multiple regression. A hierarchical regression was used to determine whether other factors in addition to deliberate practice or chess-related experience improve the prediction of chess skills. In addition, since the variances of three types of activities in chess experience were confounded, there is no theoretical basis for assuming that common variances should be attributed to one of the variables and not the others, a commonality analysis was used to identify and to disentangle the unique and common variances among these three variables. As discussed previously, Ericsson et al.’s (1993) theory of deliberate practice and the chess-related experience approach claim that the individual chess skill differences can be simply attributed to the amount of deliberate practice and chess experience, respectively.

The incremental variances of each variable are presented in the $\Delta R^2$ column in Table 6 (see Table D-4 for detailed results of this analysis in Appendix D). In the following discussion, the incremental variances explained by each variable from actual data are presented first, and the incremental variances explained after correcting the correlation coefficients for unreliability are presented in the parenthesis.

In other to be most favorable to experience variables, the first step was to enter the Log study alone, Log playing with opponents, and Log number of tournament variables into the regression model. This means that if there were any common variance among chess experience and other factors, all of the common variance would be attributed to chess experience. The three chess experience variables accounted for 52.1%
(60.2%) of the variance ($p < .001$). As discussed previously, the variance for three types of activities in chess experience were confounded and there is no theoretical basis for assuming that common variance should be attributed to one of the variables and not the others. Thus, a commonality analysis was used to identify and disentangle the unique and common variances among these three variables of chess-related experience. The minimum and maximum variance explained for study alone and playing chess are presented in Table 6 (also see Table D-5 for the full results of the commonality analysis for all six variables in Appendix D). The Venn diagram in Figure 21A illustrates the unique and common variances for these three types of chess related experience, and the Venn diagram in Figure 21B illustrates the variances after correcting the correlation coefficients for unreliability. The minimum incremental variance for study alone accounted for was 6.4% (8.9%), whereas the maximum accounted for was 30.5% ($0.064 + 0.027 + 0.107 + 0.107 = 0.305$) (41.9%) (see Table 6). The minimum incremental variance for playing chess accounted for was 21.6% ($0.004 + 0.016 + 0.196 = 0.216$) (18.3%) and the maximum was 45.7% ($0.004 + 0.016 + 0.196 + 0.027 + 0.107 + 0.107 = 0.457$) (51.3%). Among these three chess-related experiences, the one with largest unique variance was playing chess in tournaments. This suggests that it is possible that the effect of studying alone presented by previous studies were confounded with other chess related experiences.
After controlling for all three chess-related experiences, step 2 in the regression model was to enter PC cognitive ability to see whether the chess players’ domain-general fluid intelligence can explain some of the chess skill variances. The chess players’ cognitive ability or fluid intelligence accounted for an additional 3.9% (5.7%) of variance ($p = 0.014$).

After controlling for chess experience and PC cognitive ability, step 3 in the regression model was to enter chess-specific fluid intelligence, which accounted for an additional 2.5% (9.8%) of variance ($p = .041$).

After controlling for chess experience, PC cognitive ability, and chess-specific fluid intelligence, the final step was to enter chess-specific crystallized intelligence, which accounted for an additional 7% (6%) ($p < .001$) of variance. These findings support the view that chess players’ domain-general cognitive ability, chess-specific fluid intelligence and chess-specific crystallized intelligence, contribute to individual differences in chess skill even after controlling for chess experience.

In addition, the results of the commonality analysis in Table 7 show that playing chess in tournaments and chess-specific crystallized intelligence are able to account for
most of the variance, if the maximum variance is considered. The unique variance of chess-specific crystallized intelligence contributed 7% (6%), which was the largest of all the predictors. This supports the view that playing chess in tournaments and obtaining chess knowledge are important factors in addition to studying alone.

Although the role of practice has been emphasized for a long time (e.g., by Chase & Simon, 1973; Ericsson et al., 1993), the results in this study indicate that Ericsson went too far by claiming that deliberate practice is sufficient to explain all individual differences in chess skill. In the analysis designed to be most favorable to the study alone variable, this variable explained only 30.5% of the variance. Regarding the view that only chess-related experience is important and natural ability is irrelevant, the results analyzed to be most favorable to three chess-related experience variables show that these three variables taken together explained a total of 52.1% of the variance. Thus, this study indicates that domain-specific deliberate practice or domain-specific experience is necessary, but not sufficient to explain the individual differences in chess skills.

Furthermore, domain-general fluid intelligence, chess-specific fluid intelligence, and chess-specific crystallized intelligence contribute to chess skill independently of practice. Chess-related crystallized intelligence accounted for substantial variance, and its unique variance (see Table 7) was larger than any other variable. Ericsson et al. (1993) argued that the high association between chess knowledge and chess skill is due to the amount of deliberate practice and that this association is the evidence for deliberate practice. At first glance, this argument seems compelling, but after controlling for chess experience and other variables, chess-specific crystallized intelligence still significantly improved the prediction of chess skill. Moreover, cognitive ability was more highly
associated with chess-specific crystallized intelligence ($r(75) = .37$) than study alone was ($r(75) = .29$). Thus, deliberate practice (or study alone) does not fully explain the high association between chess knowledge and chess skills. Therefore, the results of this current study support Pfau and Murphy’s (1988) claimed that chess knowledge is an important chess skill determinant.

Table 6. The results of the incremental variances for five potential relevant variables for predicting chess skills. The uncorrected columns indicate the variances in actual data, and the corrected columns indicate the variances after controlling for the unreliability of the measurements.

<table>
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<tr>
<th>Variable</th>
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<th>Corrected</th>
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<tbody>
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<td>.216</td>
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<td>Chess-Specific Fluid Intelligence</td>
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<td>Chess-Specific Crystallized Intelligence</td>
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</tbody>
</table>

Table 7. Commonality analysis of six variables predicting chess skills. The results include each predictor’s unique ($U$) and total variances ($r^2$). The uncorrected columns indicate the variances in actual data, and the corrected columns indicate the variances after correcting the correlation coefficients for any unreliability in the measurements.

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Corrected</th>
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<td>$r^2$</td>
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<td>.305</td>
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<tr>
<td>Log Playing with Opponents</td>
<td>.012</td>
<td>.154</td>
</tr>
<tr>
<td>Log Playing in Tournaments</td>
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<td>.427</td>
</tr>
<tr>
<td>PC Cognitive Ability</td>
<td>.005</td>
<td>.071</td>
</tr>
<tr>
<td>Chess-Specific Fluid Intelligence</td>
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<td>.220</td>
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<tr>
<td>Chess-Specific Crystallized Intelligence</td>
<td>.07</td>
<td>.425</td>
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</table>
In order to compare these results with previous studies, the two studies in Charness et al.’s (2005) article and one study in Gobet and Campitelli’s (2007) article were reanalyzed. Although the predictors used in Charness et al.’s (2005), Gobet and Campitelli’s (2007), and the present studies differ, it is still informative to compare the confounded variance between studying alone and playing with opponents. A commonality analysis was used to disentangle the variances confounded between studying alone and playing chess in three different studies. The minimum and maximum incremental variances are presented in Table 8. The previous studies used the self-reporting method to measure the amount of time the players had played chess seriously with opponents (e.g., in tournaments). The unique variance explained by self-reported playing chess times were low in both Charness et al.’s (2005) studies, but high in Gobet and Campitelli’s (2007). In these three studies, the confounded variance between studying alone and playing chess are not trivial. The confounded variances between studying alone and playing chess were 16.2 %, 6.6%, and 14.8% in Charness et al.’s (2005) study 1 and study 2 and Gobet and Campitelli’s (2007) study, respectively. In this study, an objective method was used to obtain the amount of games the participants had played in tournaments. It shows that this variable accounts for higher unique variance than any other variable and suggests that the relationship between studying alone and chess skills may be weaker than what previous studies claimed. Thus, deliberate practice (or study alone) does not sufficiently explain individual differences in chess skill. Overall, in agreement with Gobet and Campitelli’s (2007)’s conclusion, the role of practice in achieving high levels of expertise is necessary but not sufficient.
Table 8.
The results of the minimum and maximum incremental variances for studying alone and playing chess in chess skills in three different studies.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Present Study</th>
<th>Charness et al Study 1</th>
<th>Charness et al. Study 2</th>
<th>Gobet &amp; Campitelli</th>
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<tr>
<td>Study Alone (Self-Report)</td>
<td>.064 .305</td>
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<td>.028 .176</td>
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General Discussion

In 1973, Simon and Chase proposed recognition-action theory to explain how chess experts can make relatively good chess moves: The claimed that after 10,000 to 50,000 hours of practice, chess players are able to reach a master performance level by learning thousands of patterns (or chunks) and storing them in long-term memory. When deciding on a move, a familiar pattern evokes a move associated with it and bring the move into the short-term memory for consideration. Twenty year later, Ericsson and his colleagues (1993) emphasized the importance of practice in acquiring a skill, and also described a special kind of practice called “deliberate practice” that involves guidance by teachers or coaches. According to Ericsson et al.’s (1993) deliberate practice theory, anyone could become an expert if they engage in 10,000 hours of deliberate practice. This theory also holds that deliberate practice is the primary source of the individual differences in chess skill. The importance of deliberate practice in acquiring a skill has been frequently cited and discussed in many popular books, and extensively cited in scholarly journals and textbooks to emphasize the importance of deliberate practice.

Most studies estimated deliberate practice time by asking the participants to report how many hours per week they had seriously studied chess alone. However, as discussed here, deliberate practice may be part of what occurs when players study alone, but studying alone may involve chess-related experiences other than deliberate practice. Few studies have asked the participants to report one other important chess experience: how many hours per week they had seriously played chess with opponents. However, playing chess does not meet Ericsson’s criterion for deliberate practice, and it involves a bit of circular reasoning to justify it as deliberate practice simply because it is valuable.
Therefore, in this study, deliberate practice is considered a subset of studying alone, and studying alone, playing chess with opponents, and playing chess in tournaments are all considered part of chess-related experience. Since no clear definition of practice was provided by Simon and Chase (1973), if any practice is involved in players’ chess-related activities, it would be involved in chess-related experience.

Study 1 revealed that CS, a young and exceptional chess player, defeated a grandmaster after playing chess seriously for only 3 years and 7 months. CS had studied chess alone for approximately 156 hours and engaged in a total of 3,749 hour of chess-related activities. The time she spent on deliberate practice, as defined by Ericsson, would clearly be less than 156 hours and possibly 0 hours since it is not clear if any of her studying alone time meets Ericsson’s definition of deliberate practice. The short amount of time she spent studying alone, along with her exceptional achievement in chess, is particularly difficult to reconcile with Ericsson’s 10-year/10,000-hour practice rule. If all CS’s hours of chess-related experience counted as practice as envisioned by Simon and Chase’s (1973), the amount of time CS spent practicing was estimated to be at most 3,749 hours. This relatively short total time spent on chess-related experience is also difficult to reconcile with Chase and Simon’s recognition-action theory. Moreover, the comparison between CS’s performance and McLaughlin’s golf performance shows that CS and McLaughlin’s skill acquisition rates were very different. These results contradict the argument that pure deliberate practice is sufficient to explain individual differences in skill acquisition.

CS’s performance in one cognitive task, the visual short-term memory, was exceptional. She performed better than all of the 62 age-matched children and was better
than all but three of the 77 adult chess players tested in Study 2. However, due to the weak relationship between VSTM and chess skills found in Study 2, this extraordinary performance may not be directly associated with her chess skills. Perhaps, there are other cognitive abilities that mediate between her visual short-term memory and her chess skill.

Study 2 provides evidence that study alone or together with other chess experience is necessary but not sufficient to explain the individual differences in chess skill. Domain-general fluid intelligence, domain-specific fluid intelligence and domain-specific crystallized intelligence all contribute to chess skill independently and additionally to study alone and chess experience, especially chess-specific crystallized intelligence.

The results of this study are consistent with Pfau and Murphy’s (1988) claim that chess knowledge is an important determinant of chess skill. An unanswered question is how CS and a few chess players in Study 2 were able to obtain a high level of chess knowledge after spending only a limited amount of time studying chess.

In summary, both studies provide evidence for the assertion that there are other factors in addition to practice and chess experience that contribute to chess skill. These findings call into question Ericsson’s 10,000-hour rule, and provide evidence challenging the view that chess expertise is solely a function of practice (Ericsson, 2006, Simon & Chase 1973). Despite their problems accommodating the present findings, practice is still important in acquiring a skill. However, it appears that the improvement with practice in the recognition-action mechanism is not sufficient for players to reach a high level of expertise, and deliberate practice is not the only factor contributing to skill acquisition. It appears that the widely-accepted explanation of the development of chess expertise in
terms of the building up of thousands of patterns of chess pieces is not sufficient. This explanation has particular difficulty explaining how chess knowledge can be still so highly correlated with chess skill even after chess-related experiences are statistically controlled. Besides knowledge, it is likely that factors such as the ability to search deeply, plan strategically, and apply positional principles are critical determinants of a player’s skill level. Overall, in agreement with Gobet and Campitelli’s (2007) conclusion, the role of practice in achieving high levels of expertise is necessary but not sufficient.
Notes

1 According to McLaughlin’s diary/blog, he counted tournaments played as part of deliberate practice. He counted each tournament game as having played 2 hours of deliberate practice. It might violate the criteria of Ericsson’s deliberate practice, but he justified it by stating: “When I play a tournament round like the one I participated in today I can make the same number of swings and theoretically spend the same amount of time learning or practicing the game but the round took about 6 hours. I can’t exactly say that I spent 6 hours ‘practicing’ today as a lot of the time was just waiting. But, there are certain things you can only learn on the course so I have to count it for something. I decided from the beginning that 18 holes was going to be counted as 2 hours. Everything else is the exact time spent” (retrieved from http://thedianplan.com/5000-of-10000-practice-hours-completed-half-way/).

2 The percentiles were calculated based on the database in 2015. There were 64,069 members in the entire USCF population, with a mean rating of 857 and standard deviation of 609. There were 49,556 members in the junior group (under 21), with a mean rating of 645 and standard deviation of 472. There were 34,164 members in children group (age 12 and below) with a mean rating of 506, and standard deviation of 370.

3 To be conservative, CS’s data was excluded. The analyses were based on the 77 adult chess players.
References


Ericsson, K. A. (2014c). Supplemental online materials for “A challenge to estimates of an upper-bound on relations between accumulated deliberate practice and the associated performance in domains of expertise: Comments on Macnemara (sic),


Appendix A: Chess Knowledge Task

1. One usually develops the ... first
   a. Knights
   b. Bishops
   c. Rooks
   d. Queen

2. In the middle game a passed center-pawn should be blocked by
   a. a knight
   b. a rook
   c. a king
   d. a queen

3. In a white KP versus black K ending, the white king is preferably placed
   a. in front of the pawn
   b. behind the pawn
   c. separated from the pawn by 2 squares
   d. next to the pawn

4. One of black’s main problems in the Queen’s Gambit Declined, Orthodox Defense, is how to
   a. survive white’s attack
   b. avoid losing control of the center
   c. develop his white squared bishop
   d. avoid double pawns

5. I open up the center when
   a. I control the center
   b. I have the pair of bishops
   c. I haven’t castled yet
   d. I control the light squares

6. In a rook ending with a passed pawn, the defending player should usually place his (her) rook
   a. in the “smaller part”
   b. in the “larger part”
   c. in front of the pawn
   d. behind the pawn
7. In which opening white will often castle queenside?
   a. French
   b. Sicilian
   c. Ruy Lopez
   d. Polish

8. Generally, the best way to answer a wing attack is to
   a. counterattack on the same wing
   b. defend on the attacked wing
   c. counterattack on the opposite wing
   d. counterattack in the center

9. The ending of KBB versus KN is known as
   a. theoretically drawn
   b. won for KBB
   c. only won for KBB if the K of KN is in a corner
   d. only won for KBB if the N is far away of the K

10. In the “Von Schara-Hennig Gambit”
    a. white sacrifices a pawn
    b. white sacrifices a piece
    c. black sacrifices a pawn
    d. black sacrifices a piece

11. When white is an exchange up, what is meant by “exchange”?
    a. The difference between two minor pieces and a rook
    b. The difference between a rook and a minor piece
    c. The pair of bishops
    d. The difference between a queen and a rook with a minor piece

12. Which of the following is the best defensive setup for the knights in a KNN versus KQ ending (no pawns)?
    a. no setup in particular, the queen wins against any setup
    b. no setup in particular, the knights draw with nearly every setup
    c. the knights should be mutually defending each other
    d. the knights should be placed side-by-side with the king defending them
13. In which opening it is possible for white to get the largest pawn front (connected pawns on the fourth rank)?
   a. Marshall
   b. Cochrane
   c. Grunfeld
   d. King’s Gambit

14. In the battle of a rook versus a minor piece and 2 pawns, the rook has the advantage if
   a. the rook is active
   b. the extra pawns have not yet advanced to the fifth rank
   c. the extra pawns are on different wings
   d. the ending approaches

15. The ending KQ versus KBN is known as
   a. won for KQ
   b. drawn
   c. in exceptional cases a draw
   d. in exceptional cases won by KQ

16. The bishop on h7 captures the knight on c3
   a. Possible
   b. Not possible
   c. Depends
   d. I do not know

17. How many moves do you need at least to play the knight f6 to a1?
   a. 3
   b. 4
   c. 5
   d. 6

18. What is the maximum amount of squares that the bishop can cover?
   a. 13
   b. 14
   c. 15
   d. 16
Appendix B: Chess Position Memory Task

Position 1

Position 2

Position 3

Position 4

Position 5

Position 6
Appendix C: Chess-Related Activity Survey

I. Chess Activities

1. At what age did you learn the chess moves? ______________ (Age)
2. At what age did you start playing chess seriously? ______________ (Age)
3. We are interested in how relevant you consider various chess activities listed below with respect to improving your current chess skills. Please start by reading through all activities. Then circle a value on the top scale between 1 (not at all relevant) and 7 (highly relevant) depending on how relevant for improving your current chess you consider a given activity. Please note that in the first two categories we distinguish between activities which are serious in the sense that they are focused, solitary activities motivated by your desire to improve your chess skill and those activities you do mainly for fun.

<table>
<thead>
<tr>
<th>Activity</th>
<th>not at all relevant</th>
<th>highly relevant</th>
</tr>
</thead>
<tbody>
<tr>
<td>serious analysis of positions alone (chess books, -magazines, data bases, postal chess etc.)</td>
<td>1</td>
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</tr>
<tr>
<td>reading chess literature for fun (chess books, -magazines, data bases etc.)</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>active participation in chess tournaments</td>
<td>1</td>
<td>7</td>
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<tr>
<td>blitz chess</td>
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<td>7</td>
</tr>
<tr>
<td>rapid chess (about 30 min per game)</td>
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<tr>
<td>playing chess games outside tournaments</td>
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<tr>
<td>playing chess computer</td>
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<td>receiving formal instruction</td>
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<tr>
<td>providing formal instruction</td>
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<tr>
<td>analyses of positions with others (during tournaments, etc.)</td>
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</tr>
<tr>
<td>chess problems (chess columns, etc.)</td>
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</tbody>
</table>
4. We now would like to know for how much time you engage(d) in the activities you have just rated during the present year and when you started to seriously engage in playing chess. Please try to estimate as precisely as possible the number of hours during a most typical week for both points in time. You can include comments for those activities that occurred less frequently, like 2 hrs / month, or 5 x 6 hrs a year. Please fill in “0” if you did not engage in a given activity during a given time.

<table>
<thead>
<tr>
<th>Activity Description</th>
<th>Time you spend in a most typical week of this year (Hours per Week)</th>
<th>Time you spent in a most typical week in the year after you started seriously playing (Hours per Week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>serious analysis of positions alone (chess books, magazines, data bases, postal chess etc.)</td>
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<tr>
<td>reading chess literature for fun (chess books, -magazines, data bases etc.)</td>
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<td>analyses of positions with others (during tournaments, etc.)</td>
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<tr>
<td>chess problems (chess columns, etc.)</td>
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</table>
5. The table below has two columns where we would like you to give estimates of your time investment into (1) serious analysis of positions you did alone (using chess books, magazines, data bases, playing postal chess, or the like) and (2) the amount of time you spent seriously playing opponents. This includes standard chess, blitz, or rapid chess, however, we want you to restrict your estimates to serious competition, like in tournaments. Note that postal chess is part of the solitary activities (first column) and should not be included here.

On the left you will find age as a reference point. You may add years (e.g. 1980) for your own reference. It is not necessary to provide entries for each single year! Please estimate the number of hours you spent during a most typical week on solitary study and playing serious games. Start out with the age when your chess activities began and fill in an estimate for each activity. Draw a vertical line until the next age, when this amount changed according to your memory, and continue until your current age. An example is provided on the next page.

**Please estimate the hours for a typical week!**

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</table>
The player in the sample table above began playing chess at age 10, spending about 1hr/week studying alone and about 0.5hr/week playing others. At age 11, this increased to 2hr/week alone and 1hr/week playing others. From ages 12 to 14, the amount of time spent playing others remained the same (1hr/week), while the amount of time spent studying alone went from 4hr/week (age 12) to 3hr/week (age 13) and back to 4hr/week (age 14). From ages 15 to 19, study alone was about 5hr/week and about 2hr/week was spent playing opponents. From ages 20 to 22, this player neither studied alone nor played any serious games with others. At age 23, chess study resumed with 2hrs/week spent on study alone and 1hr/week playing opponents; this continued through age 27. From ages 28 to 30, both study alone and time spent playing others was at 2hr/week, and both increased to 3hr/week at age 31. At age 32, the time spent playing others remained the same (3hr/week), while the time spent on study alone went up to 4hr/week. From ages 33 to 37, study alone and time spent playing serious games with others both dropped to 2hr/week and from ages 38 to 43, the player spent no time studying alone or playing serious games with others. From 44 to 45 (the player’s current age), this player resumed chess study alone (2hr/week) and spent about 1hr/week playing serious games with others.
II. **Specific Aspects of Playing Chess**

In this part of our questionnaire we are interested in specific aspects of playing chess. We have distinguished between openings, tactics, middle game strategies, and end games.

1. How good do you think you are at . . .?

   - very poor

   **Grandmaster Level**
   - openings
   - tactics
   - middle game strategies
   - end games

2. Openings:
   i. How many different openings are you familiar with, in the sense that you would feel comfortable playing (or playing against) them in an informal game?
      ____ (number)
   ii. How many opening lines do you have command of at a level of 10 moves deep?
      ____ (number)
   iii. How many different openings do you actually play within a year? _____ (number)

3. We would like to know, to which degree you focus(focused) on four different aspects in your study time (seriously study alone). Please give percentage estimates summing to 100% for the present year in the first column and for the year when you had started seriously engaging in playing chess in the second column. As an example, when half of your time was spent on studying openings during your initial year, you should put 50% in the first row of column 2.

   currently: | when you started to play seriously:
   --- | ---
   openings | _______% | _______%
   tactics | _______% | _______%
   middle game strategies | _______% | _______%
   end games | _______% | _______%
   100% | 100%

4. How frequently do you practice …
   … when preparing for tournaments? ______ (per week)
   … when practicing for skill improvement? ______ (per week)
   … when practicing for skill maintenance? ______ (per week)
III. General Aspects of Playing Chess

The following section covers a broad range of aspects regarding chess practice, tournament preparation, and tournament play. Please indicate how often you perform a given activity or whether you agree/disagree with an item by circling the appropriate number to the right of the item.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>never / strongly disagree</th>
<th>always/ strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. My main goal is to gain rating points in the tournament</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. I set aside time each day to practice</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Hard work is more important than innate talent in becoming a chess master</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. I am satisfied to draw against stronger opponents</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Even if I go a long time without improving my rating, I find that I still enjoy studying chess</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. My main goal is to win the tournament</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. When I first began playing chess, I noticed I had a talent for it</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. I enjoy chess because of the feedback that the ELO or USCF rating system gives me.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. I daydream during my practice sessions</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. I stay with a fixed practice schedule</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. To become a chess master one must start at an early age</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. I enjoy chess because of the opportunities for friendships that it provides</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. When I lose, I study and practice much harder</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. My main goal is to win a prize in the tournament</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. I enjoy chess because of the opportunities to compete at a high level</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. My main goal is to enjoy playing in the tournament</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. I feel that at some point, increased study will not improve my chess rating</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Very few people possess the talent to become Grandmasters</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. I feel that winning is the most important thing in chess</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. I play through sequences of moves from recorded games mentally, not physically</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. When you started playing chess, how important is it for you? Not at all</td>
<td>1 2 3 4 5 Very Important</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1---------2---------3---------4---------5---------6---------7
IV. **Biographical Information**

Finally, we would like you to answer some simple questions about your biography.

1. Age: ____

2. Birthdate: _____________

3. Sex: _______ (f / m)

4. Years of School _____________

5. Current Occupation (last, if retired): _______________________________

6. What is your current chess rating (and type of rating) for......
   ** If rated by more than one organization please separate by ‘/’ (ex: 2124 USCF/2000FIDE) ** Organization: USCF / FIDE / CFC / ELO / DWZ / NEZ / INGO

<table>
<thead>
<tr>
<th>current rating</th>
<th>year attained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td>Blitz (5min)</td>
<td></td>
</tr>
</tbody>
</table>

7. What is your highest chess rating (and type of rating) for......
   ** If rated by more than one organization please separate by ‘/’ (ex: 2124 USCF/2000FIDE) ** Organization: USCF / FIDE / CFC / ELO / DWZ / NEZ / INGO

<table>
<thead>
<tr>
<th>highest rating</th>
<th>year attained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td>Blitz (5min)</td>
<td></td>
</tr>
</tbody>
</table>

8. Please estimate your rating at these ages up to your current age:

   i. rating organization ______

   ii. Estimation:

<table>
<thead>
<tr>
<th>Standard</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Blitz</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
</table>
9. Did you ever join a chess club or a group where chess was played on a regular basis (club, school workshop, etc.)? If YES, at what age for the first time __________ (Age)

10. At what age did you play your first tournament game?
   • Rated tournament __________ (Age)
   • Other (non-rated) tournaments? __________ (Age)

11. How many tournaments have you played in the past year __________
    …in the first year that you played chess seriously __________

12. Did you ever receive any formal chess instruction from a teacher or trainer? ___Yes ___No
    INDIVIDUALLY: from (Age) __________ to (Age) __________
    GROUP: from (Age) __________ to (Age) __________

13. Did you ever provide chess instruction? ___Yes ___No
    from (Age) __________ to (Age) __________

14. Did you ever consider becoming a professional chess player? ___Yes ___No
    at what age? __________ (Age)

15. Did you ever play chess on a professional basis? ___Yes ___No
    • When did you start (age)? __________ (Age)
    • When did you quit (age)? __________ (Age)

16. How many chess books do you own (excluding magazines)? ________ (number)
    ......magazines do you subscribe to? ________ (number)
    ......chess databases (ChessBase, etc.) do you own? ________
    (number)

17. How many chess books have you purchased in the past year (excluding magazines)? ________

18. At what age did you decide to pursue your current (last) profession? ________ (Age)
Appendix D: Additional Analytical Reports

Figure D-1. The boxplots for forward and backward digit spans in the healthy children group ($n = 34$). The horizontal dashed lines indicate CS’s performance in the tasks.

Figure D-2. The boxplots for forward and backward visuo-spatial memory spans in the healthy children group ($n = 34$). The horizontal dashed lines indicate CS’s performance in the tasks.
Figure D-3. The boxplots for approximate number system and automated symmetry span in the healthy children group (n = 34). The horizontal dashed lines indicate CS’s performance in the tasks.

Table D-1.
CS’s six cognitive abilities compared with the healthy children group.

<table>
<thead>
<tr>
<th>Cognitive Ability Task</th>
<th>CS</th>
<th>Healthy Children (n = 34)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
</tr>
<tr>
<td>Forward Digit Span</td>
<td>7</td>
<td>7.91</td>
</tr>
<tr>
<td>Backward Digit Span</td>
<td>5</td>
<td>4.59</td>
</tr>
<tr>
<td>Approximate Number System (Rescaled)</td>
<td>1.27</td>
<td>1.08</td>
</tr>
<tr>
<td>Forward Visual-Spatial Memory Span</td>
<td>6</td>
<td>5.53</td>
</tr>
<tr>
<td>Backward Visual-Spatial Memory Span</td>
<td>6</td>
<td>5.35</td>
</tr>
<tr>
<td>Automated Symmetry Span</td>
<td>21</td>
<td>24.79</td>
</tr>
</tbody>
</table>
Table D-2.
A multiple regression model for variables predicting the USCF rating of 77 chess players.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>$SE$</th>
<th>$t$</th>
<th>$p$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>559.29</td>
<td>232.73</td>
<td>2.4</td>
<td>.019</td>
<td>[95.57 - 1023.02]</td>
</tr>
<tr>
<td>Square Root of Experience</td>
<td>8.03</td>
<td>1.11</td>
<td>7.23</td>
<td>&lt; .001</td>
<td>[5.82 - 10.25]</td>
</tr>
<tr>
<td>Visual Short-Term Memory</td>
<td>224.93</td>
<td>109.03</td>
<td>2.06</td>
<td>.043</td>
<td>[7.68 - 442.18]</td>
</tr>
</tbody>
</table>

Table D-3.
The results of the multiple regression for six variables predicting chess skills.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$b$</th>
<th>$\beta$</th>
<th>$SE$</th>
<th>$t$</th>
<th>$p$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-466.4</td>
<td>0</td>
<td>250</td>
<td>-1.87</td>
<td>.066</td>
<td>[-1064, -77]</td>
</tr>
<tr>
<td>Log study alone</td>
<td>225.4</td>
<td>.27</td>
<td>74</td>
<td>3.07</td>
<td>.003</td>
<td>[72, 365]</td>
</tr>
<tr>
<td>Log playing opponents</td>
<td>119.5</td>
<td>.13</td>
<td>76</td>
<td>1.58</td>
<td>.118</td>
<td>[-32, 267]</td>
</tr>
<tr>
<td>Log number of tournaments</td>
<td>190.1</td>
<td>.25</td>
<td>69</td>
<td>2.74</td>
<td>.008</td>
<td>[63, 337]</td>
</tr>
<tr>
<td>PC cognitive ability</td>
<td>24.6</td>
<td>.08</td>
<td>24</td>
<td>1.04</td>
<td>.301</td>
<td>[-23, 71]</td>
</tr>
<tr>
<td>Chess-specific fluid intelligence</td>
<td>149.1</td>
<td>.08</td>
<td>154</td>
<td>.97</td>
<td>.336</td>
<td>[466, 1557]</td>
</tr>
<tr>
<td>Chess-specific crystallized intelligence</td>
<td>1032.7</td>
<td>.35</td>
<td>274</td>
<td>3.76</td>
<td>&lt; .001</td>
<td>[-160, 449]</td>
</tr>
</tbody>
</table>

Note. Multiple $R^2 = .66$; adjusted $R^2 = .63$. $F(6, 70) = 22.18, p < .001$. 
Table D-4.
The results of the hierarchical regression, which include the variance ($R^2$) and probability level ($p$) in each variable for predicting chess skills. The columns of uncorrected indicate the variance in actual data, and the column of corrected indicates the variance after correcting the correlation coefficients for any unreliability in the measurements.

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Uncorrected</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>log study alone</td>
<td>.305</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>log playing with opponents</td>
<td>.325</td>
<td>.144</td>
</tr>
<tr>
<td>log number of tournaments</td>
<td>.521</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC cognitive ability</td>
<td>.560</td>
<td>.014</td>
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<tr>
<td>Step 3</td>
<td></td>
<td></td>
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<tr>
<td>chess-specific fluid intelligence</td>
<td>.586</td>
<td>.041</td>
</tr>
<tr>
<td>Step 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chess-specific crystallized intelligence</td>
<td>.655</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Table D-5.
The results of the commonality analysis for the unique and common variances and the percentages for total contribution of the six variables in predicting chess skills. The columns of uncorrected indicate the variance in the actual data, and the columns of corrected indicate the variance after correcting the correlation coefficients for any unreliability in the measurements. The six variables include Log study alone (X1), Log playing with opponents (X2), Log playing in tournaments (X3), PC cognitive ability (X4), chess-specific fluid intelligence (X5), and chess-specific crystallized intelligence (X6).

<table>
<thead>
<tr>
<th></th>
<th>Uncorrected</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unique to X1</td>
<td>.0463</td>
<td>.0267</td>
</tr>
<tr>
<td>Unique to X2</td>
<td>.0124</td>
<td>.0187</td>
</tr>
<tr>
<td>Unique to X3</td>
<td>.0370</td>
<td>.0086</td>
</tr>
<tr>
<td>Unique to X4</td>
<td>.0054</td>
<td>.0015</td>
</tr>
<tr>
<td>Unique to X5</td>
<td>.0046</td>
<td>.0016</td>
</tr>
<tr>
<td>Unique to X6</td>
<td>.0697</td>
<td>.0604</td>
</tr>
<tr>
<td>Common to X1 and X2</td>
<td>.0341</td>
<td>5.20</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>Common to X1 and X3</td>
<td>.0230</td>
<td>3.50</td>
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<td>-.0043</td>
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<td>Common to X2 and X4</td>
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<tr>
<td>Common to X5 and X6</td>
<td>.0208</td>
<td>3.17</td>
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<td>6.53</td>
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<td>.02</td>
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<td>Common to X1, X2, and X5</td>
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<td>-.02</td>
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<tr>
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<td>Common to X1, X3, X4, and X5</td>
<td>-0.0011</td>
<td>-0.17</td>
</tr>
<tr>
<td>Common to X2, X3, X4, and X5</td>
<td>0.0004</td>
<td>0.06</td>
</tr>
<tr>
<td>Common to X1, X2, X3, and X6</td>
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<td>5.05</td>
</tr>
<tr>
<td>Common to X1, X2, X4, and X6</td>
<td>-0.0024</td>
<td>-0.37</td>
</tr>
<tr>
<td>Common to X1, X3, X4, and X6</td>
<td>-0.0031</td>
<td>-0.47</td>
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<td>-0.0001</td>
<td>-0.02</td>
</tr>
<tr>
<td>Common to X1, X2, X5, and X6</td>
<td>-0.0005</td>
<td>-0.08</td>
</tr>
<tr>
<td>Common to X1, X3, X5, and X6</td>
<td>0.0383</td>
<td>5.84</td>
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<td>Common to X2, X3, X5, and X6</td>
<td>0.0012</td>
<td>0.19</td>
</tr>
<tr>
<td>Common to X1, X4, X5, and X6</td>
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<td>-0.41</td>
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<tr>
<td>Common to X2, X4, X5, and X6</td>
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<td>-0.09</td>
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<td>Common to X3, X4, X5, and X6</td>
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<td>Common to X1, X2, X3, X4, and X5</td>
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</tr>
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<td><strong>Total</strong></td>
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<td><strong>100</strong></td>
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Appendix E: CS’s Additional Interview Report

I was interested in knowing how relevant CS considered various chess activities to be in improving her chess skills. During the interview, CS was asked to respond using a 7-point Likert scale where 1 indicating “not at all relevant” and a rating of 7 indicating “highly relevant.” She said her experience in seriously analyzing positions alone, actively participating in chess tournaments, and solving chess problems were highly relevant (7 out of 7). Regarding other chess activities, she said receiving formal instruction (5 out of 7), playing blitz chess (4 out of 7), playing rapid chess (2 out of 7), and reading chess literature for fun (3 out of 7) were somewhat relevant to her chess skills. She indicated that playing chess games outside of tournaments and with computers was not relevant to her skills at all (1 out of 7). Her chess experience did not include providing formal instruction and analyzing position with others during tournaments.

I was also interested in knowing how much effort she considered different types of chess activities. CS was asked to respond using a 7-point Likert scale, with 1 indicating “not effortful” and a rating of 7 indicating “very effortful.” She said her experience in seriously analyzing position alone, active participating in chess tournaments, and solving chess problems are very effortful (7 out of 7). She also rated that receiving formal instruction (5 out of 7) and playing blitz chess (2 out of 7) were somewhat effortful. She did not feel other chess activities, such as reading chess literature for fun, playing chess games outside tournaments, and playing chess in computers, were effortful at all (1 out of 7).

I was also interested in how CS had allocated her time studying openings, tactics, middle game strategies, and end games when she had seriously studied chess alone for
the present year. CS said she spent 15% of her time studying openings, 40% on tactics, 40% on middle game strategies, and 5% on end games. CS also said that when she practiced, she aimed to improve her skills to prepare for tournaments or to maintain her skills.

A series of questions were asked related to CS’s general attitude about her chess playing. CS was asked to respond using a 5-point Likert scale, with 1 indicating “never/strongly disagree” and 5 indicating “always/strongly agree.” CS was encouraged to not only give a rating, but also to talk about anything she wanted to share. CS said her main goals were to gain rating points (5 out 5) and win tournaments (5 out 5). She was not very concerned with winning a prize (2 out 5) or enjoying playing in the tournaments (2 out 5). She said winning is important but not everything to her, and she enjoyed playing chess because it provided her with opportunities for friendships (5 out 5) and opportunities to compete at a high level (5 out 5). She also said that she loved to see her opponents suffer when she reached a winning position (5 out 5) and that she viewed her opponents with pity when she reached a winning position (5 out 5), especially girls. CS recalled that when she first started playing chess, boys did not want to play her. After she became strong, boys were more likely to be very upset when they lost to her. CS also tried to win against stronger opponents (4 out 5) and win a tactically brilliant game (5 out 5). When she lost a game, she would study and practice much harder (5 out 5). She tried to set time aside each day to practice and keep a fixed practice schedule, but sometimes there were too many other responsibilities stopping her from spending the time she should on chess preparation.
CS disagreed that to become a master one must start playing chess at an early age (1 out 5). She believed that hard work is more important than innate talent in becoming a chess master (5 out 5) and strongly disagreed that only very few people possess the necessary talent to become a grandmaster (1 out 5). However, she also reported that she had noticed she had a talent for chess when she first began playing (5 out 5).

During the interview, we also talked about her emotions and her concentration status when she played. CS said before a game, she had no difficulty at all controlling her emotions, but if she was in a difficult position, she could feel her heart beating quickly. When CS was playing chess in tournaments, she liked to walk around to check other players’ positions rather than sit at her table.

When I asked CS how many chess resources (e.g., magazine, books, databases) she had, she said that there were fewer than 20 chess books, no magazines, and one chess database at her home, with most of the chess books belonging to her father.