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Perception in chess: Evidence from eye movements

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Abstract

We review and report findings from a research program by Reingold, Charness and their colleagues (Charness *et al* 2001; Reingold *et al.* 2001a, 2001b) that employed eye-movement paradigms and provided strong support for the suggestion of de Groot (1946, 1965) and Chase and Simon (1973a, 1973b) that a perceptual advantage is a fundamental component of chess skill. We demonstrated dramatically larger visual spans for experts while processing structured, but not random, chess positions. In addition, consistent with the encoding of chunks rather than individual pieces, experts made fewer fixations, and fixated between related pieces, rather than on pieces. It was also shown that chess piece saliency influenced the selection of experts' saccadic endpoints, and that experts completed the perceptual encoding phase and started the problem-solving phase sooner than intermediates. Finally, we demonstrated that experts, but not less-skilled players, extract chess relations using automatic and parallel procedures.

Introduction

Chess research dates back to the beginning of modern experimental psychology during the late 1800s and early 1900s (e.g. Binet 1894; Cleveland 1907; Djakow *et al.* 1927). Since the initiation of the field of artificial intelligence (AI), the pioneers of this discipline considered chess an ideal model domain for exploring search and evaluation processes in their attempt to construct skillful chess programs (see Berliner 1978 for a review). Indeed, during the last century, chess research has proven to be very instrumental in enhancing our understanding of human expertise and in contributing to the study of AI (for reviews see Charness 1992; Ericsson and Charness 1994; Gobet and Charness in press; Gobet *et al.* 2004). The usefulness of chess for the study of cognitive science is strongly advocated in the proposal by Simon and Chase (1973)

that similar to the use of *Drosophila* (the fruit fly) as a model organism for the study of genetics, chess offers cognitive scientists an ideal task environment for the study of cognitive processes in general, and skilled performance in particular. Consistent with this idea, Newell and Simon (1972) selected chess as one of the three model tasks that they used in developing their highly influential information processing theory of human problem solving.

Chess research is appealing in part because it offers a rich, ecologically valid environment, which at the same time permits rigorous experimental control. One key methodological advantage in this area is the existence of an interval-level chess rating scale that is based on the outcome of competitions between players (Elo 1965, 1986), and which provides a true gold standard for the measurement of skill. In the vast majority of other areas of expertise, identifying true experts and quantifying the difference in skill across individuals is often a very complex and difficult methodological hurdle. In order to illustrate the chess ratings scale, Fig. 14.1 shows a distribution of ratings provided by the United States Chess Federation. Note that currently, the

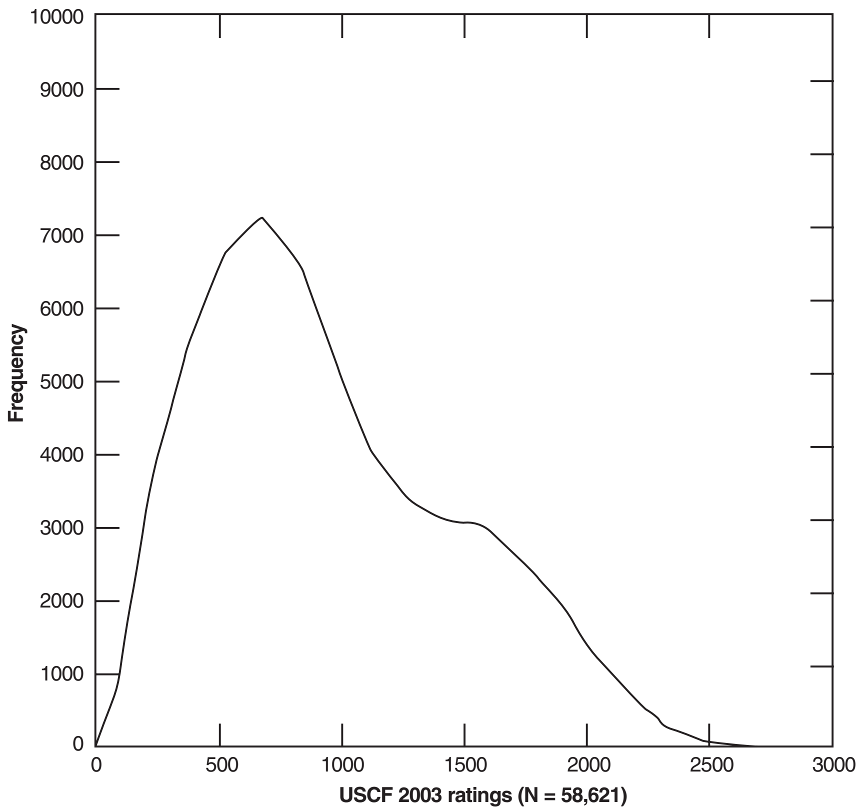

Figure 14.1 The United States Chess Federation (USCF) 2003 rating distribution (n = 58,621).

world's best players achieve ratings just above 2800 rating points. In addition, Grandmaster, International Master and Master levels of performance approximately correspond to 2500, 2400, and 2200 rating points respectively. As well, Expert and Class A levels are often defined as corresponding to the ranges 2000–2199 rating points and 1800–1999 rating points respectively.

Other characteristics of chess, including an efficient and extensive documentation of domain specific knowledge, and the prevalence of formalized symbolic representations, greatly facilitate using chess as a task environment for cognitive research and modeling, and for AI investigations. Chess is also ideal for studying nonverbal spatial problem solving. Furthermore, given that chess is played across the lifespan (4- or 5-year-old children to elderly adults) it offers a rare opportunity for studying the relation between age and skill.

Arguably, the most important contribution of chess research is in producing a major theoretical shift in the conceptualization of expertise in cognitive science, away from viewing skilled performance as the product of superior general intelligence and innate talent, toward the recognition that expertise largely reflects domain-specific knowledge acquired through extensive deliberate practice (for a review see Ericsson and Charness 1994). This dramatic change in perspective originated from pioneering work on chess by de Groot (1946, 1965) and Chase and Simon (1973a, 1973b). Prior to the publication of this research the prevailing view was that chess grandmasters were vastly superior to their less-able opponents, in terms of their general intelligence and thinking skills, and in terms of their ability to plan and consider long sequences of chess moves and countermoves. However, de Groot's research challenged some of these assumptions.

In his research de Groot (1946, 1965) instructed two groups of players (experts vs. grandmasters) to think aloud as they identified the best move for chess positions. From his analysis of the players' verbal protocols de Groot determined that although grandmasters were better than expert players in selectively exploring the most promising moves, they did not search further ahead through the sequences of moves as compared with their less-skilled counterparts. Thus, de Groot failed to document the expected difference between experts and grandmasters in the depth and breadth of the serial search through the space of possible moves. More recent research confirmed that depth-of-search effects as a function of skill are relatively small, and are only found when weaker players than those in de Groot's sample are included in the study (Charness 1981; Gobet 1998a; Holding and Reynolds 1982), for instance, those rated up to about 2000 rating points (Elo 1986). (In the Elo system, players are rated on an interval level scale, based on tournament performance, that starts at approximately 0 points and extends upwards. Grandmasters typically are rated about 2500 Elo points or higher; masters are about 2200–2399 points; experts are those between 2000 and 2199 points.) In contrast, performance on another task introduced by de Groot was shown to vary markedly as a function of chess skill. In this task players were briefly shown chess positions (2–15 s). Following this brief exposure, grandmasters were able to reproduce the locations of the chess pieces almost perfectly (about 93 per cent correct for positions containing about 25 pieces) and substantially better than expert players.

In a classic study, Chase and Simon (1973a, 1973b) replicated and extended de Groot's findings, demonstrating that after viewing valid (game) chess positions for 5 s, chess masters were able to reproduce these positions much more accurately than less-skilled players. However, there was little difference as a function of expertise when random board configurations were used instead of game positions. More recently, a very small but reliable advantage in recall for random configurations has been shown for expert players, although this is probably attributable to the occasional presence of familiar configurations in random positions (Gobet and Simon 1996a, 2000). Chase and Simon's (1973a, 1973b) finding that a master was only superior in the 5-s recall task when structured positions, rather than randomized positions, were presented, challenged the view that chess masters are superior in terms of their cognitive apparatus or processes (e.g. hardware aspects of perception, attention or memory). Rather, Chase and Simon (1973a, 1973b) postulated that knowledge of patterns specific to the domain of chess supported effective search for good moves. Soon, similar findings were reported for experts in other domains including bridge players (Charness 1979), music students (Beal 1985), electronics technicians (Egan and Schwartz 1979), and basketball players (Allard *et al.* 1980). Further illustrating the critical importance of knowledge structures for performance, work by Chi (1978) comparing skilled child chess players with novice adults, showed an advantage for children on chess recall but an adult advantage for digit recall. Furthermore, Simon and Chase (1973) reported that a 10-year period of intense preparation is necessary to reach the level of an international chess master strongly refuting the view that chess mastery can be achieved effortlessly in some individuals with superior general intelligence (see Ericsson *et al.* 1993 for a review).

As should be clear from the above discussion, research on chess by de Groot (1946, 1965) and Chase and Simon (1973a, 1973b) fundamentally transformed the study of expertise by highlighting the importance of domain-specific knowledge acquired through practice, and by de-emphasizing the role of innate talent and general ability in underlying skilled performance. In addition, these researchers introduced important investigative tools that have proven invaluable in subsequent studies of expertise such as the 5-s recall task employing domain-related and randomized patterns (see Ericsson and Smith 1991 for a review), and the think-aloud protocol analysis (see Ericsson and Simon 1993 for a review).

A thorough review of the contributions of chess research to the study of cognitive processes in general, and expertise in particular, is beyond the scope of the present chapter (for reviews see Charness 1992; Ericsson and Charness 1994; Gobet and Charness, in press). Rather, we will focus on an important argument advanced by de Groot (1946, 1965) and Chase and Simon (1973a, 1973b), which is best understood by considering the juxtaposition of the two key results reported by these investigators:

1) de Groot's (1946, 1965) finding that grandmasters select better moves than their less-able counterparts despite the absence of a difference across groups in the depth or breadth of the search.
2) Chase and Simon's (1973a, 1973b) finding that the master's advantage in encoding and recalling structured chess positions does not generalize to a condition in

which chess-related patterns are obliterated by randomly rearranging pieces on the chessboard.

Taken together, these findings suggest that chess grandmasters use efficient perceptual encoding of chess configurations to generate the most promising candidate moves and to restrict their reliance on the effortful and slow serial search through the space of possible moves. According to this view the efficiency of these pattern recognition processes in encoding chess configurations and the quality of the moves triggered by the extracted patterns is strongly correlated with chess expertise. However, the knowledge of chess experts concerning familiar chess-related patterns is rendered largely ineffective during the perceptual organization and internal representation of the randomized chess configurations.

Consistent with the above argument both de Groot (1946, 1965) and Chase and Simon (1973a, 1973b) highlight the importance of perceptual encoding of chess configurations as the key determinant of chess skill. For example, in a seminal paper entitled 'Perception in Chess', Chase and Simon (1973a) introduced their chunking theory of skilled performance in chess, stressing the role of perceptual encoding. Echoing an earlier conclusion by de Groot (1946, 1965) that the efficiency of perceptual encoding processes was a more important differentiator of chess expertise than was the ability to think ahead in the search for good moves, Chase and Simon (1973a) argued 'that the most important processes underlying chess mastery are these immediate visual-perceptual processes rather than the subsequent logical-deductive thinking processes' (p. 215). Chase and Simon (1973a, 1973b) postulated that the link between the initial *perceptual phase* and a subsequent *search phase* of the problem-solving process was to be found in the associations between perceptual chunks and plausible move generation. Through extensive study and practice, expert players build up associations between perceptually recognizable chunks (i.e. groups of chess pieces related by type, color, or role) and long-term memory structures that trigger the generation of plausible moves for use by a search mechanism. Search is thereby constrained to the more promising branches in the space of possible moves from a given chess position. The size of an expert's vocabulary of chess-related configurations (chunks) was initially estimated to be between 10 000–100 000 chunks (Simon and Gilmartin 1973) with 50 000 taken as the best estimate (Simon and Chase 1973). However, a more recent estimate puts the number of chunks at approximately 300 000 (Gobet and Simon 2000). In addition, small perceptual chunks are most likely supplemented by larger structures termed templates (Gobet and Simon 1996b; Gobet and Simon 1998).

In the remainder of this chapter we review the available empirical evidence pertaining to the suggestion of Chase and Simon (1973a, 1973b) and de Groot (1946, 1965) that a perceptual advantage is a fundamental component of chess skill. In particular, the present review is predominantly focused on key findings obtained from studies employing eye-movement monitoring methodology. Accordingly, we begin with a brief review of evidence concerning perceptual encoding in chess based on early studies employing eye-movement measurement. We then provide a detailed summary and review of a research program by Reingold, Charness and their colleagues (Charness *et al.* 2001;

Reingold *et al.* 2001a, 2001b) that employed more modern eye-movement paradigms and provided strong support for enhanced perceptual encoding as a function of chess expertise.

Predictions and early studies

An important goal of the present review is to illustrate the potential role of eye-movement measurement in supplementing traditional measures of performance such as reaction time (RT), accuracy, and verbal reports as a means for investigating the perceptual aspects of skilled performance in general, and chess skill in particular. Given the pivotal role played by eye-movement paradigms in the study of reading skill (see Rayner 1998 for a review) it is surprising that there are very few empirical studies which have employed these techniques in chess. One facilitating factor for using eye-movement measurement in chess is that just like words and sentences, the chess board is easily, visually segmentable. In addition, if as suggested by Chase and Simon (1973a, 1973b) and de Groot (1946, 1965), chess masters perceptually encode chess positions more efficiently by relying upon larger patterns of related pieces (i.e. chunks), then several predictions concerning differences in eye-movement patterns between expert and intermediate players can be made. For example, encoding of chunks rather than individual pieces may mean fewer fixations, and fixations between related pieces, rather than on pieces. This may also imply that in any given fixation experts process information about a larger segment of the chessboard than less-skilled players, constituting an increase in the perceptual or visual span as a function of expertise. That is, experts are expected to make greater use of parafoveal processing than intermediate players. In addition, experts may make greater use of automatic and parallel extraction of chess relations relative to intermediate players.

Several early studies employing eye-movement measurement provided weak support for the idea that perception of chess-related configurations improves with skill. Tikhomirov and Poznyanskaya (1966) and Winikoff (1967) both found evidence that when chess players fixate on a chess piece, they also extract information about other pieces near the point of gaze and often move to fixate a related piece. Based on this general process, Simon and Barenfeld (1969) devised a computer model to simulate the initial scanning patterns chess players might use when encoding a chess position. Their simulation, PERCEIVER, produced eye-movement patterns that resembled those of chess players. Reynolds (1982) and Holding (1985) re-examined the eye-movement data collected by Tikhomirov and Poznyanskaya (1966), and noted that many fixations did not fall on pieces, but on empty squares. However, because these studies were not focused on individual differences, there was no report of systematic variation in the proportion of fixations on empty squares as a function of skill.

Re-analyzing the work of Jongman (1968), de Groot and Gobet (1996) reported no significant difference in the proportion of fixations on empty squares as a function of skill. These authors cautioned, however, that the negative results do not necessarily refute the chunking hypothesis. They pointed out that the crude frame-by-frame analysis of film records of eye movements and the transformation of gaze positions from a three-dimensional chessboard viewed by the players to a two-dimensional

co-ordinate system may have resulted in the introduction of noise making it difficult to estimate the accuracy of the computed gaze position. Furthermore, de Groot and Gobet (1996) demonstrated that skilled players made more fixations along the edges of squares (28.7 per cent of fixations) as compared with novices (13.7 per cent), providing some indication that the skilled players may be able to encode two or more pieces in a single fixation. In addition, on the basis of their analysis of retrospective verbal reports, de Groot and Gobet (1996) concluded that the best players tended to perceive groups of pieces, rather than individual pieces. Finally, they developed a successful computer simulation that depended heavily on chunk differences to simulate eye-movement patterns differences between novices and experts.

Recent studies

In this section of the chapter we provide an extensive review of the findings we reported in several previous publications (Charness *et al* 2001; Reingold *et al.* 2001a, 2001b). In addition, we report new data from several additional experiments, which we conducted, that replicate and extend the published findings. We also include re-analysis of published data in order to facilitate the integration of results across papers.

Visual span and chess expertise

In Reingold *et al.* (2001a) we predicted that the perceptual advantage demonstrated by chess experts is mediated by a larger visual span for chess-related, but not for chess-unrelated, visual patterns. Such an increase in the visual span as a function of skill would indicate that while examining structured but not random chess configurations, experts extract information from a larger portion of the chessboard during an eye fixation (hence the term visual span, also referred to in the literature as the perceptual span or the span of effective vision, see Jacobs 1986; Rayner 1998). We tested this prediction by employing two different tasks: 1) A 'change blindness' flicker paradigm, and 2) A check detection paradigm. The tasks and results are described below.

The participants in the flicker paradigm were 16 novices who reported playing no games of chess in the past year and very few games over their lifetime, 8 intermediates and 8 experts. Mean Chess Federation of Canada (CFC) ratings were 1483 (range = 1300–1700) and 2278 (range = 2200–2400) for the intermediates and experts respectively. Another group of 20 novices, 10 intermediates, and 10 experts participated in the check detection task. CFC ratings for the expert players ranged between 1950–2352 (mean = 2117) and CFC ratings for the intermediates ranged between 962–1387 (mean = 1226). Eye movements were measured with an SR Research Ltd. EyeLink system.

The change blindness flicker paradigm

The flicker paradigm was introduced by Rensink *et al.* (1997). In the present application of this paradigm, two types of configurations were used: chess configurations (with 20 chess pieces in each) selected from a large database of chess games, and random configurations, which were created by repeatedly and randomly exchanging

pieces in the chess configurations. Thus, random positions maintained the same spatial configuration but destroyed the chess relation information. Each random or chess configuration was modified by changing the identity but not the color of a single piece to create a modified display (see the two diagrams in the top row of Fig. 14.2 for an illustration of an original and a modified display of a chess configuration). In each trial, images of the original and modified board configurations were displayed sequentially and alternated repeatedly with a blank interval between each pair of configurations (i.e. original, blank, modified, blank, original …). Each variant of the configuration (i.e. original, modified) was presented for 1000 ms, with the display blanking for 100 ms between each alternation. As soon as participants detected the changing piece (the target), they ended the trial by pressing a button and naming the alternating pieces. Previous research indicated that participants are surprisingly poor

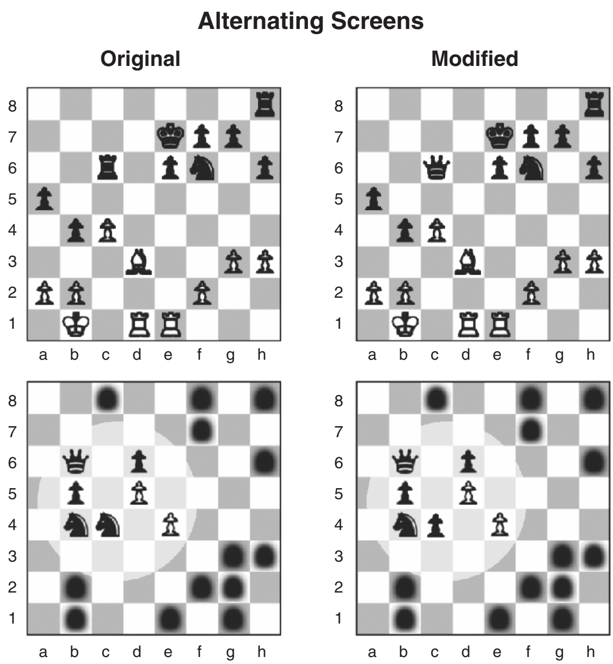

Figure 14.2 Illustration of the gaze-contingent flicker paradigm. The top row displays an original (left) and a modified (right) chess configuration taken from an actual game (the changed piece is in square c6). The top row also illustrates a no-window baseline trial in which the entire display was visible. The bottom row displays an original (left) and a modified (right) chess configuration (the changed piece is in square c4) in a gaze-contingent window condition, with chess pieces outside the window being replaced by blobs masking their identity and color (note that the difference in luminance between the regions inside and outside the window was not present in actual experimental displays and was added here for illustrative purposes).
From Reingold *et al.* (2001a).

at change detection in the flicker paradigm, a phenomenon termed 'change blindness' (Rensink *et al.* 1997; see Simons and Levin 1997 for a review). We predicted that when processing chess configurations, but not random configurations, chess experts would demonstrate larger visual spans and better change detection than less-skilled players.

In this task the visual span as a function of chess skill (novice vs. intermediate vs. expert) and configuration type (chess configuration vs. random configuration) was measured using a gaze-contingent window technique (e.g. McConkie and Rayner 1975; see Rayner 1998, for a review). As shown in Fig. 14.2 (bottom row), a gaze-contingent window requires obscuring the identity of all chess pieces except those within a certain 'window' that is continually centered on the participant's gaze position. The pieces outside a circular, gaze-centered window were replaced with gray blobs masking the actual colors and shapes. The participant's visual span was measured by varying the size of the window over successive trials and determining the smallest possible window that did not significantly differ from the participant's normative RT criteria. These criteria were established separately for chess configuration and random configuration by using baseline trials in which the entire display was visible (i.e. no-window trials; see top row of Fig. 14.2). Note that change detection in the present task required no chess knowledge and consequently we were able to explore visual span across a broad range of chess skill stretching from novice to master.

For each skill group by configuration type, Fig. 14.3, Panel A displays the average median RTs obtained in the no-window baseline trials that were used to compute the normative RT criteria. As can be clearly seen in this figure, the difference between RTs in chess vs. random configuration trials was only significant in the expert group. Furthermore, for random configuration trials RTs did not differ significantly across skill groups. In contrast, on chess configuration trials RTs were significantly different across groups, with experts being significantly faster than both intermediates and novices. The visual span results shown in Fig. 14.3, Panel B follow the same pattern as the RT results. Specifically, experts' span area for chess configurations was dramatically larger than all other skill groups by configuration type cells, which in turn did not differ from each other. Thus, consistent with Chase and Simon's hypothesis (1973a, 1973b), the increase in visual span area and speed of responding which characterizes expert performance on trials with chess, but not random configurations, clearly indicates an encoding advantage attributable to chess experience, rather than to a general perceptual or memory superiority.

The check detection task

To examine differences in the spatial distribution of fixations between experts and novices, we monitored eye movements of another sample of chess players in a check detection task. Saariluoma (1985) has shown that master players can rapidly and accurately decide whether a chess piece is attacked, and do so more quickly than their less-skilled counterparts. The rather simple chess relation of check detection (attack of a king) is highly salient and presents a good model for the extraction of chess-relevant relations among pieces. As shown in Fig. 14.4 (top 2 rows), in the present study check detection was performed using a minimized 3×3 chessboard containing a black king and one or two potentially checking pieces. At the beginning of each trial, participants

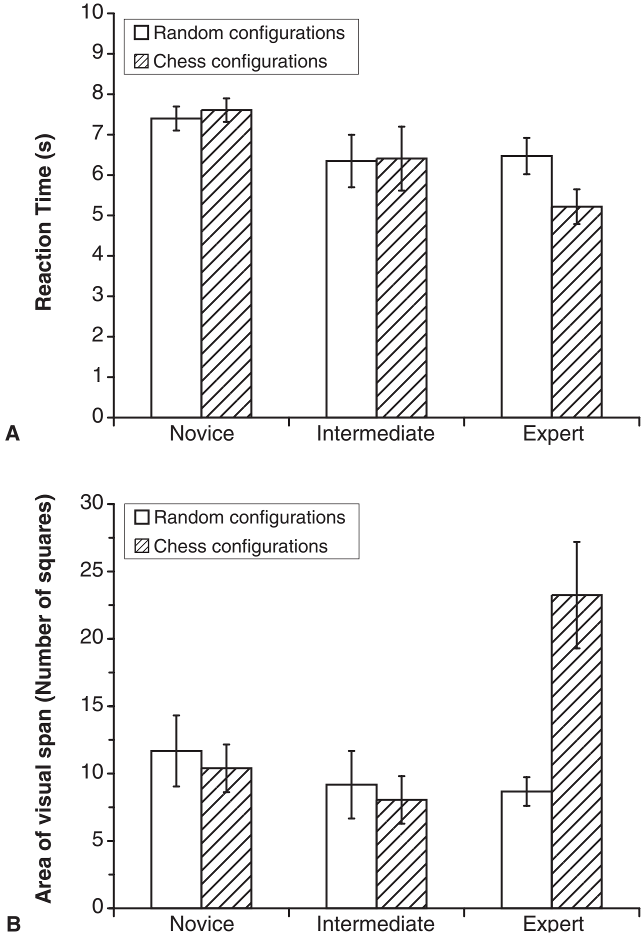

Figure 14.3 Median reaction times in the no-window baseline trials (Panel A) and area of visual span (number of squares) (Panel B) in the flicker paradigm by skill and configuration type. Data from Reingold *et al.* (2001a).

fixated the center square of the board, a square that was always empty. A large visual span in this task may result in few, if any saccades, during a trial and in fixations between, rather than on individual pieces. To demonstrate that the encoding advantage of experts is related at least in part to their chess experience, rather than to a general perceptual superiority, we manipulated the familiarity of the notation (symbol vs. letter) used to represent the chess pieces. The symbol and letter notations (row 1 vs. 2 in Fig. 14.4) were used to represent identical chess problems. However, the symbol representation is much more familiar than the letter representation. Consequently, if encoding efficiency is related to chess experience, any skill advantage should be more pronounced in the symbol than in the letter trials (i.e. a skill by notation interaction).

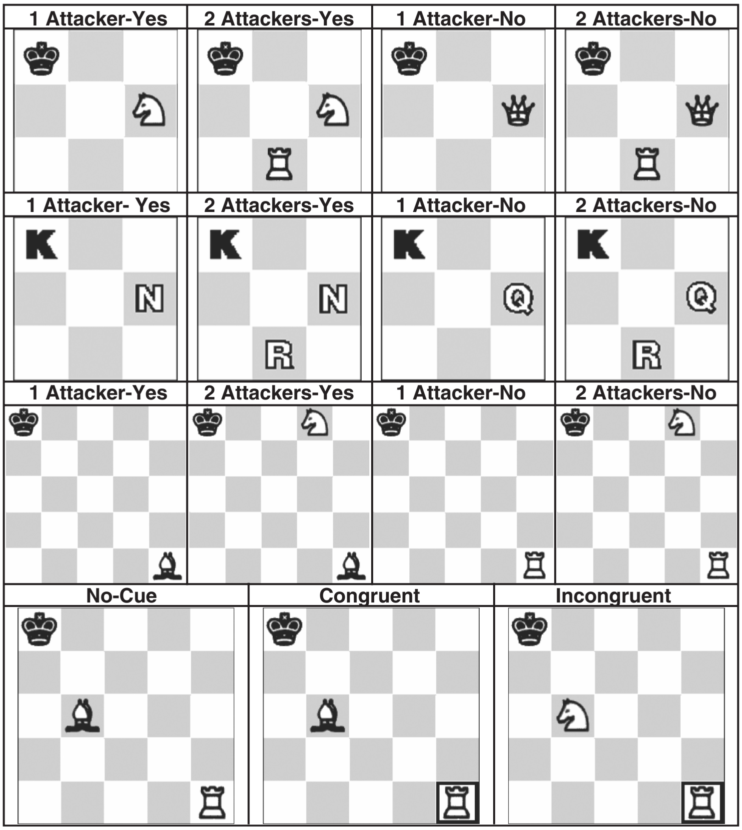

Figure 14.4 Illustration of the stimuli used in the check detection task. The top two rows illustrate the notation manipulation (row 1 – symbol vs. row 2 – letter) in Reingold *et al.* (2001a). The third row illustrates the manipulation of check status (present/'yes' vs. absent/'no' trials) by number of attackers (one vs. two) in Reingold *et al.* (2001b). The bottom row illustrates the Stroop manipulation in Reingold *et al.* (2001b) and in a replication study (see text for details). Three conditions are shown, the no-cue condition that consisted of 'no' trials with two attackers and two conditions in which a cued non-checking attacker (shown surrounded by a frame) appeared together with an attacker that was either congruent (i.e. non-checking) or incongruent (i.e. checking). In the latter two conditions the task was to determine if the cued attacker was checking the king while ignoring the other attacker.

In order to compare the spatial distributions of gaze positions in the check detection task across the novice, intermediate and expert groups, Fig. 14.5 shows scattergrams with each dot representing an individual gaze position. An inspection of the scattergrams collapsing across all trial types (i.e. the spatial layout of chess pieces, check status, and notation), with initial gaze positions included (the top row of Fig. 14.5), reveals a greater concentration of black pixels in the center of the scattergram

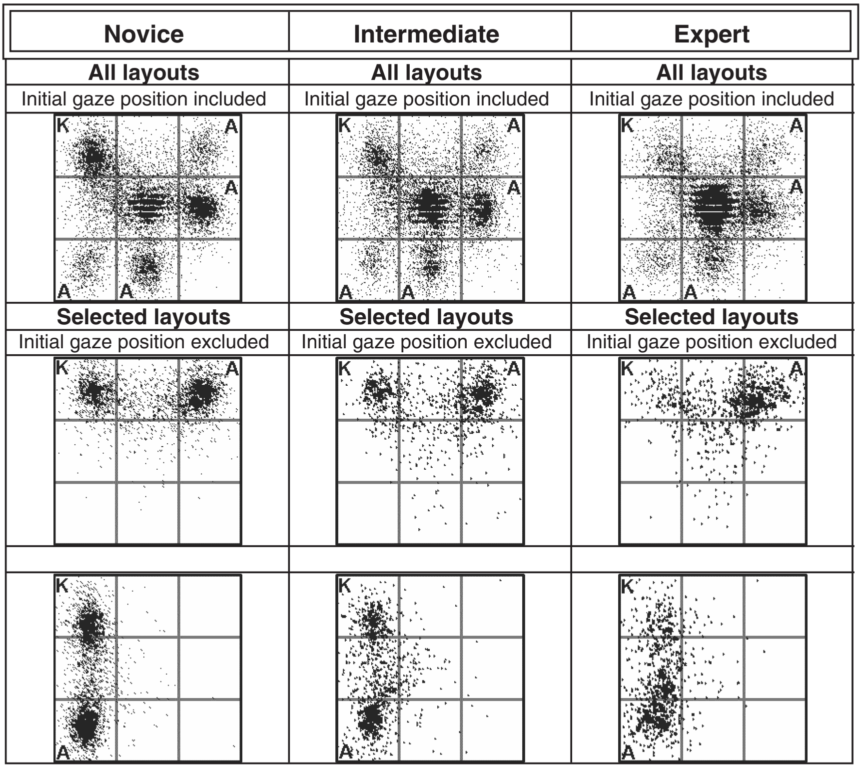

Figure 14.5 Scattergrams of gaze positions in the check detection task by skill. The capital letter 'A' represents the position of an attacker piece and 'K' represents the position of the king. Data from Reingold *et al.* (2001a).

for the experts as compared with the intermediates and novices. This center of gravity effect reflects a large disparity between skill groups in the proportion of trials without an eye-movement (i.e. no-saccade trials). In such trials the gaze position remained in the center square of the chessboard throughout the duration of the trial. For each skill group by notation type, Panel A of Fig. 14.6 displays the proportion of no-saccade trials. As can be clearly seen in this figure, only the expert group demonstrated a substantial proportion of no-saccade trials and the proportion of such trials was greater for the symbol notation than the letter notation in this group of players.

As shown in Fig. 14.6 Panel B, in trials in which eye movements occurred, experts made fewer fixations than intermediates and novices. More importantly, for both experts and intermediates, but not for novices, the symbol notation resulted in fewer fixations than the letter notation. In order to compare the spatial distribution of fixation positions across groups we computed the proportion of fixations landing on squares containing chess pieces (henceforth proportion on pieces). Examining scattergrams with initial gaze positions excluded (the middle and bottom rows of Fig. 14.5) clearly indicates that experts made proportionately fewer fixations on pieces

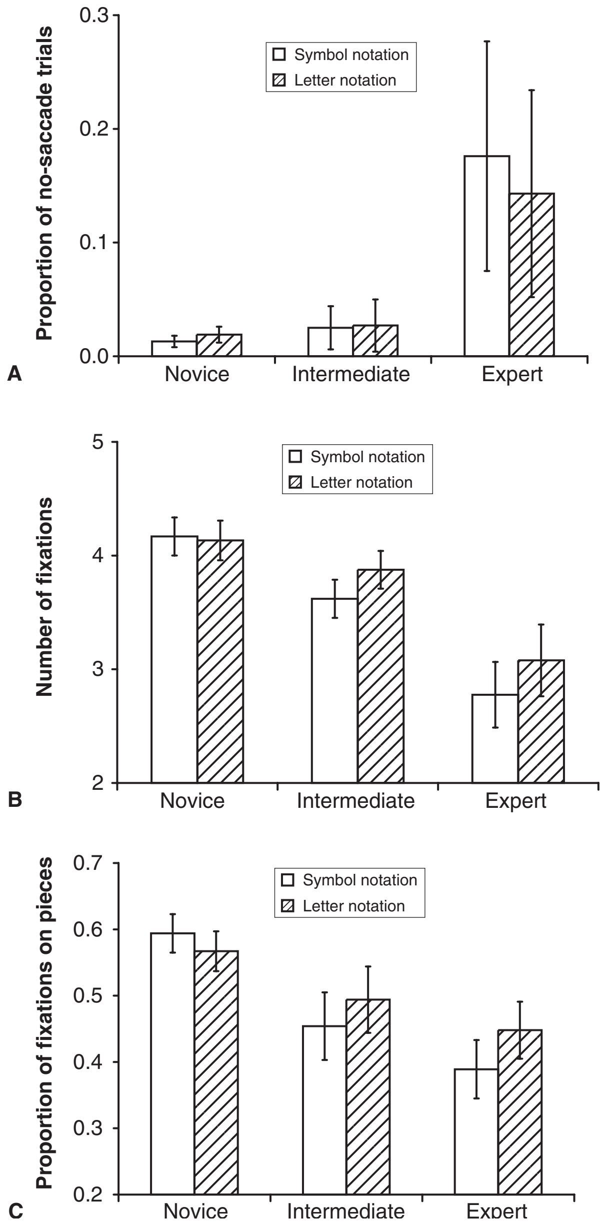

Figure 14.6 Proportion of no-saccade trials (Panel A), number of fixations (Panel B) and the proportion of fixations on pieces (Panel C) in the check detection task by skill and notation. Data from Reingold *et al.* (2001a).

than did intermediates and novices. As shown in Fig. 14.6, Panel C, for both experts and intermediates, the symbol notation resulted in fewer fixations on pieces than the letter notation, with the opposite being the case for novices.

Thus, consistent with Chase and Simon's (1973a, 1973b) chunking hypothesis, in the check detection task, chess experts made fewer fixations and placed a greater proportion of fixations *between* individual pieces, rather than *on* pieces. The magnitude of these effects was stronger for the more familiar symbol notation than for the letter notation, demonstrating that the experts' encoding advantage is related at least in part to their chess experience, rather than to a general perceptual superiority.

Automatic and parallel extraction of chess relations as a function of expertise

Based in part on the dramatic demonstration of larger visual span in chess experts, Reingold *et al.* (2001b) proposed that one possible mechanism that may allow chess masters to process chess configurations more efficiently is automatic and parallel extraction of several chess relations that together constitute a meaningful chunk. A prerequisite for the encoding of chess relations is the identification of pieces and locations. Thus, we envision a two-phase process underlying the encoding of meaningful chess positions. In the first phase, players encode the identity (type and color) and location of chess pieces (the locations of pieces are encoded via absolute location coding rather than relative location coding; Gobet and Simon 1996b; Saariluoma 1994). It is important to note that identification of pieces and locations is likely to involve multiple processes, some of which are serial in nature (e.g. directing or focusing of spatial attention that is often accompanied by eye movements) and consequently, total encoding time will be sensitive to the number of pieces in a configuration. In the second phase, which may partially overlap (i.e. cascade) with the first phase (see McClelland 1979 for a framework for analyzing processes in cascade), players process internal representations that contain piece identity and location information to extract or compute chess relations. This process can be seen as binding pieces into chess chunks.

Based on the results reviewed above, it is likely that the main perceptual advantage for experts is not in the identification of single chess pieces and board locations (i.e. phase 1 processes), but rather in the extraction of relational information between pieces (i.e. phase 2 processes). This is powerfully demonstrated by the strong skill effects on the area of the visual span obtained with actual chess configurations (i.e. where relational information is intact), coupled with the absence of skill effects on span size obtained with random configurations (i.e. where relational information is broken down). Accordingly, the research described in this section was specifically designed to test the hypothesis of automatic and parallel extraction of chess relations by experts.

We employed a check detection task in a minimized 5×5 section of the chessboard, containing a king and one or two potentially checking pieces. In the first part of the experiment we manipulated checking status (i.e. the presence or absence of a checking piece for 'yes' and 'no' trials respectively) and the number of attackers (one or two). As shown in the four diagrams in the third row of Fig. 14.4, adding a distractor (i.e. a non-checking piece) created trials with two attackers. We reasoned that if the chess relations between each of the attackers and the king are processed in a serial

self-terminating manner, the RT cost of adding a distractor should be differentially greater in ‘no’ trials than in ‘yes’ trials. This is the case because an accurate response in ‘no’ trials requires considering both potentially checking relations, whereas, by chance, on half of the ‘yes’ trials the checking relation is examined first, permitting an accurate termination of the trial without considering the second attacker. In contrast, parallel processing of chess relations will manifest as comparable RT costs for adding a distractor across both types of trials. See Treisman and Gelade (1980) and Wolfe (1998) for a similar methodology aimed at documenting parallel visual search.

Note that we are predicting a reaction time cost for adding an attacker (i.e. one vs. two attackers), even for expert players, due to the prerequisite encoding of piece identity and location prior to the extraction of chess relations. The cost should occur because serial processing in phase 1 is assumed to be sensitive to the number of pieces in the configuration. Although the same prediction applies also to the check detection task in Reingold *et al.* (2001a) (see the four diagrams in the top row of Fig. 14.4) it was not tested in the published paper. We therefore present the results of an identical analysis for both papers (Reingold *et al.* 2001a, 2001b).

Given our interest in documenting automatic extraction of chess relations by experts, we also attempted to demonstrate a skill-related interference effect. The vast majority of studies investigating expertise in general, and chess skill in particular, have documented facilitation effects as a function of skill. That is, experts always outperformed their less-skilled counterparts. However, theories of attention and automaticity have long recognized that interference, such as that in the Stroop paradigm (Stroop 1935; see MacLeod 1992 for a review), is a much more compelling demonstration of automaticity relative to facilitation paradigms (for a related methodology in unconscious memory research see Jacoby 1991; Jacoby *et al.* 1993; Reingold 1995; Reingold and Toth 1996; Toth *et al.* 1994). This is the case because despite a strong incentive to consciously oppose automatic influences, such automatic influences are nevertheless manifested. In a typical demonstration of the Stroop effect, the irrelevant meaning of a color word interferes with the naming of an incongruent ink color in which it is written. Thus, skilled readers cannot strategically avoid the automatic encoding of word meanings despite its detrimental effects on performance.

Accordingly, in the second part of the experiment reported in Reingold *et al.* (2001b) we contrasted the standard check detection trials with two attackers, with trials in which one of two attackers was cued (colored). In this condition, the task was to determine if the cued attacker was checking the king while ignoring the other attacker. In order to avoid any predictability in the stimulus set, the checking status of the cued and uncued attackers were manipulated separately (i.e. yes/yes, yes/no, no/yes and no/no). However, as shown in the bottom row of Fig. 14.4, our predictions focus exclusively on contrasting three conditions: a no-cue condition (i.e. no cueing) which consisted of the standard check detection ‘no’ trials with two attackers, and two conditions in which a cued non-checking attacker appeared together with an attacker that was either congruent (i.e. non-checking, no/no) or incongruent (i.e. checking, no/yes) (henceforth the congruent and incongruent conditions). Note that all of these trials are ‘no’ trials even though the incongruent condition contains a checking attacker. That is, in the incongruent condition, the semantics of the cued chess relation

(i.e. no check) is inconsistent with the semantics of the configuration as a whole (i.e. check). Serial processing of chess relations will manifest as faster RTs in the congruent condition, than in the no-cue condition, as the cueing constrains the search space. In contrast, parallel processing of chess relations should result in no benefit from cueing in the congruent condition. In addition, if parallel processing of chess relations occurs, cueing should produce slower RTs in the incongruent, than in the congruent condition, demonstrating Stroop-like interference.

We also conducted a replication study to the Stroop condition reported in Reingold *et al.* (2001b). The main difference across these two studies was that eye-movement measurement was added in the replication experiment. A more minor difference concerns the method used across studies to cue an attacker in the congruent and incongruent conditions. Specifically, in the published study, the cued attacker was colored, whereas in the replication study, a colored bold frame surrounded the cued attacker (see bottom row of Fig. 14.4).

In both Reingold *et al.* (2001b) and the replication study, three groups of 14 participants were included (14 novices, 14 intermediates and 14 experts). In Reingold *et al.* (2001b) CFC ratings for expert players ranged between 2100–2351 (mean = 2218) and CFC ratings for the intermediates ranged between 1401–2000 (mean = 1799). In the replication study CFC ratings for expert players ranged between 2053–2317 (mean = 2171) and CFC ratings for the intermediates ranged between 1436–1995 (mean = 1738).

Results

The differential cost of adding an attacker in a 'yes' vs. a 'no' trial

Figure 14.7 shows the results from the check status by number of attackers manipulation in both Reingold *et al.* (2001b) (see Fig. 14.7, Panel A for results; see third row in Fig. 14.4 for an illustration of the stimulus displays and conditions) and in the symbol notation condition in Reingold *et al.* (2001a) (see Fig. 14.7, Panel B for results; see top row in Fig. 14.4 for an illustration of the stimulus displays and conditions). As shown in Fig. 14.7 the results are extremely similar across studies and are therefore discussed together. Average median RTs were computed for each group and condition (trials on which participants responded incorrectly were excluded). As can be seen in Fig. 14.7, the group by check status by number of attackers interaction was significant. This interaction is best understood by considering the differences in the increase in RTs from one to two attackers for 'yes' vs. 'no' trials. For experts, there was a comparable cost for adding an attacker in both 'yes' trials (Reingold *et al.* 2001b = 171 ms; Reingold *et al.* 2001a = 131 ms) and 'no' trials (Reingold *et al.* 2001b = 167 ms; Reingold *et al.* 2001a = 123 ms). For intermediates, the corresponding increase for 'yes' trials (Reingold *et al*; 2001b = 203 ms; Reingold *et al.* 2001a = 258 ms) was numerically, but not significantly, smaller than 'no' trials (Reingold *et al.* 2001b = 262 ms; Reingold *et al.* 2001a = 291 ms). Finally for novices, the increase for 'yes' trials (Reingold *et al.* 2001b = 330 ms; Reingold *et al.* 2001a = 299 ms) was substantially and significantly smaller than 'no' trials (Reingold *et al.* 2001b = 458 ms; Reingold *et al.* 2001a = 422 ms). Analyzing error rates across the same conditions revealed no evidence of a speed-accuracy tradeoff. Thus, in both studies, we documented a greater increase in RT cost for adding a

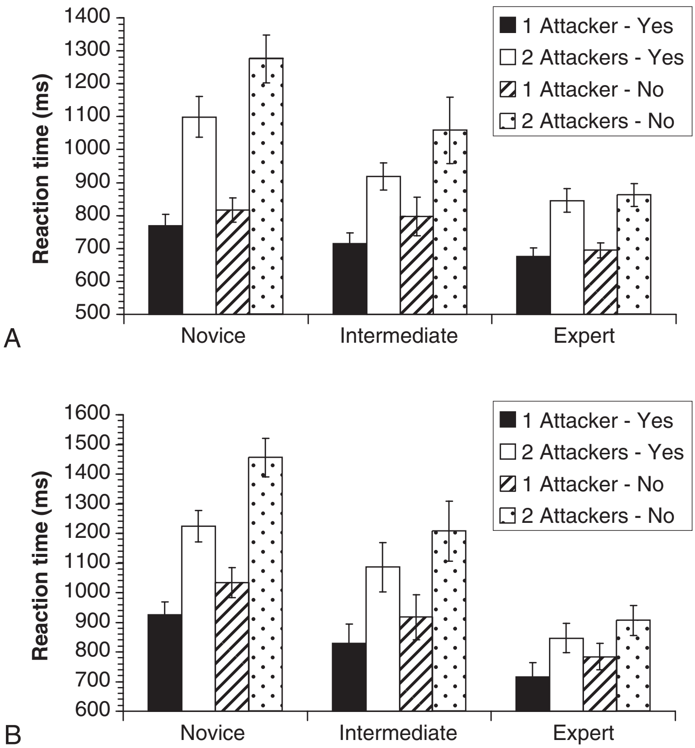

Figure 14.7 Average median reaction times (ms) in the check detection task by skill (expert vs. intermediate vs. novice) by check status (present/'Yes' vs. absent/'no' trials) and by number of attackers (1 vs. 2) in Reingold *et al.* (2001b) (Panel A) and Reingold *et al.* (2001a) (Panel B).

distractor (i.e. one vs. two attackers) in 'no' vs. 'yes' trials for weaker players, but not for experts. This is consistent with the hypothesis that chess experts can extract some chess relations in an automatic and parallel manner.

The chess Stroop condition

As discussed above, with respect to the Stroop manipulation there are two sets of critical contrasts: the no-cue and congruent conditions, and the congruent and incongruent conditions (see bottom row of Fig. 14.4). Figure 14.8, Panel A shows the pattern of RTs across these conditions in Reingold *et al.* (2001b). In addition, Fig. 14.8, Panels B–D present the results of the eye-movement measures for these conditions in the replication experiment.

The no-cue condition included 'no' trials with two uncued attackers. This condition was compared with the congruent condition which was identical to the no-cue condition in all respects except that one of the two attackers was cued and participants were asked to decide whether the cued attacker was checking, disregarding the other attacker.

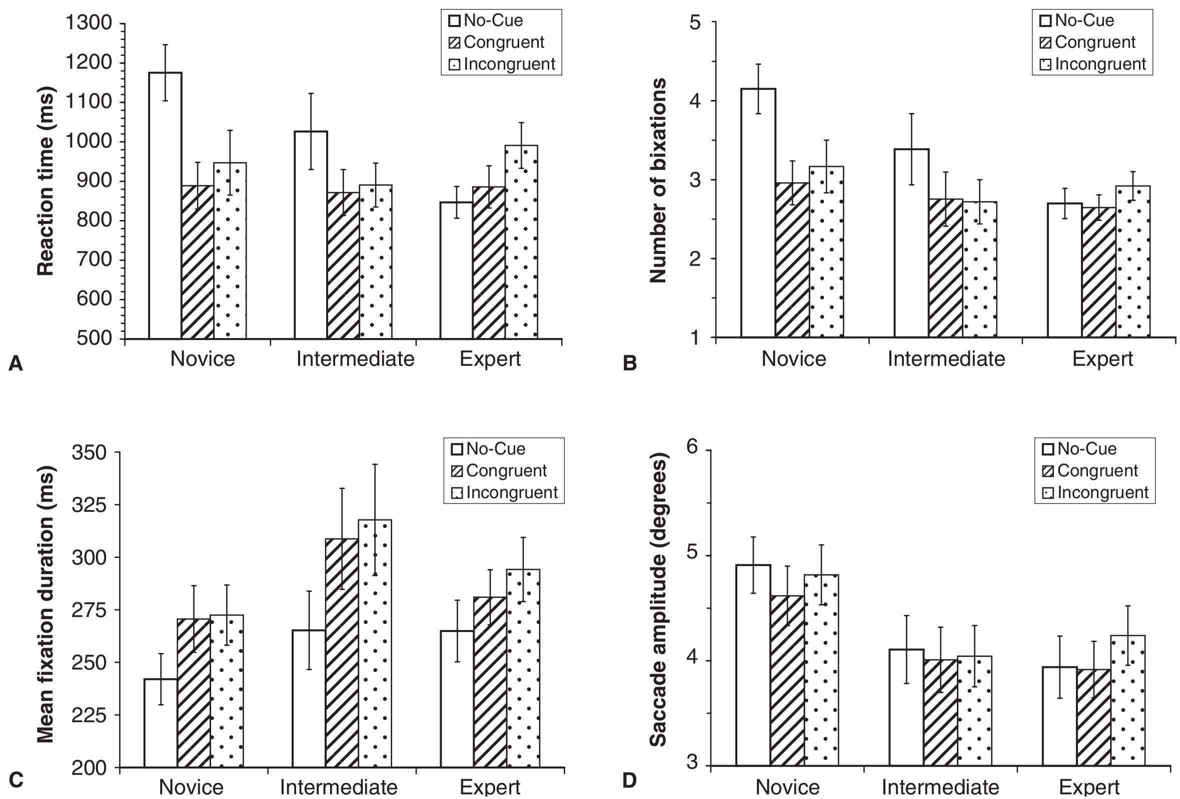

Figure 14.8 Average median reaction times (Panel A), number of fixations (Panel B), mean fixation duration (Panel C) and mean saccade amplitude (Panel D) in the check detection task by skill and condition (no-cue vs. congruent vs. incongruent). Data from Reingold *et al.* (2001b) and a replication study (see text for details).

If processing of chess relations is serial, the cueing in the congruent condition should improve performance compared with the no-cue condition because it eliminates the necessity to examine one of two potentially checking relations. On the other hand, in the case of parallel extraction of chess relations, cueing should not produce such facilitation. In addition, if parallel processing of chess relations occurs, cueing should produce worse performance in the incongruent, than in the congruent condition, demonstrating Stroop-like interference.

When comparing the congruent and the no-cue conditions in Fig. 14.8, Panel A, it is clear that experts derived no benefit from cueing (there was a non-significant trend in the opposite direction: 24 ms). In marked contrast, for both the intermediates and novices, the cueing in the congruent condition produced substantial facilitation relative to the no-cue condition (intermediates: 187 ms, novices: 386 ms). A very similar pattern was obtained in the replication experiment. Figure 14.8, Panel B shows that for intermediates and novices, cueing in the congruent condition produced facilitation in the form of fewer fixations relative to the no-cue condition. In contrast, for experts there was no significant difference in the number of fixations across these conditions.

When comparing the congruent and the incongruent conditions in Fig. 14.8, Panel A, it is evident that the experts demonstrated Stroop-like interference (a significant 105 ms slowing). Intermediates demonstrated no significant interference (19 ms slowing) and novices demonstrated marginally significant interference (58 ms slowing). Note, however, that for both the intermediates and novices, but not for the experts, the beneficial effects of cueing (i.e. constraining the search space) far outweighed any disruption caused by the uncued checking attacker, resulting in a net facilitation effect (incongruent vs. no-cue: intermediates: 136 ms facilitation; novices: 228 ms facilitation; experts: 144 ms interference). Similarly, as shown in Fig. 14.8, experts demonstrated Stroop-like interference effects on the eye movements measures producing significantly more fixations (Panel B), longer mean fixation duration (Panel C) and larger amplitude saccades (Panel D) in the incongruent condition as compared with the congruent condition.

Summary

Across all of the experiments employing the check detection paradigm (Reingold *et al.* 2001a, 2001b; and the eye-movement replication study reported here), there are three convergent findings demonstrating parallel extraction of chess relations by experts. First, we documented a greater increase in RT cost for adding a distractor (i.e. one vs. two attackers) in 'no' vs. 'yes' trials for weaker players, but not for experts. Second, when contrasting the no-cue condition with the congruent condition, it is clear that, unlike weaker players, experts do not benefit from cueing. Note that these two conditions are identical in terms of pieces and locations (both require the same 'no' response) and consequently, this contrast provides a particularly powerful way for isolating the chess relation extraction processes. Finally, although parallel extraction of features normally facilitates performance, in the case of the artificial incongruent condition, it produced Stroop-like interference in skilled performers because they could not prevent the generation of a positive response (check present) to the configuration as a whole, even though the cued attacker was non-checking and the correct response was 'no'.

The move-choice task and the issue of ecological validity

Given the strong support for enhanced perceptual encoding as a function of chess expertise obtained in the studies reviewed above (i.e. Reingold *et al.* 2001a, 2001b), in Charness *et al.* (2001) we attempted to extend these findings to the more ecologically valid task of choosing the best move with full chessboard displays (henceforth, the move-choice task). We chose to investigate the move-choice task for several reasons. First, eye-movement studies have long shown that the nature of the task set for the observer can result in very different patterns of fixations for the same visual configuration (e.g. Yarbus 1967). The fixation patterns for memorizing a chess position (de Groot and Gobet 1996) or performing simple check detection (Reingold *et al.* 2001a) may not be representative of those in problem solving situations. Second, de Groot (1946, 1965) demonstrated that performance on the move-choice task (quality of move chosen) discriminates well between chess players at different levels of skill.

In this section of the paper we review the findings from two experiments that recorded eye movements of players during the performance of the move-choice task. An experiment by Charness *et al.* (2001) and an unpublished follow-up experiment. Twelve intermediate and 12 expert chess players participated in the experiment by Charness *et al.* (2001). CFC ratings for the expert players ranged between 2100–2350 (mean = 2238). CFC ratings for the intermediates ranged between 1400–1923 (mean = 1786). Ten intermediates, and ten experts participated in the follow-up experiment. CFC ratings for the expert players ranged between 1912–2332 (mean = 2105). CFC ratings for the intermediates ranged between 968–1355 (mean = 1245). In each study five experimental chess positions were used. All positions had a clear best move. Prior to the presentation of each position, players were told who was to move (white or black). Players were asked to choose and announce the best move as quickly and as accurately as possible.

Charness *et al.* (2001)

Given our interest in documenting the influence of expertise on perceptual encoding, in Charness *et al.* (2001) we focused on the first 1–2 s of eye fixations in each trial. This was considered important in order to attribute any potential skill differences to the perceptual, rather than the problem-solving phase. In other words, given that experts encode positions more quickly than intermediate players, going much beyond five fixations might lead to a skill-related confound of fixations used to encode the initial representation vs. fixations that promote problem-solving processes (e.g. search through the space of possible moves). Hence, we investigated the spatial distribution of the first five fixations produced by players who attempt to choose the best move for a given position.

We tested two specific predictions. First, on the basis of the chunking hypothesis and the results of Reingold *et al.* (2001a, 2001b), we predicted that a greater proportion of fixations would occur on empty squares for experts, as compared with intermediates. Second, among fixations occurring on individual pieces, we predicted that a greater proportion of fixations would occur on salient pieces (i.e. tactically active pieces) for experts, as compared with intermediates. The latter prediction is based on a finding by de Groot and Gobet (1996) that the number and total duration of fixations landing on chess pieces during a memorization task were at least partially correlated with

the degree of importance or relevance of these pieces in a given position, and that the magnitude of this correlation increased as a function of skill. Similarly, based on their simulation of eye-movement data collected by Tikhomirov and Poznyanskaya (1966), Simon and Barenfeld (1969) argued that fixations fell on what they defined as the salient pieces for the position. In Charness *et al.* (2001) we determined piece saliency for the five positions used in the experiment by asking two international masters to classify pieces as salient or non-salient.

The top panel of Fig. 14.9 illustrates one of the positions used in the experiment. Pieces that were classified as salient are shown in this panel surrounded by a bold frame.

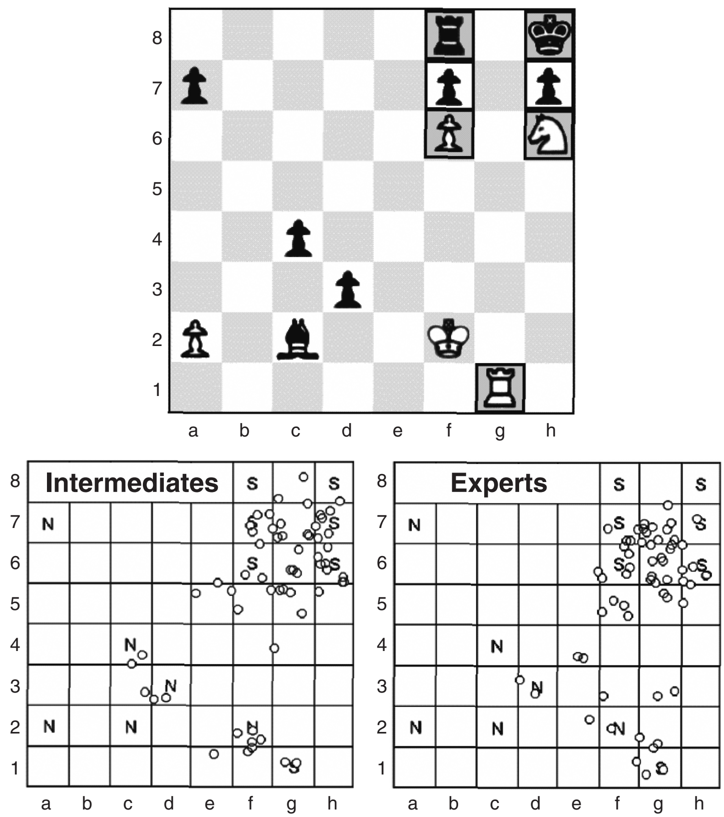

Figure 14.9 One of the positions used in the move choice task; (top panel) and scattergrams of gaze positions corresponding to the first five fixations produced by intermediates (bottom left panel) and experts (bottom right panel) while attempting to choose the best move in this position. Note: chess pieces surrounded by a bold frame in the top panel were judged to be salient (important) in the position by two international masters. In the bottom panels – S = Salient piece; N = Non-salient piece. Best move for this position = white rook moves to g8 check, black rook takes white rook, White knight takes pawn at f7 mate. Data from Charness *et al.* (2001).

The bottom panels in this figure show scattergrams aggregating the first five fixations for this position across intermediates (bottom left) and experts (bottom right). Each circle represents an individual fixation, and fixations were classified as falling on an empty square, or on a square occupied by a salient or a non-salient piece. To facilitate visual comparison across scattergrams, the letter S replaces salient pieces and the letter N replaces pieces that are not salient. As can be clearly seen by comparing the scattergrams, consistent with the chunking hypothesis, experts produced a greater proportion of fixations on empty squares than intermediates (experts: mean = 0.52; intermediates: mean = 0.41). In addition, consistent with de Groot and Gobet (1996), among fixations on pieces, experts produced a greater proportion of fixations on salient pieces than intermediates (experts: mean = 0.80; intermediates: mean = 0.64).

Follow-up experiment

Whereas in Charness *et al.* (2001) the focus was on the first five eye fixations (approximately the first 1–2 s) during the performance of the move-choice task, in the follow-up experiment we recorded fixations during the first 10 s in each trial. We hypothesized that an examination of changes in the number and duration of fixations, which may occur as the trial progresses, would be potentially useful in distinguishing between perceptual encoding and problem solving, or solution retrieval and evaluation. Specifically, perceptual encoding was expected to involve shorter fixations and consequently a greater number of fixations in a given time interval than problem solving. We were also interested in the proportion of fixations with durations greater than 500 ms. Such fixations have been previously identified as reflecting visual problem solving and evaluation (e.g. Nodine *et al.* 1978).

Figure 14.10 shows scattergrams aggregating all fixations in the first 10 s across intermediates (left panel) and experts (right panel) for one of the positions used in

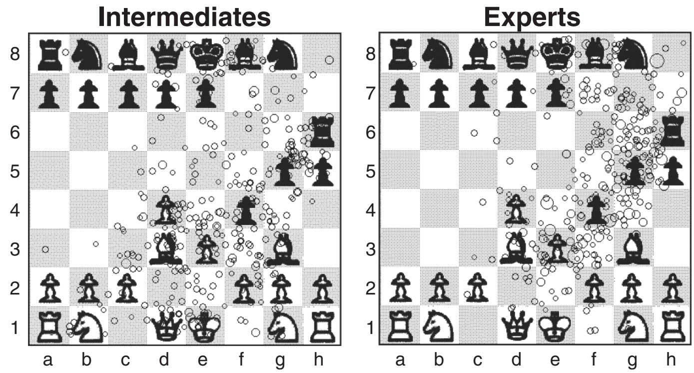

Figure 14.10 Scattergrams aggregating all fixations in the first 10 seconds across intermediates (left panel) and experts (right panel) for one of the positions used in the move choice task in follow-up experiment. Each circle represents an individual fixation, and the diameter of the circle increases as a function of an increase in fixation duration. Best move for this position = white queen takes pawn at h5 check, black rook takes white queen, white bishop moves to g6 mate.

the experiment. Each circle represents an individual fixation, and the diameter of the circle increases as a function of an increase in fixation duration. As can be clearly seen by comparing the scattergrams, consistent with the chunking hypothesis and the findings of Charness *et al.* (2001), experts produced a greater proportion of fixations on empty squares than intermediates (experts: mean = 0.55; intermediates: mean = 0.43). In addition, as indicated by a comparison of the relative size of circles across scattergrams, experts clearly produced a higher proportion of longer fixations than intermediates.

To analyze this issue more formally, we divided the 10-s period of eye-movement recording in the beginning of each trial into two 5-s intervals. We then computed the mean number of fixations and the proportion of fixations with durations > 500 ms in the first and second 5-s intervals across all trials for each player. Figure 14.11 displays these two dependent variables by skill group and interval. As can be seen in this figure, the pattern of performance is qualitatively different across experts and intermediates. Specifically, for intermediates there was no difference across intervals in the number of fixations and in the proportion of long fixations (i.e. > 500 ms).

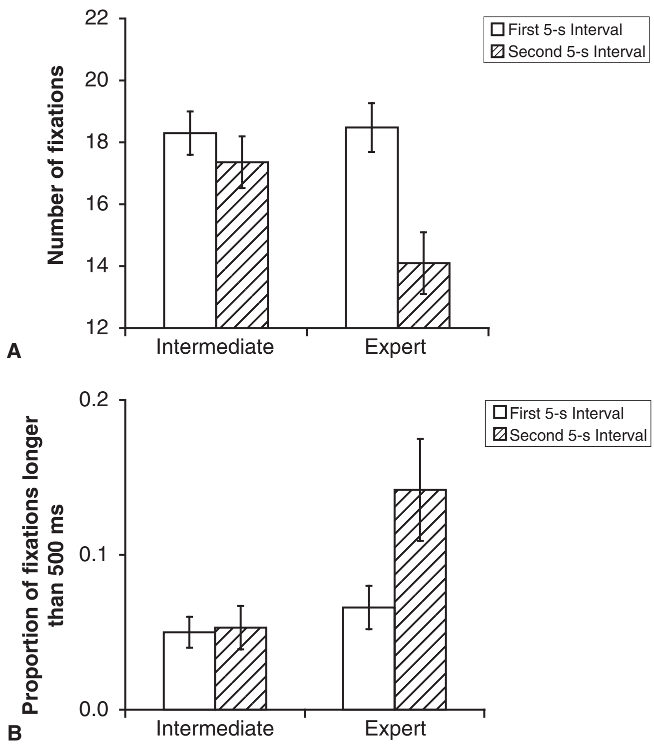

Figure 14.11 Number of fixations (Panel A), and the proportion of fixations longer than 500 ms. (Panel B) in the move choice task by skill and interval (first 5-s interval vs. second 5-s interval).

In marked contrast, experts produced substantially fewer fixations and a much greater proportion of long fixations as the trial progressed. This indicates that during the second 5-s interval in a trial, experts started engaging in problem solving, whereas intermediates were still perceptually encoding the chess configurations. This provides further support for the hypothesis of enhanced efficiency of pattern recognition processes in encoding chess configurations as a function of chess expertise.

Conclusions

The present review illustrates that eye-movement paradigms may prove invaluable in supplementing traditional measures of performance such as RT, accuracy, and verbal reports as a means for understanding human expertise in general, and chess skill in particular. Specifically, by employing eye-movement methodology, the research reviewed and reported here provided powerful and direct evidence for the suggestion of de Groot (1946, 1965) and Chase and Simon (1973a, 1973b) that a perceptual advantage is a fundamental component of chess skill.

The use of the gaze contingent window paradigm demonstrated that advanced chess skill attenuates change blindness by improving target detection in meaningful, but not scrambled chess configurations, and that this is due to a larger visual span size in the former, but not in the latter condition. The methodology reviewed here provided compelling evidence that in the case of check detection, a task that is well defined and for which positional uncertainty is minimized, experts, but not less-skilled players, extract chess relations using automatic and parallel procedures. Such procedures may help explain the greater reliance on parafoveal processing and the larger visual spans demonstrated by experts while examining chess configurations. In addition, the demonstration of a Stroop-like interference effect in experts, but not in intermediates, highlights the fact that expert–novice differences are qualitative, rather than just quantitative in nature. By examining the spatial distribution of fixations in both the simplified check detection task and the ecologically valid move-choice task it was demonstrated that consistent with the encoding of chunks rather than individual pieces, experts made fewer fixations, and fixations between related pieces, rather than on pieces. Furthermore, in the move-choice task the finding that piece saliency influences the selection of experts' saccadic endpoints during the first 1–2 s following display onset clearly supports the role of parafoveal or peripheral processing of chess configurations in guiding their eye movements. This is the case because random or systematic region-by-region scanning patterns (e.g. a reading like pattern from the top-left to the bottom-right section of the chessboard) would not be expected to result in similar findings of saccadic selectivity by piece salience. Finally, in the move-choice task, the comparison of the number and duration of fixations across the first and second 5-s intervals indicated that experts completed the perceptual encoding phase and started the problem solving or search phase sooner than intermediates.

The results of the eye-movement and chess studies reviewed and reported here are consistent with other demonstrations of superior perceptual encoding of chess-related material by experts in immediate recall tasks (see Gobet 1998b for a review), check detection tasks (Church and Church 1983; Milojkovic 1982; Saariluoma 1984),

enumeration tasks (e.g. count the number of bishops – Saariluoma 1985, 1990), and a same-different task for side-by-side quarter-board positions (Ellis 1973). The present results are also consistent with another line of research investigating the importance of perceptual pattern recognition processes in mediating expertise in chess. Recently, convergent evidence for the critical role of perceptual encoding processes is emerging from studies that investigate the influence of extreme time pressure on chess performance (Burns 2004; Calderwood *et al.*1988; Chabris and Hearst 2003; Gobet and Simon 1996c).

Time pressure would be expected to be very detrimental to the slow and effortful problem solving or search and evaluation processes. In contrast, the fast perceptual pattern recognition processes should be much less impacted by time pressure. Based on this logic, Burns (2004) conducted a very extensive investigation of archival data on blitz chess. In blitz chess tournaments players are afforded less than 5 per cent of the time available during regular chess tournaments. Burns (2004) demonstrated that up to 81 per cent of variance in chess skill was accounted for by how players performed under the tremendous time pressure characteristic of blitz chess. More importantly, by computing for each player a score that quantified the degree to which their relative performance was influenced by time pressure associated with blitz chess, Burns (2004) was able to document that among weaker players skill differences were attenuated by playing blitz chess thereby demonstrating the importance of problem solving and search processes for less-skilled performers. In contrast, this effect all but disappeared for top players (with ratings > 2200).

Consistent with the findings of Burns (2004), Gobet and Simon (1996c) used ratings to analyze simultaneous exhibition matches played by world champion Gary Kasparov. Despite having substantially less time than his opponents, the decline in Kasparov's performance in such matches was rather modest (his rating in simultaneous matches was 2646 whereas his regular tournament rating at that time was 2750). Similarly, although in regular chess tournaments players are allowed on average about 3 min per move, Calderwood *et al.* (1988) demonstrated that chess masters generate promising moves even when allowed only about 5 s per move, and Chabris and Hearst (2003) showed that when world-class grandmasters are allowed on average less than 30 s per move, there was only a slight increase in the number of errors per 1000 moves (5.02 in regular games vs. 6.85 in speeded games). Thus, consistent with the findings of the eye-movement research reviewed and reported here, the results from investigations of the influence of severe time pressure on chess performance suggest a greater reliance on fast perceptual pattern recognition processes by top chess experts than by their less-skilled counterparts.

Finally, the studies reviewed and reported here provide a powerful illustration that in addition to the seminal contribution of chess research to the study of expertise, chess offers cognitive scientists a valuable model task environment for the study of complex cognitive processes such as perception, problem solving, and memory. For example, a fundamental research question in cognitive science concerns the effects of stimulus familiarity on perception in general (e.g. word, letter, object, face and scene superiority effects; see Reingold and Jolicoeur 1993), and visual search in particular (see Shen and Reingold 2001). As shown in Fig. 14.12, chess ratings are highly

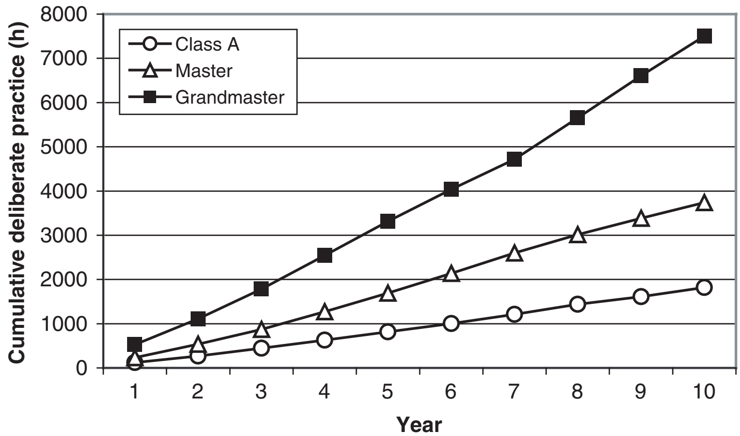

Figure 14.12 Cumulative deliberate practice for the first 10 years by Class A players (mean rating = 1903; *n* = 71–86), Masters (mean rating = 2321; *n* = 27) and Grandmasters (mean rating = 2542; *n* = 5). Data from Charness *et al.* (1996).

correlated with the degree of familiarity and experience with chess specific knowledge and materials. Consequently, skill effects reviewed here, such as ones obtained with the manipulation of notation in the check detection task, which kept the semantics constant while changing the familiarity of the surface representation of a chess problem, and with the manipulation of configuration type (i.e. chess vs. random) in the gaze contingent flicker paradigm, provided powerful demonstrations of the effects of familiarity on perception. Thus, similar to other visual context effects, for experts, but not novices, the coherent and familiar context of a chess configuration enhances the perception of constituent chess relations.

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