Psychonomic Bulletin & Review
2001, 8 (3), 504-510

Perceptual automaticity in expert chess players: Parallel encoding of chess relations

EYAL M. REINGOLD
University of Toronto, Toronto, Ontario, Canada

NEIL CHARNESS and RICHARD S. SCHULTETUS
Florida State University, Tallahassee, Florida

and

DAVE M. STAMPE
University of Toronto, Toronto, Ontario, Canada

A check detection task in a 5 × 5 section of the chessboard, containing a King and one or two potential checking pieces was employed. The checking status (i.e., the presence or absence of a check) and the number of attackers (one or two) were manipulated. It was found that the reaction time cost for adding a distractor was differentially greater in *no* trials than *yes* trials for novice, but not for expert, chess players. In addition, we contrasted standard check detection trials with trials in which one of two attackers was cued (colored red) and the task was to determine the checking status of the cued attacker while ignoring the other attacker. We documented a Stroop-like interference effect on trials in which a cued nonchecking attacker appeared together with an attacker that was checking (i.e., incongruent). These findings suggest automatic and parallel encoding procedures for chess relations in experts.

In chess, detecting a threat to the King, major pieces, or key squares on the board is an essential component of victory; an overlooked threat can be devastating. Given its importance to the game, it is surprising that few studies have dealt with threat detection; rather, most focus on memory retrieval operations in choose-a-move or immediate recall tasks. The major goal of the present study was to investigate the suggestion of Chase and Simon (1973a, 1973b) and de Groot (1978) that a perceptual advantage is a fundamental component of chess skill. We explored the processes involved in threat detection, using a simple check detection task containing a King and one or two attackers. Accordingly, we will briefly summarize previous research and theorizing relevant to the perceptual aspects of chess skill. We then outline the present methodology and document both facilitation and interference effects, demonstrating parallel and automatic extraction of chess relations by expert chess players.

Chase and Simon (1973a, 1973b) proposed that skilled chess players might use information in long-term memory (LTM) to improve their perceptual encoding efficiency for chess configurations. The fundamental unit of their recognition-association theory is the chunk, which is composed of a group of pieces related by type, color, or role (e.g., attacker–defender, etc.). Through extensive study and practice, players build up structures in LTM of pieces that are frequently encountered together, along with information about their relations to one another, to the board, and to the position as a whole. Expert players then use this knowledge in LTM to encode and manipulate more chess-related information in a given mental operation than do less skilled players, who utilize smaller information units or chunks. Simon and Gilmartin (1973) estimated the number of patterns the expert player might have stored in LTM to be around 50,000. This early estimate has since been expanded to 300,000 chunks (Gobet & Simon, 2000). It has also been proposed that small perceptual chunks are most likely supplemented by larger structures, termed *templates* (Gobet & Simon, 1996b).

In an unpublished study, Ellis (1973) documented skill differences on a same–different task for side-by-side pairs of dot patterns or quarter-board positions involving only a few chess pieces (the display size for each quarter-board position or dot pattern was varied from three to seven items). Experts outperformed novices for the chess positions, but not for dot patterns, a result consistent with the view that acquired structures, rather than innate differences in perception, underlie performance in this task. Furthermore, a correlation between stimulus size and re-

Preparation of this paper was supported by a grant to E.M.R. from the Natural Science and Engineering Research Council of Canada and by NIA Grant 5R01 AG13969 to N.C. The authors thank Colleen Ray for her helpful comments on an earlier draft of this manuscript. We thank Fernand Gobet, Chad Marsolek, and an anonymous reviewer for their valuable input. Correspondence concerning this article should be addressed to E. M. Reingold, University of Toronto, Department of Psychology, 100 St. George Street, Toronto, ON M5S 3G3, Canada (e-mail: reingold@psych.utoronto.ca).

action times (RTs) was found for both skill levels with the dot patterns, but only for the novices when chess positions were used. This suggests that the skilled players were comparing the positions holistically, whereas the novices were comparing them piece by piece.

Saariluoma (1985, 1990) also found evidence of early processing advantages in the performance of expert and novice chess players on a set of enumeration tasks. As was expected, the skilled players outperformed the novices on selective enumeration tasks (e.g., count the number of bishops) with game positions, which have a familiar organization and some expectation as to where a specified piece is likely to be found. However, skilled players also outperformed the novices on selective enumeration with random positions and arrays of pieces. From this, Saariluoma (1985, 1990) concluded that skilled players gain an advantage in the basic perceptual processing of chess positions, as well as in the memory and retrieval systems. Consistent with this hypothesis, no skill differences were apparent for total enumeration (count all the pieces), which does not require any piece discriminations. Saariluoma (1984) also looked at check detection performance for positions containing only the King and an attacker, finding a skill difference here as well. He suggested that the difference was not in piece identification, since there were only a couple of pieces, but rather in determining whether the attacker was located in the correct position to attack the King (see also Church & Church, 1983; Milojkovic, 1982).

Several studies employing eye movement measurement have also supported the idea that perception of chess-related configurations improves with skill. Both Tikhomirov and Poznyanskaya (1966) and Winikoff (1967) found evidence that when chess players fixated on a chess piece, they also extracted information about other pieces near the point of gaze and often moved to fixate a related piece. On the basis of 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.

Reanalyzing the work of Jongman (1968), de Groot and Gobet (1996) found that skilled players made more fixations along the edges of squares (28.7% of fixations), as compared with novices (13.7%), providing some indication that skilled players may be able to encode a larger portion of the chess board in a single fixation. They also noted a greater distance between successive fixations by skilled players, suggesting that they cover a larger area during a given fixation than do weaker players.

Consistent with this interpretation, in a recent study, Reingold, Charness, Pomplun, and Stampe (2001) provided strong evidence for an increase in the visual span (i.e., the region of the visual field from which information is extracted during a fixation) of chess experts during the processing of chess-related material. These authors employed a gaze-contingent window paradigm (e.g., McConkie & Rayner, 1975; see Rayner, 1998, for a review) to modify in real time the portion of a chessboard (window) in which chess pieces were clearly visible. The window was always centered on the point of gaze, and outside the window gray blobs replaced chess pieces, masking their identity and color. 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 interfere with the participant's task performance. Reingold et al. reported that when processing chess configurations, but not random configurations of chess pieces, chess experts demonstrated substantially larger visual spans than did less skilled players. During span measurement, players attempted to detect a single changing chess piece produced by the repeated alternation of otherwise identical chessboard displays. The increase in visual span size facilitated experts' change detection in chess configurations, but not in random configurations, thereby attenuating the surprisingly poor detection of changes previously demonstrated under similar experimental conditions, a phenomenon termed *change blindness* (Rensink, O'Regan, & Clark 1997; see Simons & Levin, 1997, for a review). Reingold et al. also measured the performance of expert, intermediate, and novice chess players on a check detection task with the Black King and either one or two White attackers, placed on a 3×3 section of the chessboard. In this task, experts made fewer fixations per trial and had a greater proportion of fixations between individual pieces, rather than on the pieces themselves. These findings are consistent with the encoding of chunks, rather than individual pieces, and provide further evidence for a skill-related increase in visual span size.

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 & Simon, 1996a; Saariluoma, 1994). It is important to note that the identification of pieces and locations is likely to involve multiple processes, some of which are serial in nature (e.g., the 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 the binding of pieces into chess chunks.

On the basis of the studies reviewed above, it is likely that the main perceptual advantage for experts is not in the identification of single chess pieces and board loca-

tions (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 effects of skill obtained with actual game positions (i.e., where relational information is intact), coupled with the weak or absent effects of skill obtained with random chess positions (i.e., where relational information is broken down). Thus, parallel encoding of chess relations by experts is hypothesized to occur following the initial extraction of feature information that is necessary to identify and localize pieces on a chessboard. The present study was specifically designed to test this hypothesis.

Another important goal underlying the present study is the attempt to demonstrate a skill-related interference effect. The vast majority of studies investigating expertise in general, and chess skill in particular, 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, Ste-Marie, & Toth, 1993; Reingold, 1995; Reingold & Toth, 1996; Toth, Reingold, & Jacoby, 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 (but see Besner & Stolz, 1999a, 1999b; Besner, Stolz, & Boutilier, 1997; Stolz & Besner, 1996, 1999).

The present methodology was designed as an attempt to document Stroop-like interference in chess experts (for weak evidence of Stroop-like interference in a chess-related imagery task, see Bachmann & Oit, 1992). We employed a check detection task in a minimized 5×5 section of the chessboard, containing a King and one or two potential 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 is shown in the top row of Figure 1, adding a distractor (i.e., a nonchecking 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, in *no* trials, an accurate response requires considering both potential 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 & Gelade, 1980, and Wolfe, 1998, for a similar methodology whose aim was to at document parallel visual search). Note that we are predicting an RT cost for adding an attacker (i.e. one vs. two attackers), even for expert players, owing to the prerequisite encoding of piece identity and location prior to the extraction of chess relations (because serial processing in Phase 1 is sensitive to the number of pieces in the configuration).

In the second part of the experiment, we contrasted the standard check detection trials that had two attackers with trials in which one of two attackers was cued (colored red). In this condition, the task was to determine whether the cued attacker was checking the King, while ignoring the other attacker. In order to avoid any predictability in the stimulus set, the checking statuses of the cued and uncued attackers were manipulated separately (i.e., *yes/yes, yes/no, no/yes,* and *no/no*). However, as is shown in the bottom row of Figure 1, our predictions were focused exclusively on contrasting three conditions: a no-cue condition (i.e., no cuing), which consisted of *no* trials with two attackers, and two conditions in which a cued nonchecking attacker appeared together with an attacker that was either congruent (i.e., nonchecking, *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, since the cuing constrains the search space. In contrast, parallel processing of chess relations should result in no benefit from cuing in the congruent condition. In addition, if parallel processing of chess relations occurs, cuing should produce slower RTs in the incongruent than in the congruent condition, demonstrating Stroop-like interference. We document parallel encoding by experts and serial extraction of chess relations by less skilled players.

METHOD

Participants

Forty-two paid participants (14 novices, 14 intermediates, and 14 experts) were included in the study. All the participants had normal or corrected-to-normal vision. Chess Federation of Canada (CFC) ratings for the expert players ranged from 2,100 to 2,351 (M = 2,218). CFC ratings for the intermediate players ranged from 1,401 to 2,000 (M = 1,799). The mean rating in the CFC is about 1,600, with a standard deviation of about 200. The players ranged in age between 18 and 31 years. The novices were inexperienced chess players (ages 19–25), who typically reported playing no games of chess in the past year and very few games over their lifetimes.

Materials and Design

A minimized 5×5 chessboard was displayed subtending a visual angle of 12° horizontally and vertically and including chess pieces approximately 2° in diameter. Stimulus displays were presented on a 17-in. Viewsonic 17PS monitor connected to a Pentium computer.

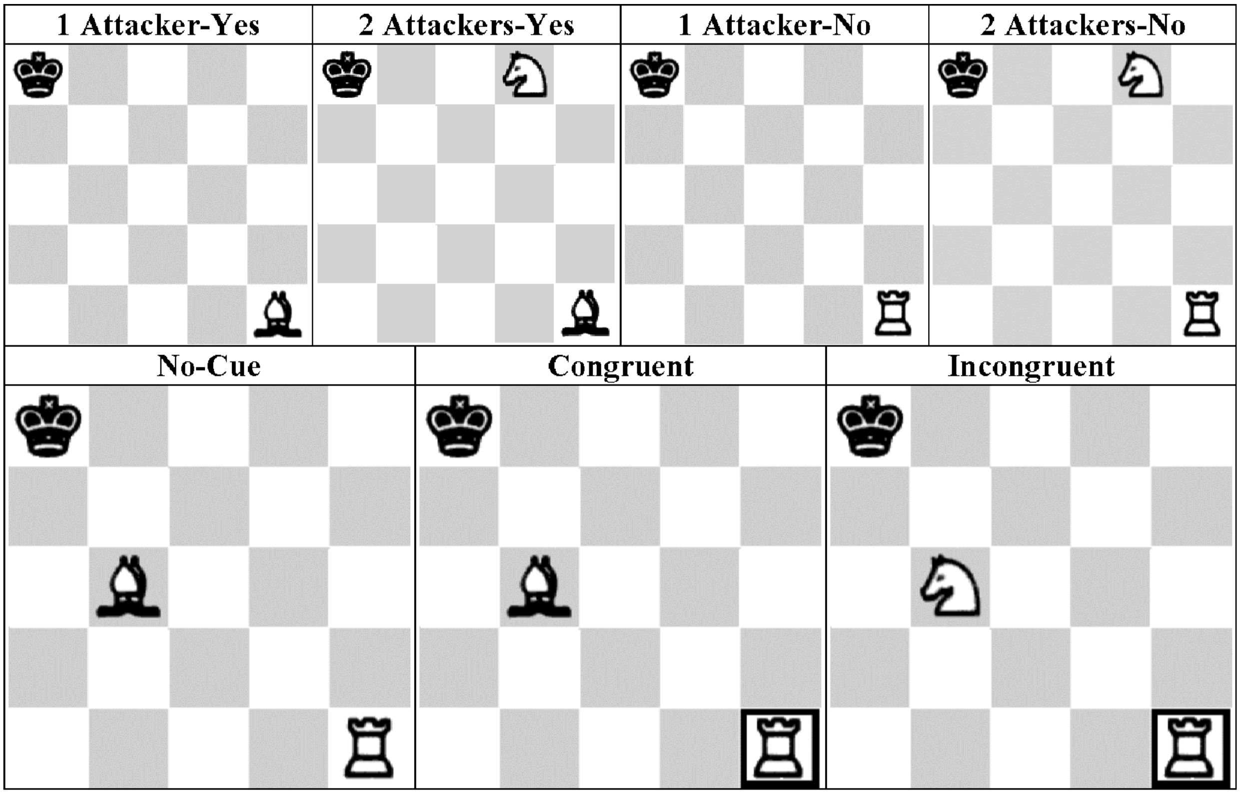

Figure 1. Examples of the check detection trials used in the experiment. The top row illustrates the manipulation of check status (*present/yes* vs. *absent/no* trials) by number of attackers (one vs. two). The bottom row illustrates the no-cue condition that consisted of *no* trials with two attackers and two conditions in which a cued nonchecking attacker appeared together with an attacker that was either congruent (i.e., nonchecking) or incongruent (i.e., checking). In the latter two conditions, the task was to determine whether the cued attacker was checking the King, while ignoring the other attacker. The frame used to illustrate the cuing manipulation in this figure was not present in actual trials. Instead, the cued attacker was colored red.

Each display contained a Black King in the top-left or top-right square and one or two potential checking pieces (from the combinations of rook, bishop, and knight). In the first part of the experiment, the trials were balanced for the number of White attackers (one or two) and checking status (check or no check present; see Figure 1), so that there were 96 trials for each of the four conditions (48 with the King in the top-left square and 48 with the King in the top-right square). In addition, each type of attacker (bishop, knight, or rook) and the spatial layout of the occupied squares appeared equally often in check and no-check positions.

In the second part of the experiment, only the two attacker positions from the previous part of the experiment were used, and double-check positions were added to create all four possible combinations of checking for both attackers (i.e., *yes/yes*, *yes/no*, *no/yes,* and *no/no*). On half the trials, one of the attackers was colored red (i.e., the cuing manipulation). There were 48 trials per condition for trials with cuing. For standard trials with no cuing, there were 96 no-check trials, 48 single-check trials, and 48 double-check trials. Consequently, for both the cuing and the no-cue conditions, there were equal numbers of *yes* and *no* trials.

Procedure

Prior to every trial, the participants were asked to fixate a marker in the center of the display. Following a buttonpress, an experimental display was presented and remained on the screen until the trial was terminated. In the first part of the experiment, the players were instructed to determine as quickly and accurately as they could whether or not the Black King was in check. They used one of two buttons to indicate their responses, with the mapping of buttons to responses counterbalanced across participants. After 24 practice trials, during which they could ask any questions about the task or symbols, 384 experimental trials (eight blocks of 48 trials, with blocks containing an equal number of trials in each of the four check status × number of attackers conditions) were administered. In the second part of the experiment, the participants were told that only two-attacker trials would be displayed. If there was no cuing of one of the attackers, they were to perform the task in the same way as before. If, however, one attacker was colored red (cued), they were to determine and respond to the checking status of the red attacker and ignore the other attacker. After 16 practice trials with cuing, 288 experimental trials (six blocks of 48 trials, with blocks containing equal numbers of cuing and noncuing trials and *yes* and *no* trials) were administered.

RESULTS

The results from the check status × number of attackers manipulation are shown in panel A of Figure 2, which displays the average median RTs obtained for each group and condition (trials on which participants responded incorrectly were excluded). As can be seen from this figure, the group × check status × number of attackers interaction was significant [$F(2,39) = 5.76$, $p < .01$]. This

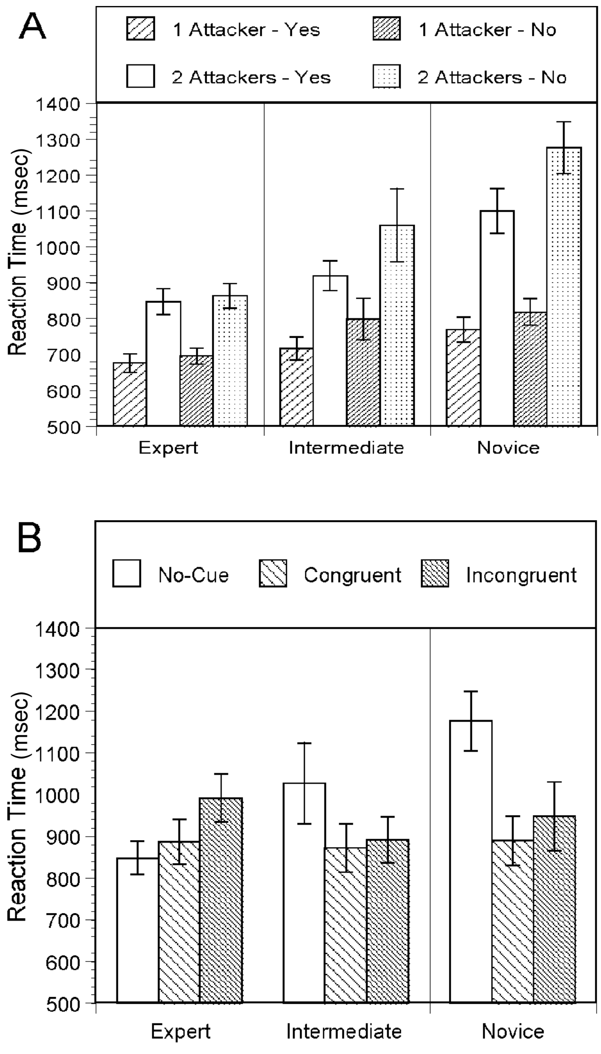

Figure 2. Average median reaction times (in milliseconds) in the check detection task by skill (expert vs. intermediate vs. novice), by check status (*present/yes* vs. *absent/no* trials), by number of attackers (one vs. two; panel A), and by skill and condition (no-cue vs. congruent vs. incongruent; panel B).

interaction is best understood by considering the differences in the increase in RTs from one to two attackers for *yes* versus *no* trials. For experts, there was a comparable cost for adding an attacker in both *yes* (171 msec) and *no* (167 msec) trials ($t < 1$). For intermediates, the corresponding increase for *yes* trials (203 msec) was numerically, but not significantly, smaller than that for *no* trials [262 msec; $t(13) = 1.41$, $p = .18$]. Finally, for novices, the increase for *yes* trials (330 msec) was substantially and significantly smaller than *no* trials [458 msec; $t(13) = 6.47$, $p < .001$]. An analysis of error rates across the same conditions revealed no evidence of a speed–accuracy tradeoff. Error rates were generally low (4% across conditions), and neither the main effect of skill nor its interactions were significant (all Fs < 1).

Panel B of Figure 2 presents the results obtained in two sets of critical contrasts: the no-cue and congruent conditions, and the congruent and incongruent conditions (i.e., the second part of the experiment; see the bottom row of Figure 1). 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 (colored red) and the participants were asked to decide whether the cued attacker was checking, disregarding the other attacker. If processing of chess relations is serial, the cuing in the congruent condition should improve performance, as compared with the no-cue condition, because it eliminates the necessity of examining one of two potential checking relations. On the other hand, in the case of parallel extraction of chess relations, cuing should not produce such facilitation. When comparing the congruent and the no-cue conditions in panel B of Figure 2, it is clear that experts derived no benefit from cuing (there was a nonsignificant trend in the opposite direction: 24-msec slowing; $t < 1$). In marked contrast, for both the intermediates and the novices, the cuing in the congruent condition produced substantial facilitation, relative to the no-cue condition [intermediates, 187-msec facilitation, $t(13) = 3.39$, $p < .01$; novices, 386-msec facilitation, $t(13) = 10.06$, $p < .001$)]. This accounts for the significant skill group × condition (no-cue vs. congruent) interaction [$F(2,39) = 15.65$, $p < .001$]. Put differently, the strong skill effect in the no-cue condition [$F(2,39) = 5.09$, $p < .01$] completely disappeared as a result of cuing in the congruent condition ($F < 1$).

When comparing the congruent and the incongruent conditions in panel B of Figure 2, it is evident that the experts demonstrated Stroop-like interference [a significant 105-msec slowing; $t(13) = 4.38$, $p < .001$]. Intermediates demonstrated no significant interference (19-msec slowing; $t < 1$), and novices demonstrated marginally significant interference [58-msec slowing; $t(13) = 2.03$, $p < .06$], accounting for the significant skill × condition (congruent vs. incongruent) interaction [$F(2,39) = 3.99$, $p < .05$]. Note, however, that for both the intermediates and the novices, but not for the experts, the beneficial effects of cuing (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-msec facilitation, $t(13) = 2.18$, $p < .05$; novices, 228-msec facilitation, $t(13) = 4.40$, $p < .001$; experts, 144-msec interference, $t(13) = 3.91$, $p < .01$].

An analysis of the error rates for skill × condition (no-cue, congruent, and incongruent) demonstrated only a significant effect of condition, with all groups producing more errors in the incongruent condition (5%) than in the no-cue and congruent conditions [1%; $F(2,78) = 26.46$, $p < .001$]. Finally, comparing both error rates and RTs across skill groups in the two conditions in which a checking piece was cued (i.e., *yes/yes* and *yes/no* trials) demonstrated no effects of group or condition and no interactions (all Fs < 1.72, $p > .19$). Thus, it appears that cuing

an attacker in these conditions largely eliminated the advantage of expertise by constraining the search space.

To summarize, 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* versus *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 cuing. Note that these two conditions are identical in terms of pieces and locations (as well, both require the same *no* response) and consequently, this contrast provides a particularly powerful way of 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 nonchecking and the correct response was *no*.

DISCUSSION

Consistent with previous studies (Church & Church, 1983; de Groot & Gobet, 1996; Ellis, 1973; Jongman, 1968; Milojkovic, 1982; Reingold et al., 2001; Saariluoma, 1984, 1985, 1990; Simon & Barenfeld, 1969; Tikhomirov & Poznyanskaya, 1966; Winikoff, 1967), the present investigation demonstrated superior perceptual encoding of chess-related material by experts. The methodology introduced here provided compelling evidence that at least 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 (see Reingold et al., 2001). Perhaps the most unique aspect of the present study is the demonstration of a Stroop-like interference effect in expert players, but not in intermediate players. Whereas most studies of expertise focus on documenting facilitation effects (but see Frensch & Sternberg, 1989), the present demonstration of facilitation and interference effects highlights the fact that expert–novice differences are qualitative, rather than just quantitative, in nature. In particular, we demonstrated parallel extraction of chess relations in experts, and serial self-terminating extraction in novices.

Finally, similar to other visual context effects with such stimuli as words (see Baron, 1978, Johnston, 1981, and Krueger, 1975, for reviews), letters (Reingold & Jolicœur, 1993; Schendel & Shaw, 1976), faces (e.g., Gyoba, Arimura, & Maruyama, 1980; Homa, Haver, & Schwartz, 1976; Purcell & Stewart, 1986, 1988; van Santen & Jonides, 1978), and real-world scenes (Biederman, 1972, 1981; Biederman, Glass, & Stacey, 1973; Palmer, 1975), the present findings provide a powerful demonstration of the effects of familiarity on perception. Specifically, a coherent and familiar context (i.e., a chess configuration) enhanced the perception of constituent elements (i.e., chess relations).

REFERENCES

Bachmann, T., & Oit, M. (1992). Stroop-like interference in chess players' imagery: An unexplored possibility to be revealed by the adapted moving-spot task. *Psychological Research*, **54**, 27-31.

Baron, J. (1978). The word-superiority effect: Perceptual learning from reading. In W. K. Estes (Ed.), *Handbook of learning and cognitive processes* (Vol. 6, pp. 131-166). Hillsdale, NJ: Erlbaum.

Besner, D., & Stolz, J. A. (1999a). Unconsciously controlled processing: The Stroop effect reconsidered. *Psychonomic Bulletin & Review*, **6**, 449-455.

Besner, D., & Stolz, J. A. (1999b). What kind of attention modulates the Stroop effect? *Psychonomic Bulletin & Review*, **6**, 99-104.

Besner, D., Stolz, J. A., & Boutilier, C. (1997). The Stroop effect and the myth of automaticity. *Psychonomic Bulletin & Review*, **4**, 221-225.

Biederman, I. (1972). Perceiving real world scenes. *Science*, **177**, 77-80.

Biederman, I. (1981). On the semantics of a glance at a scene. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 213-253). Hillsdale, NJ: Erlbaum.

Biederman, I., Glass, A. L., & Stacey, E. W., Jr. (1973). Scanning for objects in real world scenes. *Journal of Experimental Psychology*, **97**, 22-27.

Chase, W. G., & Simon, H. A. (1973a). The mind's eye in chess. In W. G. Chase (Ed.), *Visual information processing* (pp. 215-281). New York: Academic Press.

Chase, W. G., & Simon, H. A. (1973b). Perception in chess. *Cognitive Psychology,* **4**, 55-81.

Church, R. M., & Church, K. W. (1983). Plans, goals, and search strategies for the selection of a move in chess. In P. W. Frey (Ed.), *Chess skill in man and machine* (2nd ed., pp. 131-156). New York: Springer-Verlag.

de Groot, A. D. (1978). *Thought and choice in chess*. (2nd ed.). The Hague: Mouton.

de Groot, A. D., & Gobet, F. (1996). *Perception and memory in chess*. Assen, The Netherlands: Van Gorcum.

Ellis, S. H. (1973). Structure and experience in the matching and reproduction of chess patterns. *Dissertation Abstracts International,* **34**, 5B (University Microfilms No. AAG73-26954).

Frensch, P. A., & Sternberg, R. J. (1989). Expertise and intelligent thinking: When is it worse to know better? In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 5, pp. 157-188). Hillsdale, NJ: Erlbaum.

Gobet, F., & Simon, H. A. (1996a). Recall of random and distorted chess positions: Implications for the theory of expertise. *Memory & Cognition*, **24**, 493-503.

Gobet, F., & Simon, H. A. (1996b). Templates in chess memory: A mechanism for recalling several boards. *Cognitive Psychology*, **31**, 1-40.

Gobet, F., & Simon, H. A. (2000). Five seconds or sixty? Presentation time in expert memory. *Cognitive Science*, **24**, 651-682.

Gyoba, J., Arimura, M., & Maruyama, K. (1980). Visual identification of line segments embedded in human face patterns. *Tohoku Psychologica Folia*, **39**, 113-120.

Homa, D., Haver, B., & Schwartz, T. (1976). Perceptibility of schematic face stimuli: Evidence for a perceptual Gestalt. *Memory & Cognition*, **4**, 176-185.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory & Language*, **30**, 513-541.

Jacoby, L. L., Ste-Marie, D., & Toth, J. T. (1993). Redefining automaticity: Unconscious influences, awareness and control. In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention, selection, awareness and control: A tribute to Donald Broadbent* (pp. 261-282). Oxford: Oxford University Press.

Johnston, J. C. (1981). Understanding word perception: Clues from studying the word-superiority effect. In O. J. L. Tzeng & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 65-84). Hillsdale, NJ: Erlbaum.

Jongman, R. W. (1968). *Het oog van de meester* [The eye of the master]. Assen, The Netherlands: Van Gorcum.

Krueger, L. E. (1975). Familiarity effects in visual information processing. *Psychological Bulletin*, **82**, 949-974.

MacLeod, C. M. (1992). The Stroop task: The "gold standard" of attentional measures. *Journal of Experimental Psychology: General*, **121**, 12-14.

McClelland, J. L. (1979). On the time relations of mental processes: A framework for analyzing processes in cascade. *Psychological Review*, **86**, 287-330.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception & Psychophysics*, **17**, 578-586.

Milojkovic, J. D. (1982). Chess imagery in novice and master. *Journal of Mental Imagery*, **6**, 125-144.

Palmer, S. E. (1975). The effects of contextual scenes on the identification of objects. *Memory & Cognition*, **3**, 519-526.

Purcell, D. G., & Stewart, A. L. (1986). The face-detection effect. *Bulletin of the Psychonomic Society*, **24**, 118-120.

Purcell, D. G., & Stewart, A. L. (1988). The face-detection effect: Configuration enhances detection. *Perception & Psychophysics*, **43**, 355-366.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, **124**, 372-422.

Reingold, E. M. (1995). Facilitation and interference in indirect/implicit memory tests and in the process dissociation paradigm: The letter insertion and the letter deletion tasks. *Consciousness & Cognition*, **4**, 459-482.

Reingold, E. M., Charness, N., Pomplun, M., & Stampe, D. M. (2001). Visual span in expert chess players: Evidence from eye movements. *Psychological Science*, **12**, 49-56.

Reingold, E. M., & Jolicœur, P. (1993). Perceptual versus postperceptual mediation of visual context effects: Evidence from the letter-superiority effect. *Perception & Psychophysics*, **53**, 166-178.

Reingold, E. M., & Toth, J. P. (1996). Process dissociations versus task dissociations: A controversy in progress. In G. Underwood (Ed.), *Implicit cognition* (pp. 159-202). Oxford: Oxford University Press.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, **8**, 368-373.

Saariluoma, P. (1984). *Coding problem spaces in chess*. (Commentationes Scientiarum Socialium, Vol. 23). Turku: Societas Scientiarum Fennica.

Saariluoma, P. (1985). Chess players' intake of task-relevant cues. *Memory & Cognition*, **13**, 385-391.

Saariluoma, P. (1990). Apperception and restructuring in chess players' problem solving. In K. J. Gilhooly, M. T. G. Keane, R. H. Logie, & G. Erdos (Eds.), *Lines of thought: Reflections on the psychology of thinking* (pp. 41-57). London: Wiley.

Saariluoma, P. (1994). Location coding in chess. *Quarterly Journal of Experimental Psychology*, **47A**, 607-630.

Schendel, J. D., & Shaw, P. (1976). A test of the generality of the word-context effect. *Perception & Psychophysics*, **19**, 383-393.

Simon, H. A., & Barenfeld, M. (1969). Information-processing analysis of perceptual processes in problem solving. *Psychological Review*, **76**, 473-483.

Simon, H. A., & Gilmartin, K. (1973). A simulation of memory for chess positions. *Cognitive Psychology*, **5**, 29-46.

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, **1**, 261-267.

Stolz, J. A., & Besner, D. (1996). Role of set in visual word recognition: Activation and activation blocking as nonautomatic processes. *Journal of Experimental Psychology: Human Perception & Performance*, **22**, 1166-1177.

Stolz, J. A., & Besner, D. (1999). On the myth of automatic semantic activation in reading. *Current Directions in Psychological Science*, **8**, 61-65.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, **18**, 643-661.

Tikhomirov, O. K., & Poznyanskaya, E. (1966). An investigation of visual search as a means of analyzing heuristics. *Soviet Psychology*, **5**, 2-15.

Toth, J. P., Reingold, E. M., & Jacoby, L. L. (1994). Toward a redefinition of implicit memory: Process dissociations following elaborative processing and self-generation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **20**, 290-303.

Treisman, A., & Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology*, **12**, 97-136.

van Santen, J. P. H., & Jonides, J. (1978). A replication of the face-superiority effect. *Bulletin of the Psychonomic Society*, **12**, 378-380.

Winikoff, A. W. (1967). *Eye movements as an aid to protocol analysis of problem solving behavior*. Unpublished doctoral dissertation, Carnegie-Mellon University, Pittsburgh.

Wolfe, J. M. (1998). Visual search. In H. Pashler (Ed.), *Attention* (pp. 13-73). Hove, U.K.: Psychology Press/Erlbaum.

(Manuscript received April 13, 2000;
revision accepted for publication December 4, 2000.)