

Chess players' eye movements reveal rapid recognition of complex visual patterns: Evidence from a chess-related visual search task

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To explore the perceptual component of chess expertise, we monitored the eye movements of expert and novice chess players during a chess-related visual search task that tested anecdotal reports that a key differentiator of chess skill is the ability to visualize the complex moves of the knight piece. Specifically, chess players viewed an array of four minimized chessboards, and they rapidly searched for the target board that allowed a knight piece to reach a target square in three moves. On each trial, there was only one target board (i.e., the “Yes” board), and for the remaining “lure” boards, the knight’s path was blocked on either the first move (the “Easy No” board) or the second move (i.e., “the Difficult No” board). As evidence that chess experts can rapidly differentiate complex chess-related visual patterns, the experts (but not the novices) showed longer first-fixation durations on the “Yes” board relative to the “Difficult No” board. Moreover, as hypothesized, the task strongly differentiated chess skill: Reaction times were more than four times faster for the experts relative to novices, and reaction times were correlated with within-group measures of expertise (i.e., official chess ratings, number of hours of practice). These results indicate that a key component of chess expertise is the ability to rapidly recognize complex visual patterns.

potential threats in briefly presented X-ray images of baggage items (Gale, Mugglestone, Purdy, & McClumpha, 2000), and by orthodontists who show an enhanced ability to make judgments about facial symmetry (Jackson, Clark, & Mitroff, 2013). Similarly, there is a long history of using chess to explore the perceptual aspect of visual expertise (for reviews, see Charness, 1992; de Groot & Gobet, 1996; Gobet & Charness, 2006; Reingold & Charness, 2005; Reingold & Sheridan, 2011). The chess domain provides a window into the limits of human perceptual and cognitive abilities, because it constitutes a complex and challenging task environment that permits carefully controlled and ecologically valid experimental manipulations. In addition, chess is an ideal domain for studying human expertise because it incorporates an official rating system for objectively quantifying the level of expertise (Elo, 1965, 1986) and chess players vary widely in terms of many characteristics, including age and skill level (Charness, Tuffiash, Krampe, Reingold, & Vasyukova, 2005). Given the importance of perceptual expertise in many fields, the goal of the present study was to further explore the ability of expert and novice chess players to rapidly detect complex visual patterns using a novel experimental paradigm. Accordingly, we will begin by briefly reviewing prior work on perceptual skill in the domain of chess, and we will then introduce the paradigm used in the present study.

Some of the strongest evidence for the perceptual component of chess expertise comes from de Groot’s (1946) pioneering work showing that chess experts have a remarkable ability to reproduce briefly presented chess positions. Extending the work by de Groot (1946), Chase and Simon (1973a, 1973b) also demonstrated that chess experts have much better recall than

Introduction

A hallmark of visual expertise in many domains is the ability to rapidly recognize complex domain-related visual patterns (for a review, see Reingold & Sheridan, 2011). This remarkable perceptual skill of experts is illustrated by expert radiologists who can detect abnormalities in chest X-rays that were briefly presented for only 200 ms (Kundel & Nodine, 1975), by airport security officers who can rapidly locate

Citation: Sheridan, H., & Reingold, E. M. (2017). Chess players' eye movements reveal rapid recognition of complex visual patterns: Evidence from a chess-related visual search task. *Journal of Vision*, 17(3):4, 1–12, doi:10.1167/17.3.4.

doi: 10.1167/17.3.4

Received September 10, 2016; published March 6, 2017

ISSN 1534-7362 Copyright 2017 The Authors



novices for briefly presented chess game positions, but there was very little difference between experts and novices if the chess players were shown random configurations of chess pieces (instead of game positions). More recent work has shown that the random configuration condition produces small but reliable expert/novice differences, but the small expertise effects in this condition are likely due to the occasional presence of familiar configurations in random positions (Gobet & Simon, 1996a).

To explain the perceptual advantage of chess experts, Chase and Simon (1973a, 1973b) argued that the remarkable performance of experts was due to their extensive experience with domain-specific visual configurations, rather than from a more general superiority of perceptual or cognitive abilities. Specifically, Chase and Simon (1973a, 1973b) advanced the hypothesis that chess experts acquire memory representations for “chunks” of chess-related visual information (e.g., groups of chess pieces), which are supplemented by larger memory structures called *templates* (Gobet & Simon, 1996b, 2000). According to chunking and template theory, chess experts acquire memory structures over the course of many hours of practice, and these memory structures facilitate performance by enabling experts to rapidly encode chess configurations and by activating advantageous strategies and moves. Moreover, as discussed by Reingold, Charness, Schultetus, and Stampe (2001) and Reingold and Charness (2005), one of the mechanisms that supports the efficient performance of experts is their ability to process chess relations automatically and in parallel, which is consistent with findings that chess configurations can produce Stroop-like interference (Reingold, Charness, Schultetus et al., 2001), chess configurations can be processed unconsciously (Kiesel, Kunde, Pohl, Berner, & Hoffmann, 2009), and investigations of the Einstellung effect in chess have revealed that unconscious biases can shape the problem-solving performance of chess experts (Bilalić, McLeod, & Gobet, 2008a, 2008b; Saariluoma, 1990; Sheridan & Reingold, 2013).

Consistent with the theoretical framework advanced by de Groot, Gobet, Chase, and Simon, chess experts display a wide range of perceptual advantages that are predicted by chunking and template theory (for reviews, see Charness, 1992; de Groot & Gobet, 1996; Gobet & Charness, 2006; Reingold & Charness, 2005; Reingold & Sheridan, 2011). For example, as evidence that experts process larger visual patterns than novices, chess experts display higher proportions of fixations *between* rather than *on* chess pieces in comparison with less skilled players (Charness, Reingold, Pomplun, & Stampe, 2001; Reingold & Charness, 2005; Reingold, Charness, Pomplun, & Stampe, 2001; see also de Groot & Gobet, 1996; Jongman, 1968), and chess experts

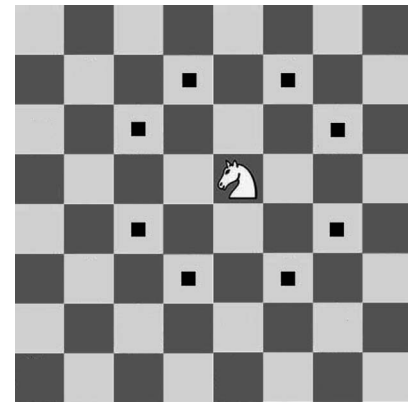


Figure 1. An illustration of the moves of the knight piece. The knight moves in an “L”-shaped pattern (i.e., two squares horizontally and one square vertically, or two squares vertically and one square horizontally). In this figure, all of the knight’s possible moves are indicated with black dots.

exhibit a larger *visual span* than less skilled players when they are fixating on domain-related visual configurations (Reingold, Charness, Pomplun et al., 2001). As well, chess experts can use their memory for chess configurations to rapidly focus on relevant information and to ignore irrelevant information (Bilalić, Langner, Erb, & Grodd, 2010; Bilalić, Turella, Campitelli, Erb, & Grodd, 2012; Charness et al., 2001; de Groot & Gobet, 1996; Reingold & Charness, 2005; Sheridan & Reingold, 2014; Simon & Barenfeld, 1969; Tikhomirov & Poznyanskaya, 1966). Finally, neuroimaging studies have uncovered expert/novice differences in brain activation in regions associated with object and pattern recognition (Bilalić et al., 2010, 2012; Bilalić, Kiesel, Pohl, Erb, & Grodd, 2011; Bilalić, Langner, Ulrich, & Grodd, 2011), and chess expertise modulates ERPs (Event-Related Potentials) to chess-related stimuli as early as 240 ms poststimulus (Wright, Gobet, Chassy, & Ramchandani, 2013). Taken together, these findings support the view that perceptual skill is a key aspect of expertise in chess.

To further explore the perceptual component of chess expertise, the present study investigated an intriguing claim by chess coaches that a key differentiator of expertise in chess is the ability to visualize the complex moves of the “knight piece.” The knight’s move trajectory is visually more complex than the other pieces because the knight moves in an “L”-shaped pattern rather than a straight line and because the knight is the only piece that can “jump” over other pieces to reach its final destination square (see Figure 1 for an illustration of the moves of the knight piece). In fact, there is a famous chess problem called “the Knight’s Tour,” which requires chess players to move a knight piece to every square on the board, without returning to the same square twice. This challenging problem is well known to chess experts, and it has also

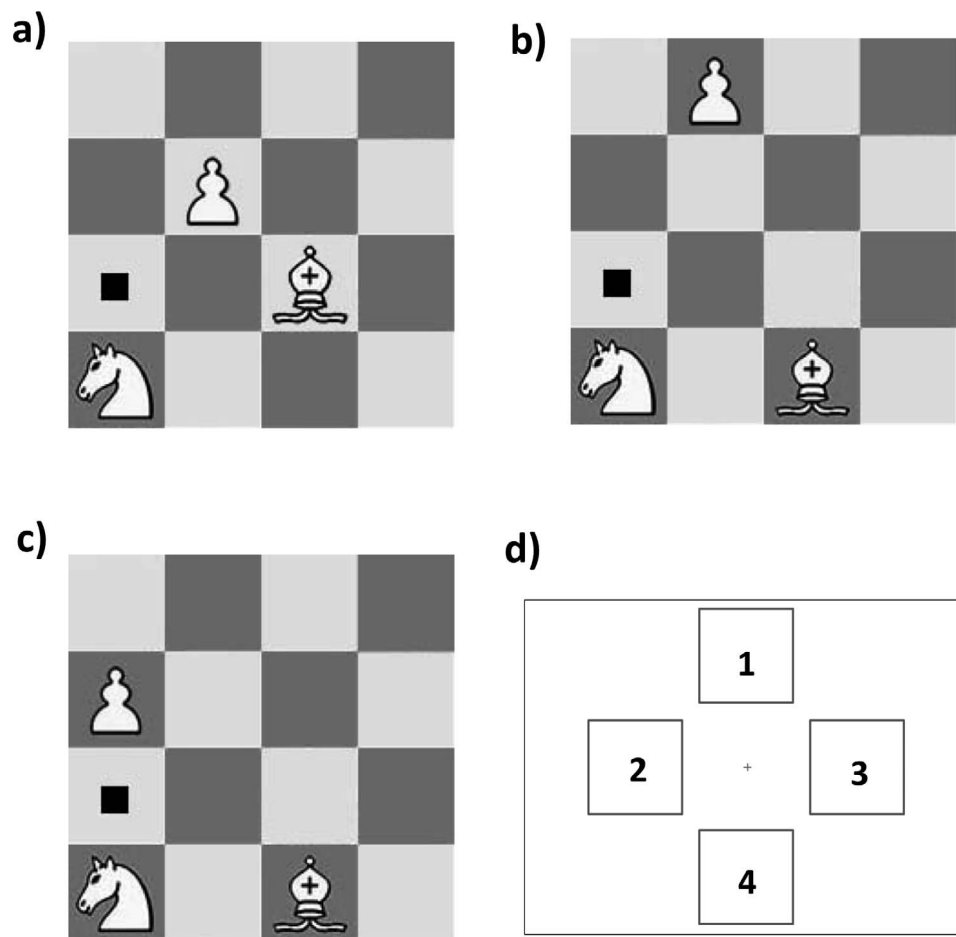


Figure 2. An illustration of the knight task. The chess players were asked to rapidly locate the chessboard that allowed the knight to reach the target square in three moves (i.e., the “Yes” condition board in Panel c). For the remaining boards, the knight’s path was blocked on either the first move (i.e., the “Easy No” condition in Panel a) or on the second move (i.e., the “Difficult No” condition in Panel b). Each trial in the experiment contained four miniature chessboards. Two of the boards were in the “Difficult No” condition, one board was in the “Easy No” condition, and the remaining board was in the “Yes” condition. These four boards were arranged around a central fixation cross (see Panel d). See text for further details.

been studied extensively by mathematicians (Elkies & Stanley, 2003; Lin & Wei, 2005), including Leonhard Euler (1759). However, even though there is anecdotal evidence that the Knight’s Tour is a good index of expertise, this task has not yet been extensively studied empirically, perhaps because the task is very complex and difficult (but see Horgan & Morgan, 1990).

In the present study, we introduced a simplified version of the Knight’s Tour as a novel laboratory task for quantifying perceptual expertise differences in chess. In this task, we monitored the eye movements of both expert and novice chess players while they viewed an array of four minimized 4×4 chess boards (see Figure 2). On each trial, their goal was to rapidly locate the target board (i.e., the “Yes” condition board) that allowed a knight piece to reach a target square in exactly three moves (it was never possible to reach the target square in fewer moves) while ignoring the other three “lure” boards in which the knight’s path to the

target square was blocked by another piece of the same color. Each trial contained two types of lure boards: for one type of “lure” board, the path of the knight was blocked on the first move (i.e., the “Easy No” condition board), and for the other type of lure board, the knight could move to at least one other square on the board before its path was blocked on the second move (i.e., the “Difficult No” condition board). For all three of the chess board conditions (“Yes,” “Easy No,” “Difficult No”), we examined a wide range of eye movement and reaction time measures (see Figures 3 and 4).

The present study’s knight task provides a strong manipulation of task complexity by incorporating two different types of discriminations between the target and lure boards: a *difficult discrimination* (i.e., “Yes” boards and the “Difficult No” boards) and an easy discrimination (i.e., “Yes” boards and the “Easy No” boards). To explore how rapidly the experts and

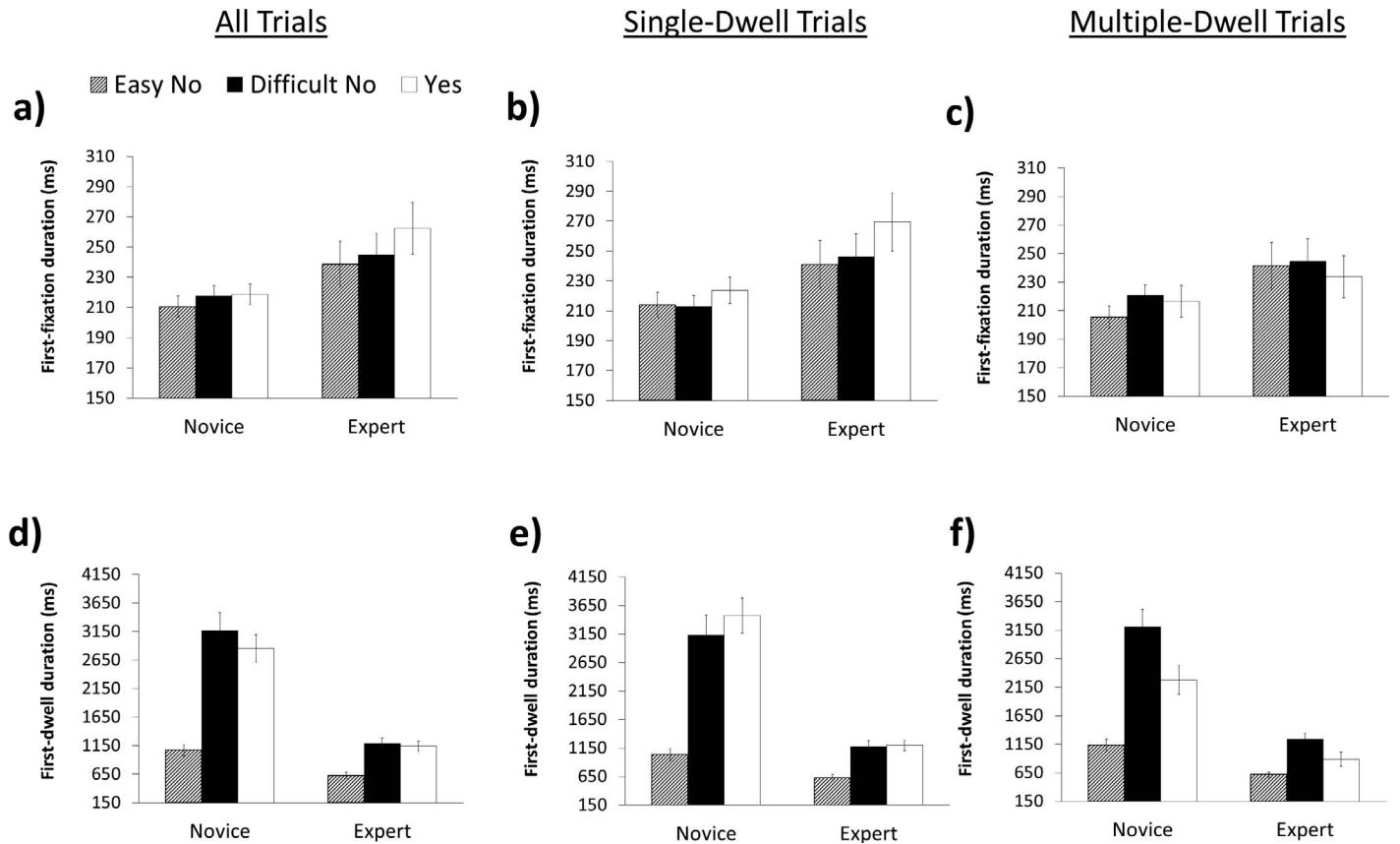


Figure 3. Expert versus novice differences in the duration of the first fixation in milliseconds (a–c) and the first dwell in milliseconds (d–f) as a function of board condition (“Easy No,” “Difficult No,” “Yes”). These measures were calculated separately for all trials (a, d), for the subset of trials with a single dwell on the “Yes” board (b, e), and for the subset of trials with multiple dwells on the “Yes” board (c, f). The errors bars indicate standard errors of means. See text for further details.

novices could process these two types of discriminations, we analyzed the duration of the very first fixation on the board (i.e., *first-fixation duration*), which is considered to be an early measure of processing (for

further discussion of this measure, see Rayner, 1998). We expected that the first-fixation data would reveal that the experts—but not the novices—can rapidly differentiate between the target “Yes” boards and the

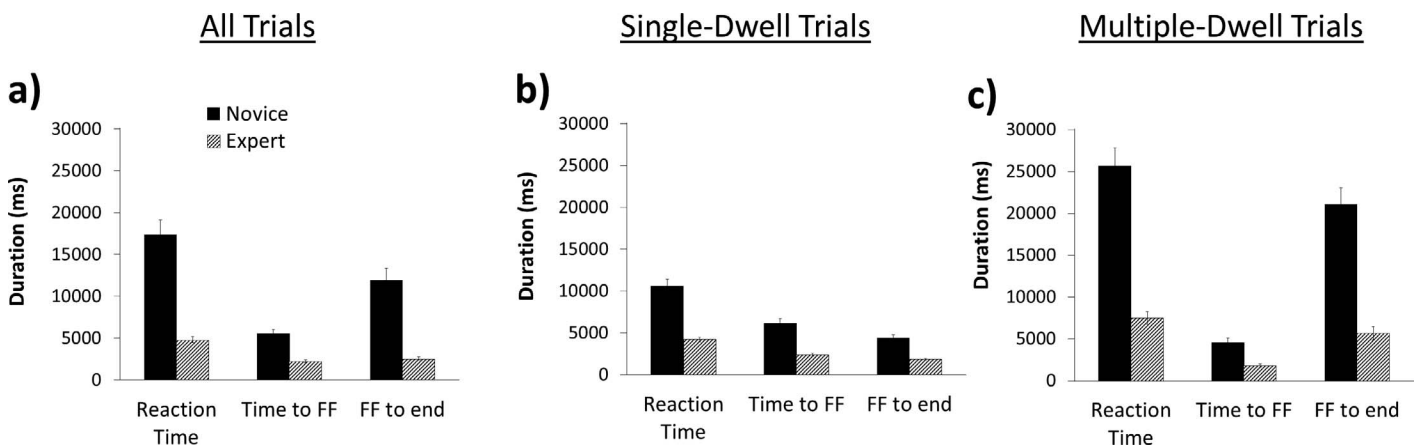


Figure 4. Expert versus novice differences in reaction time measures (in milliseconds), as a function of measure type (reaction time = overall reaction time, time to FF = time to the first fixation on the target board, FF to end = first fixation to the end). These measures were calculated separately for all trials (a), for the subset of trials with a single dwell on the “Yes” board (b), and for the subset of trials with multiple dwells on the “Yes” board (c). The error bars indicate standard errors of means. See text for further details.

“Difficult No” boards (i.e., the *difficult discrimination*), whereas both the experts and novices can rapidly distinguish between the “Yes” boards and the “Easy No” boards (i.e., the *easy discrimination*) because the easy discrimination requires a less complex analysis of the movement of the knight. This prediction follows from chunking and template theory’s assumption that experts are better than novices at using chunks and templates to maintain efficient performance despite increases in complexity and (Wright et al., 2013) supported this prediction by demonstrating larger expertise effects on ERPs during a more complex task (i.e., deciding if the white king is in check), relative to a less complex task (i.e., deciding if there is a black knight on the board).

To the extent that the experts’ first-fixation differences between “Yes” boards and “Difficult No” boards reflected rapid recognition of the target, we expected that this difference would be driven by trials with a single dwell on the target “Yes” board (i.e., a single visit to the target board comprising one or more consecutive fixations). In contrast, in trials in which chess players initially missed the target during the first dwell and then returned to it later in the trial (i.e., multiple-dwell trials on the target board), the duration of the first fixation on the target board was not expected to differ between “Yes” boards and “Difficult No” boards. Such a pattern of first-fixation results would suggest that chess expertise permits rapid recognition of extremely complex visual patterns, which would reinforce the importance of the perceptual component of expertise in chess (for a review, see Reingold & Sheridan, 2011).

To supplement the first-fixation duration measure, we also obtained a later measure of processing by analyzing the duration of the first dwell on the chessboard (i.e., *first-dwell duration*). A dwell was defined as one or more consecutive fixations on the chessboard, prior to the eyes moving to a different region of the display. For both experts and novices, we predicted that the easy discrimination would show dramatically shorter first-dwell durations for the “Easy No” than the “Yes” boards, whereas the difficult discrimination would produce a smaller effect and possibly even an effect in the opposite direction (i.e., *longer* first-dwell durations on the “Difficult No” than the “Yes” boards). We anticipated this pattern of results because the “Easy No” board can be ruled out quickly, but the “Difficult No” board could be initially mistaken for the target—particularly during multiple-dwell trials in which the target was initially missed—which could result in extensive processing of the “Difficult No” boards. Moreover, in further support of our prediction that the complexity of the discrimination (easy versus difficult) would affect first-dwell times, Chassy and Gobet (2013) demonstrated that increasing

complexity slowed down reaction times in a visual search task that used stimuli from chess game positions.

In addition, for both the first-fixation and first-dwell measures, we predicted strong expert/novices differences. According to chunking and template theory, experts can process larger chess configurations during each fixation, resulting in fewer but *longer* fixations for experts than novices (for a review of similar findings, see Reingold & Sheridan, 2011). Thus, we predicted that first-fixation durations would be longer for experts than novices, whereas first-dwell durations would be shorter for experts than novices because experts were expected to show fewer numbers of fixations within the first dwell than novices.

Finally, given our hypothesis that the knight task would provide an excellent index of chess skill, we expected that reaction times would be substantially slower for novices than experts, and we also anticipated that reaction times would correlate with within-group expertise measures (i.e., Elo rating for the experts, number of weekly practice hours for the novices). This pattern of results would validate the present task as a useful index of chess expertise while also providing empirical support for the previous anecdotal reports that the processing efficiency of the moves of the knight piece is a key differentiator of chess skill.

Method

Participants

Thirty-nine chess players (16 experts and 23 novices) were recruited from online chess forums and from local chess clubs in Toronto and Mississauga (Canada). The mean age was 29 years in the expert group and 27 years in the novice group. There was one female player in the expert group, and there were four female players in the novice group. For the expert players, the average Canadian Chess Federation rating ranged from 1876 to 2580 ($M = 2215$). All of the novice players were unrated club players who were familiar with the rules of chess but had never participated in a rated chess tournament. All of the participants had normal or corrected-to-normal vision. Written informed consent was obtained, and the rights of the participants were protected. The research program was approved by the Ethics Review Unit at the University of Toronto.

Materials and design

As shown in Figure 2, the experimental stimuli consisted of minimized 4×4 chessboards. Each of these boards contained a knight that was always located in

one of the four corner squares, one pawn, one bishop, and a target square that contained a black dot. As discussed earlier, these chessboards were used to examine three different conditions. For the “Easy No” condition (see Figure 2a), the knight was unable to move away from the starting position because both the bishop and the pawn were blocking its path. For the “Difficult No” condition (see Figure 2b), the knight was able to move to at least one other square on the board, but the knight could not reach the target square in three moves because its next move was blocked (i.e., because the square was occupied by a piece of the same color, which was either a bishop or a pawn). For the “Yes” condition (see Figure 2c), it was possible for the knight to reach the target square in three moves. Each trial in the experiment contained four of the miniature chessboards, such that two of the boards were in the “Difficult No” condition, one board was in the “Easy No” condition, and the remaining board was in the “Yes” condition. These four boards were arranged around a central fixation cross (see Figure 2d). The locations of the boards were randomly varied across trials such that the “Yes” condition board had an equal chance of occurring in each of the four locations, and there was variation in the spatial layout of the boards (i.e., the positioning of the knight, target square, and blocker pieces).

Apparatus and procedure

Eye movements were measured with an SR Research EyeLink 1000 system with high spatial resolution and a sampling rate of 1000 Hz. The experiment was programmed and analyzed using SR Research Experiment Builder and Data Viewer software. Viewing was binocular, but only the right eye was monitored. A chin rest and forehead rest were used to minimize head movements. Following calibration, gaze-position error was less than 0.5° . The chessboards were presented using images (212×212 pixels) that were created using standard chess software (Chessbase 11). These images were displayed on a 21-in. ViewSonic monitor with a refresh rate of 150 Hz and a screen resolution of $1,024 \times 768$ pixels. Participants were seated 60 cm from the monitor. The center of each of the four chessboards (see Figure 2d) was located approximately 10.2° of visual angle away from the center of the screen. The width of one square on the chessboards equaled approximately 2.1° of visual angle, and the interest areas surrounding each of the four chessboards extended slightly beyond the edge of each board (by 0.80 of a degree of visual angle on all four sides of each board).

Prior to the experiment, the participants were instructed to select the board that allowed the knight to

reach the target square in three moves. They were asked to respond as quickly and accurately as possible. At the start of each trial, the participants were required to look at a fixation point in the center of the screen, prior to the presentation of the four miniature chessboards. When the participant had reached a decision, he or she looked at a gray fixation cross located at the center of the screen and pressed a button on the response pad. This caused the fixation cross to turn green, which signaled the participants to then fixate the chessboard they had chosen in order to select it. Upon fixating the chessboard to be selected, a chime sounded and the trial ended (see Glaholt & Reingold [2012] for a similar gaze selection procedure). This gaze selection procedure was designed to avoid contaminating the eye movement measures for the four boards with the cognitive and motor processing associated with button press responses. There were 48 trials, and the experiment was approximately 30 min in duration.

Results

Our main goal was to explore the time course and magnitude of expertise differences on the knight task. Accordingly, we will begin by comparing the eye movements of experts and novices across the three board type conditions (i.e., “Easy No,” “Difficult No,” “Yes”), and we will then examine a variety of reaction time measures for the experts and novices. Finally, to further explore the utility of the knight task as an index of expertise, we will test for correlations between reaction times on the knight task and several other standard measures of chess expertise (i.e., Elo rating for the experts, number of weekly practice hours for the novices). For all of these analyses, we excluded a small proportion of trials because the participant responded incorrectly (i.e., 0.4% of trials for experts, $SE = 0.2\%$, 6.3% of trials for novices, $SE = 3.0\%$), $t(37) = 1.67$, $p = 0.104$, $\eta^2 = 0.07$. The supplementary materials (see Supplementary S1 Dataset) contain the raw data from all of the analyses in the present article.

Eye movement measures

When we analyzed the eye movements of the experts and novices across the entire trial, the experts displayed more efficient processing, as shown by shorter fixation durations, $t(37) = 3.21$, $p < 0.01$, $\eta^2 = 0.22$, and fewer numbers of fixations, $t(37) = 5.89$, $p < 0.001$, $\eta^2 = 0.48$. To examine processing as function of board type (i.e., “Easy No,” “Difficult No,” “Yes”) for the experts versus the novices, we analyzed the following two measures: (a) first-fixation duration (i.e., the duration

of the first fixation on the chessboard) and (b) first-dwell duration (i.e., the duration of the first dwell on the chessboard; a dwell was defined as one or more consecutive fixations on the chessboard, prior to the eyes moving to a different region of the display). For each of these measures, we conducted separate analyses to contrast the “Yes” and “Easy No” conditions and to contrast “Yes” and “Difficult No” conditions. Specifically, these analyses were conducted using 2×2 analyses of variance (ANOVAs), with board type (easy discrimination: “Yes” vs. “Easy No”; difficult discrimination: “Yes” vs. “Difficult No”) and level of expertise (i.e., novice vs. expert) as independent variables.¹

First-fixation duration by board type

For the first-fixation measure (see Figure 3a), fixation durations were longer for the experts than the novices: easy discrimination, $F(1, 37) = 5.70, p < 0.05, \eta^2_p = 0.13$; difficult discrimination, $F(1, 37) = 5.72, p < 0.05, \eta^2_p = 0.13$. For the easy discrimination, fixation durations were longer for the “Yes” relative to the “Easy No” condition, as reflected by a main effect of board type, $F(1, 37) = 10.47, p < 0.01, \eta^2_p = 0.22$, and the magnitude of this difference was similar for experts and novices as shown by the lack of a significant interaction, $F(1, 37) = 2.55, p = 0.119, \eta^2_p = 0.06$. However, in marked contrast, the difficult discrimination revealed that only the experts showed significantly longer fixations for the “Yes” condition relative to the “Difficult No” condition, as shown by a significant interaction between board type and expertise, $F(1, 37) = 4.39, p < 0.05, \eta^2_p = 0.11$, as well as a main effect of board type, $F(1, 37) = 5.64, p < 0.05, \eta^2_p = 0.13$, and planned contrasts revealed a significant difference between the “Yes” and “Difficult No” conditions for the experts, $t(15) = 2.53, p < 0.05, \eta^2 = 0.30$, but not the novices ($t < 1$). Thus, in support of the prediction that increasing task complexity would magnify expertise effects, the first fixation data revealed expert/novice differences for the difficult discrimination but not for the easy discrimination.

To further investigate the experts’ ability to rapidly distinguish between the “Yes” and “Difficult No” conditions, we also separately analyzed the first-fixation data for the subset of trials that elicited a single dwell on the “Yes” condition board (see Figure 3b) and the subset of trials that elicited multiple-dwells on the “Yes” condition board (see Figure 3c). Relative to the novices, the experts displayed a higher proportion of single-dwell trials (experts: $M = 0.81, SE = 0.02$; novices: $M = 0.59, SE = 0.04$), $t(37) = 3.96, p < 0.001, \eta^2 = 0.30$, and significantly fewer dwells on the “Yes” boards (experts: $M = 1.23, SE = 0.02$; novices: $M = 1.79, SE = 0.14, t(37) = 3.21, p < 0.01, \eta^2 = 0.22$).

Our rationale for conducting the single versus multiple-dwell analysis was to test our hypothesis that the “Yes” versus “Difficult No” first-fixation difference for experts was driven by a subset of single-dwell trials that elicited rapid recognition of the target (i.e., “Yes”) board. In support of this hypothesis, the single-dwell trials produced a significant “Yes” versus “Difficult No” difference for the experts, $t(15) = 2.28, p < 0.05, \eta^2 = 0.26$, but the multiple-dwell trials did not, $t < 1$, and the novices did not show any “Yes” versus “Difficult No” differences (all t s < 2 , all p s > 0.2).² Thus, the experts were capable of making a complex distinction between the “Yes” and “Difficult No” boards during the very first fixation on the board, and this difference was driven by the subset of single-dwell trials.

First-dwell duration by board type

As shown in Figure 3d through f, first-dwell durations were substantially shorter for the experts than for the novices: easy discrimination, $F(1, 37) = 30.22, p < 0.001, \eta^2_p = 0.45$; difficult discrimination, $F(1, 37) = 30.69, p < 0.001, \eta^2_p = 0.45$, which largely reflected the fact that the experts showed fewer numbers of first-dwell fixations than the novices: easy discrimination, $F(1, 37) = 25.49, p < 0.001, \eta^2_p = 0.41$; difficult discrimination, $F(1, 37) = 27.49, p < 0.001, \eta^2_p = 0.43$. For the easy discrimination, first-dwell durations were longer for the “Yes” condition relative to the “Easy No” condition, $F(1, 37) = 89.18, p < 0.001, \eta^2_p = 0.71$, and the magnitude of the expert/novice difference was larger for the “Yes” board relative to the “Easy No” condition, as shown by a significant interaction, $F(1, 37) = 27.31, p < 0.001, \eta^2_p = 0.43$. In contrast, for the difficult discrimination, first-dwell durations were shorter for the “Yes” relative to the “Difficult No” condition, $F(1, 37) = 5.44, p < 0.05, \eta^2_p = 0.13$, and the interaction was not significant, $F(1, 37) = 2.93, p = 0.095, \eta^2_p = 0.07$. When we contrasted the single-dwell and multiple-dwell trials, we discovered that the “Yes” versus “Difficult No” difference was driven solely by the multiple-dwell trials (i.e., the trials with multiple dwells on the “Yes” condition board). As can be seen from Figure 3e, f, the multiple-dwell trials showed shorter first-dwell durations for the “Yes” than the “Difficult No” condition: experts, $t(15) = 3.61, p < 0.01, \eta^2 = 0.46$; novices, $t(22) = 4.69, p < 0.001, \eta^2 = 0.50$, whereas the single-dwell trials revealed a nonsignificant numerical difference in the opposite direction: experts, $t < 1$; novices, $t(22) = 1.68, p = 0.106, \eta^2 = 0.11$. One possible explanation for these results is that during the multiple-dwell trials, the chess players initially missed the target “Yes” board—and were misled by a “Difficult No” board—which required them to spend time ruling out the “Difficult No” board before

eventually returning to the “Yes” board later in the trial.

Reaction time measures

As can be seen in Figure 4a, the overall reaction times revealed that the novices took four times as long as the experts to reach a decision, $t(37) = 5.66$, $p < 0.001$, $\eta^2 = 0.46$. To help pinpoint the source of this large expert/novice difference in reaction times, we subdivided the reaction times into two intervals: (a) “time to first fixation” (time to FF; i.e., the interval of time between the start of the trial and the onset of the first fixation on the target “Yes” chessboard) and (n) “first fixation to end” (FF to end; i.e., the interval of time between the onset of the first fixation on the “Yes” chessboard and the time point when the chess player indicated that he or she had reached a decision). Moreover, similar to the first-fixation and first-dwell measures, we separately analyzed the single-dwell trials (see Figure 4b) and the multiple-dwell trials (see Figure 4c). To analyze the impact of time interval (i.e., time to FF, FF to end), trial type (i.e., single-dwell vs. multiple-dwell), and level of expertise (i.e., expert, novice), we conducted a $2 \times 2 \times 2$ ANOVA. This analysis revealed a significant three-way interaction, $F(1, 37) = 34.04$, $p < 0.001$, $\eta^2_p = 0.48$, which stemmed from the fact that the largest expertise differences in reaction times occurred during the FF to end interval for the multiple-dwell trials. As a possible explanation for this dramatic spike in expert/novice differences, it is possible that the chess players initially missed the target during the multiple-dwell trials, and the experts were much better able to recover from a miss than the novices.

Correlations between performance and chess expertise

Given the dramatic expert/novice differences reported above, we wished to test if the knight move task would also be sensitive to within-group expertise differences. To test this hypothesis, we examined if performance on the knight task would be correlated with the Elo rating of the experts and the number of weekly practice hours of the novices. In lieu of Elo ratings for the novices, we asked each novice player to estimate the total number of hours he or she spent practicing or playing chess per week ($M = 1.67$ hr per week, $SE = 0.43$). As shown in Figure 5, all three of the knight task’s reaction time measures (overall RT, time to FF, FF to end) were significantly correlated with the experts’ Elo ratings and the novices’ number of practice hours.³ These correlations demonstrate that the knight move task is extremely sensitive to expertise differences,

even for the small sample size of 16 experts and 23 novices and despite the restricted range of the experts’ Elo ratings (i.e., 1876 to 2580).

Discussion

To investigate the perceptual component of chess expertise, the present study introduced a novel laboratory chess task that was a variant of the famous “Knight’s tour” chess problem (Euler, 1759). Critically, this task revealed that relative to novices, the chess experts showed faster recognition of complex visual patterns. The experts’ first-fixation durations were longer on the target boards in which the knight could reach the target square in three moves (i.e., the “Yes” condition; see Figure 2c) relative to the lure boards in which the path of the knight was blocked on its second move toward the target square (i.e., the “Difficult No” condition; see Figure 2b). As evidence that this “Yes” versus “Difficult No” difference reflected a rapid recognition of the target, this difference was solely driven by trials that elicited a single-dwell on the target board. Furthermore, as evidence that the level of complexity of the discrimination was an important boundary condition for this effect, we did not observe any expertise differences when we compared first-fixation durations for an easier “baseline” discrimination between the “Yes” condition and the lure boards in which the knight’s path was immediately blocked on the first move (i.e., the “Easy No” condition; see Figure 2a). This pattern of rapid differentiation by experts between complex visual patterns during their very first fixation on the board is truly impressive. In addition to revealing rapid recognition of the targets, the knight task also demonstrated dramatic expertise effects on reaction times, and more important, the knight task was sensitive enough to capture differences within groups; As shown in Figure 5, performance on the knight task was correlated with other measures of chess expertise (i.e., the Elo rating of the experts and the number of hours of practice of the novices). These correlations occurred even though the present study’s sample of experts had a restricted range of Elo ratings. Moreover, compared with previous chess laboratory tasks (for a review, see Reingold & Sheridan, 2011), the knight task produced expert/novice differences that were even more dramatic. For example, whereas the knight task produced reaction times that were more than *four* times longer for novices than experts ($\eta^2 = 0.46$), the check detection task (e.g., Reingold et al., 2001) produced reaction times that were twice as long for novices than experts ($\eta^2 = 0.17$). Thus, the knight task provides a promising methodological tool for studying individual differences in chess expertise.

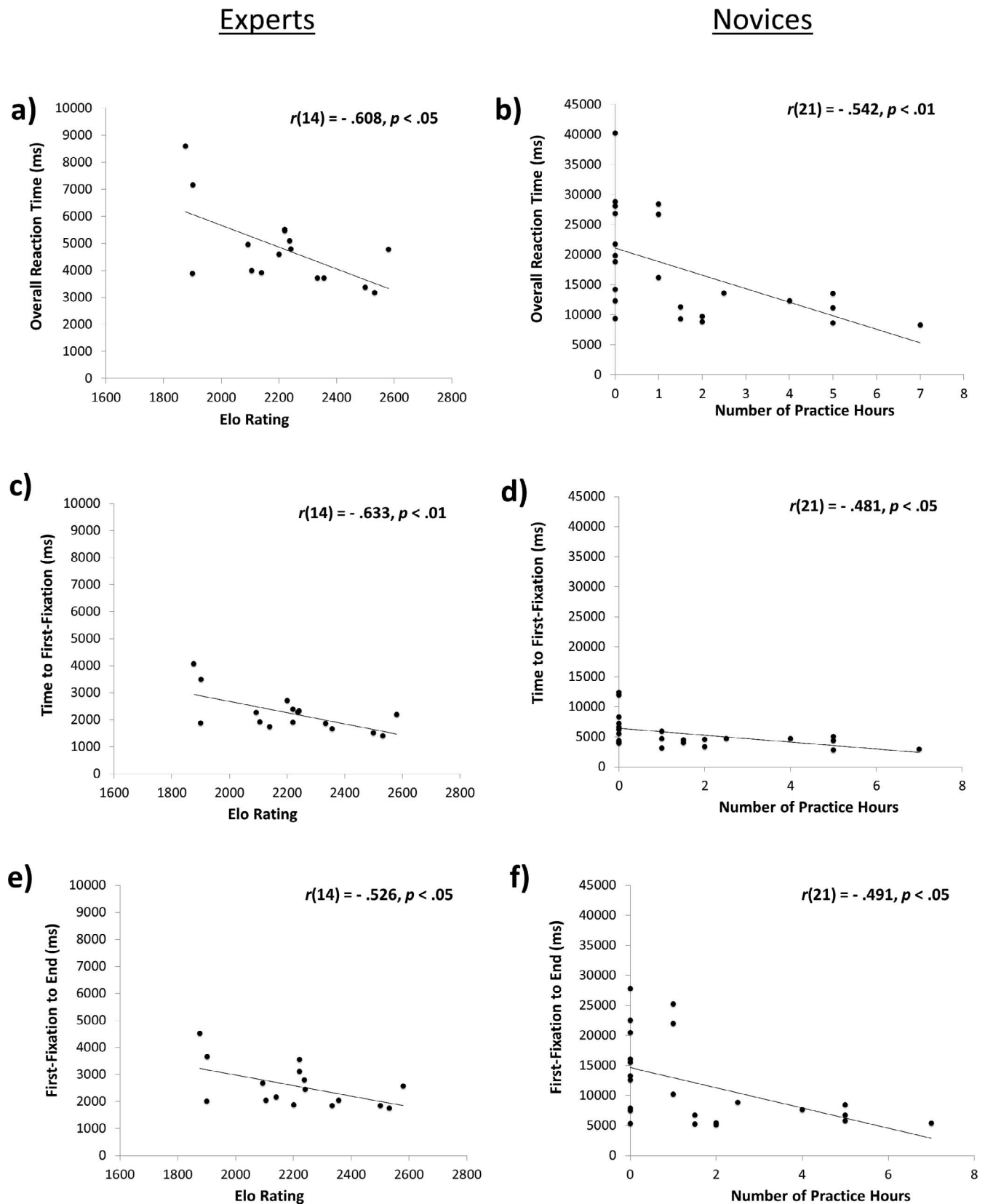


Figure 5. Scatterplots (and Pearson’s r correlation coefficients) showing the relationship between chess expertise (Elo ratings of experts, practice hours per week for the novices) and performance on the knight task, for each of the reaction time measures in milliseconds (overall RT = overall reaction time, time to FF = time to the first fixation on the target board, FF to end = first fixation to the end). See text for further details.

The above findings from the knight task are consistent with the theoretical perspective that perceptual skill is a key aspect of chess expertise (for a review, see Reingold & Sheridan, 2011). In addition, the strong manipulation of complexity in the present study (i.e., the knight task's easy vs. difficult discrimination) produced evidence that is consistent with prior work demonstrating larger expertise effects on ERPs to chess-related stimuli as a function of task complexity (Wright et al., 2013). Taken together, these results support the predictions of the chunking and template theories that increases in complexity will amplify expertise differences because, presumably, experts can use their memory for domain-related configurations to compensate for increases in complexity.

The present study provides empirical support for anecdotal claims that the knight piece is a key differentiator of chess expertise. One possible explanation for this finding is that it might be more challenging for chess players to acquire and/or use memory structures (e.g., “chunks” and “templates”) that involve the complex moves of the knight piece, as opposed to the simpler move trajectories of the other pieces. It is unclear if the novices' slower reaction times resulted from slower processing of the knight's moves and/or from more time spent recovering from errors incurred during the calculation of knight moves. Future work could explore variants of the knight task in more detail, with the goal of pinpointing the exact source of the novices' difficulty with the moves of the knight piece.

Finally, the present study's finding that chess experts could rapidly recognize complex visual patterns is similar to findings in other domains of expertise that also involve a visual search component. For example, visual expertise in medicine also entails a superior ability to encode domain-related visual patterns, as shown by findings that expert radiologists can rapidly fixate on abnormalities (for a review, see Reingold & Sheridan, 2011). Future work can continue to explore perceptual expertise in chess and other domains, with the goal of uncovering domain-general characteristics of expertise.

Keywords: chess, visual expertise, eye movements, time course, parafoveal processing, holistic processing, visual search, individual differences, expert/novice differences

Acknowledgments

We are especially grateful to all of the chess players who participated in the experiment. This research was supported by an NSERC grant to EMR.

Commercial relationships: none.

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Footnotes

¹ Although the focus of the article is on the preplanned contrasts between the target and lures (i.e., “Yes” vs. “Difficult No,” “Yes” vs. Easy No”), for comprehensiveness, we also contrasted the “Difficult No” and “Easy No” conditions using 2×2 ANOVAs, with board type (i.e., “Difficult No” vs. “Easy No”) and level of expertise (i.e., novice vs. expert) as independent variables. For the first-fixation measure, there were no significant main effects: board type, $F(1, 37) = 2.86, p = 0.099, \eta^2_p = 0.07$; expertise, $F(1, 37) = 3.80, p = 0.059, \eta^2_p = 0.09$, and no interaction ($F < 1$). For the first-dwell measure, there was a main effect of board type, $F(1, 37) = 78.13, p < 0.001, \eta^2_p = 0.68$, a main effect of expertise, $F(1, 37) = 25.98, p < 0.001, \eta^2_p = 0.41$, and a significant interaction, $F(1, 37) = 26.11, p < 0.001, \eta^2_p = 0.41$. Furthermore, we analyzed both dependent variables (i.e., first-fixation duration, first-dwell duration) using 3×2 ANOVAs, with board type (“Yes” vs. “Difficult No” vs. “Easy No”) and level of expertise (i.e., novice vs. expert) as independent variables. For the first-fixation measure, there was a main effect of board type, $F(2, 74) = 6.97, p < 0.01, \eta^2_p = 0.16$; a main effect of expertise, $F(1, 37) = 5.20, p < 0.05, \eta^2_p = 0.12$; and no interaction, $F(2, 74) = 2.32, p = 0.105, \eta^2_p = 0.059$. For the first-dwell measure, there was a main effect of board type, $F(2, 74) = 71.78, p < 0.001, \eta^2_p = 0.66$; a main effect of expertise, $F(1, 37) = 29.77, p < 0.001, \eta^2_p = 0.45$; and a significant interaction, $F(2, 74) = 23.29, p < 0.001, \eta^2_p = 0.39$.

² In addition, for both dependent variables (i.e., first-fixation duration, first-dwell duration), we separately analyzed the single-dwell and multiple-dwell trials using 2×2 ANOVAs, with board type (“Yes” vs. “Difficult No”) and level of expertise (i.e., novice vs. expert) as independent variables. For the first-fixation measure, the single-dwell trials revealed a main effect of board type, $F(1, 37) = 5.51, p < 0.05, \eta^2_p = 0.13$, and expertise, $F(1, 37) = 6.09, p < 0.05, \eta^2_p = 0.14$, whereas the multiple-dwell trials did not show any significant main effects (all $F_s < 2$, all $p_s > 0.15$), and there were no significant interactions for either the single- or multiple-dwell trials (all $F_s < 1$). In contrast, for the first-dwell measure, the single-dwell trials showed no main effect of board type, $F(1, 37) = 2.12, p = 0.154, \eta^2_p = 0.05$, and no interaction, $F(1, 37) = 1.68, p = 0.203, \eta^2_p = 0.04$, whereas the multiple trials revealed a main effect of board type, $F(1, 37) = 25.85, p < 0.001, \eta^2_p =$

0.41, and a significant interaction, $F(1, 37) = 5.30$, $p < 0.05$, $\eta^2_p = 0.13$, and both the single- and multiple-dwell trials showed a main effect of expertise, all $F_s > 25$, all $p_s < 0.001$.

³ One of the expert chess players was identified as a potential outlier. Without this participant included, the correlations between Elo rating and performance are as follows: overall reaction time: $r(14) = -0.743$, $p < 0.01$; time to FF: $r(14) = -0.752$, $p < 0.01$; and FF to end: $r(14) = -0.661$, $p < 0.01$. Interestingly, the rating of this participant has increased by several hundred points since the time of the study, suggesting that their rating at the time of the study may have been an underestimation of their chess ability. With this participant's rating changed to their current rating on the website of the Chess Federation of Canada, the correlations between Elo rating and performance are overall RT: $r(14) = -0.684$, $p < 0.01$; time to FF: $r(14) = -0.703$, $p < 0.01$; and FF to end: $r(14) = -0.600$, $p < 0.05$.

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