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A Role of Peripheral Vision in Chess? Evidence from a Gaze-contingent Method

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Abstract

Chunking theory and previous eye-tracking studies suggest that expert chess players use peripheral vision to judge chess positions and determine the best moves to play. However, the role of peripheral vision in chess has largely been inferred rather than tested through controlled experimentation. In this study, we used a gaze-contingent paradigm in a reconstruction task, similar to the one initially used by De Groot (1946). It was hypothesized that the smaller the gaze-contingent window while memorizing a chess position, the smaller the differences in reconstruction accuracy between novice and expert players. Participants viewed 30 chess positions for 20 seconds, after which they reconstructed this position. This was done for four different window sizes as well as for full visibility of the board. The results, as measured by Cohen's *d* effect sizes between experts and novices of the proportion of correctly placed pieces, supported the above hypothesis, with experts performing much better but losing much of their performance advantage for the smallest window size. A complementary find-the-best-move task and additional eye-movement analyses showed that experts had a longer median fixation duration and more spatially concentrated scan patterns than novice players. These findings suggest a key contribution of peripheral vision and are consistent with the prevailing chunking theory.

Keywords

Chess, eye movements, eye-tracking, expertise, gaze-contingent method, memory, perception

Introduction

The game of chess has been proven to be a suitable experimental framework for studying human information processing (Ericsson & Smith, 1991; Simon, 1979). Chess is highly complex, harboring an astronomical number of possible games and board positions (Allis, 1994; Shannon, 1950), and becoming a chess expert requires not only high cognitive ability but also thousands of hours of practice (Charness et al., 2005; Gobet & Campitelli, 2007; Grabner, 2014; Hambrick et al., 2014; Howard, 2012; Vaci et al., 2019). At the same time, chess is remarkably simple: The board consists of only 64 squares and six types of pieces, with rules that can be learned by virtually anyone. This simple structure makes chess suitable for analyses that may unravel the determinants of expert performance.

It is commonly believed that chess experts have learned to encode chunks, i.e., patterns that frequently recur in chess positions (e.g., Charness et al., 2001; Simon & Chase, 1973; Simon & Gilmartin, 1973). The difference between experts and novices presumably concerns the number and size of chunks available in their long-term memory (Gobet & Simon, 2000; Simon & Chase, 1973), or as phrased by Cleveland (1907) in a reflection on the learning process of chess, *"*... the chess player to take in a whole situation at a glance. Not only has the unit of perception become larger and larger but it has become more and more meaningful" (p. 299).

Evidence for the chunking theory comes largely from experiments in which chess players were tasked to memorize and reconstruct board positions. Landmark research by De Groot (1946) found that when chess experts were briefly exposed (2 to 15 seconds) to a realistic board position, they were able to place many pieces on the correct squares afterward. More recent research has shown that when the pieces were placed in a random manner on the board, chess experts were considerably less able to reconstruct the board and perform nearly on par with novices (Chase & Simon, 1973a; Jongman, 1968; for a review see Gobet & Simon, 1996). These findings are consistent with the chunking theory, which says that experts extract familiar patterns from their long-term memory.

Another key finding in chess research is that experts can quickly and accurately decide on the best move to play (De Groot, 1946; Moxley & Charness, 2013). Eye-tracking research shows that expert players arrive at the best move by focusing on crucial pieces or empty squares between crucial pieces, rather than fixating on individual pieces on the board (Bilalić et al., 2010; Charness et al., 2001; Reingold & Charness, 2005; Sheridan & Reingold, 2013, 2014, 2017; Simon & Barenfeld, 1969; Tikhomirov & Poznyanskaya, 1966). Based on these findings, it has been argued that experts use peripheral vision, rather than foveal vision alone, to detect the aforementioned chunks (Simon & Barenfeld, 1969; Smith et al., 2009). In other words, chess experts do not necessarily excel in thinking and deductive reasoning, but their advantage in chess appears to be, at least in part, of perceptual nature (see also Hendriks, 2014).

To obtain direct evidence for experts' reliance on peripheral vision and the perception of chunks, Reingold et al. (2001) conducted a change-blindness task using a gaze-contingent window. In this task, one of the 20 pieces on the board was changed, and participants viewed the board through a circular window. Outside of this window, the pieces were gray blobs that masked their color and shape. The results showed that in a baseline session without the gaze-contingent window, experts detected the changed piece faster than intermediates and novices, especially in chess (i.e., non-random) configurations. The authors then used a staircase method, in which the window size was increased (decreased) if the participant's response time was longer (shorter) than the baseline response time. The expert players converged to a larger window size than the intermediates and novices, but only for chess configurations and not for random configurations. These findings suggest that experts have a larger visual span for detecting a changed piece, while for novices and intermediates, a smaller visual span suffices.

More recently, Wang et al. (2016) examined the role of peripheral vision among players of Chinese chess, also called XiangQi. In one of their experiments, participants viewed boards for 12 seconds and then reconstructed the positions. A square-shaped gaze-contingent window was used in three different sizes (1×1, 2×2, or 4×4 squares, corresponding to a radius of 1.3°, 2.9°, and 5.3°, respectively). The results showed that novices performed poorly, correctly placing an average of 2.5, 3.1, and 3.6 of the 14 pieces for the small, medium-sized, and largest windows, respectively. Expert players, on the other hand, correctly placed 2.9, 6.0, and 7.0 pieces for the three respective window sizes. The authors concluded that experts use peripheral information to their advantage. These results provide insight into the role of peripheral vision in Chinese chess, but they deserve replication with normal chess. Some of the findings may also be considered unusual, such as the mean dwell time percentage on the chess pieces being only 3%, while 16% (14 of 90 points) were occupied with pieces. This raises questions about the accuracy of the experimental setup and suggests a need for further research.

The purpose of the current study was to build on Reingold et al. (2001) and Wang et al. (2016) and acquire additional direct evidence on chess players' reliance on peripheral vision. An experiment was conducted in which players of different strengths (novices, intermediates, experts) had to memorize a board position while limited by a gaze-contingent window of different sizes. It was hypothesized that experts rely on peripheral vision more strongly than intermediates and novices, and that novices would not be as much hampered by gaze-contingent windows. Therefore, it was expected that the performance advantage of experts relative to intermediates and novices would be most pronounced without a gaze-contingent window and would decrease with decreasing window size.

In addition to studying peripheral vision using the gaze-contingency paradigm, we aimed to gain insight into how chess players perform find-the-best-move tasks. Psychometric analyses of chess expertise show that find-the-best-move tasks have a high predictive validity for chess skill as measured through ELO ratings, more so than reconstruction tasks (Van der Maas & Wagenmakers, 2005). In recent years, there has been renewed interest in find-the-best-move tasks. Chess websites such as Chess.com, Lichess, and Chesstempo have introduced tactics games that encourage players to solve as many puzzles as possible in a short amount of time (e.g., 3 or 5 minutes). It is astonishing that expert players can complete over 50 puzzles in 5 minutes, some of which are difficult and consist of multiple moves (Chess.com, 2022). Therefore, another aim was to gain insight into how chess players of different strengths perform these tasks by analyzing their eye-movement patterns, such as fixation duration and spread of visual search.

Method

Fifteen males (five experts, five intermediates, and five novices) participated in the experiment. The experts had FIDE ELO ratings between 2001 and 2464 (*M* = 2251, *SD* = 195) and a mean age of 41.8 years (*SD* = 12.7). Three of the five experts had a chess title (two International Masters and one FIDE Master). The intermediates had ELO ratings of around 1500 (estimated from national, FIDE, or online Blitz ratings) and a mean age of 32.0 years (*SD* = 17.8). The novices knew the rules of the game but had little chess experience; they had ELO ratings lower than 1200 and a mean age of 28.6 years (*SD* = 14.9). The experiment was approved by the Human Research Ethics Committee of the TU Delft. All participants provided written informed consent.

Apparatus

Eye movements were recorded using the SR Research EyeLink 1000 Plus. To minimize head movements, a head support was used. The head support remained at the same height for all participants. While viewing was binocular, only the right eye was recorded. The experiment used a 24-inch monitor (BenQ XL2420T-B) with a display area of 531×298 mm and a screen resolution of 1920×1080 pixels. At a distance of 900 mm from the monitor to the eyes, the display subtended an approximately 33° horizontal and 19° vertical viewing angle.

Find-the-Best-Move Task

The experiment consisted of two parts: a find-the-best-move task and a reconstruction task. For the find-the-best-move task, 50 chess puzzles were used, which were copied from the website http://www.chess.com. The puzzles were presented in increasing difficulty, starting at a Chess.com rating of 500 and increasing by 40 rating points per puzzle, with the final puzzle having a rating of 2500. The chessboard covered an area of 992×992 pixels.

After eye-tracker calibration, the participants were shown a brief textual introduction and explanation of the task, followed by a practice puzzle. A combination of self-written Python code and SR Research Experiment Builder software allowed the participants to drag a piece to a square on the chessboard. The puzzles were all played with White to move. After the practice puzzle, the participants solved as many puzzles as possible within 5 minutes. No timer was shown to avoid visual distraction. After each puzzle, a slide with the text CORRECT! or INCORRECT! was displayed. If the participant reached five mistakes or the 5 minutes were over, the task ended, and the experiment continued to the introduction screen for the reconstruction task.

Reconstruction Task

Participants were tasked with reconstructing a total of 30 chess configurations. Ten positions featured a small number (12 to 19) of pieces, 30 moves into the game. Ten positions had a medium (22 to 25) number of pieces, 20 moves into the game. Finally, 10 positions had a large number (28 to 32) of pieces, 10 moves into the game. Fifteen positions were from the perspective of White, while the other 15 were from Black's perspective. Twenty positions were with White to move, while 10 were with Black to move. During the memorization phase of the reconstruction task, the chessboard covered an area of 1080×1080 pixels.

Five levels of gaze-contingent window size were used:

- A diameter of 248 pixels (1.84 squares, corresponding to a radius of 2.2°)
- A diameter of 496 pixels (3.67 squares, corresponding to a radius of 4.4°)
- A diameter of 744 pixels (5.51 squares, corresponding to a radius of 6.5°)
- A diameter of 992 pixels (7.35 squares, corresponding to a radius of 8.7°), or
- A diameter of 4200 pixels (encompassing the entire screen).

The gaze-contingent window followed the eye movements of the participant. The part of the screen outside this window was made gray (RGB: 127, 127, 127), as shown in Figure 1.

First, the participants were informed about the goal of the task: to remember the displayed chess position, which was shown for 20 s, and to reconstruct the chess position as accurately as possible. After calibrating the eye tracker, the participants performed a practice trial with a gaze-contingent window of 4.4° radius. Next, the participants were shown the 30 chess positions with different gaze-contingent windows. The participants looked at each chess position for a duration of 20 seconds ("memorization phase").

After the 20 seconds, the gaze-contingent window disappeared, and the participants had 1 minute to reproduce the position on an empty chessboard. During reconstruction, the chessboard covered 992×992 pixels and was left-aligned, with pieces to choose from on the right of the board. In this way, the participants could not rely on location cues from the previously memorized puzzle (such as by keeping their cursor still on a square to mark the position of a chess piece).

The participants could pick and drag pieces onto the board. They could also reposition pieces on different squares or drag previously-placed pieces out of the board. When the minute was over, or the participant was done and pressed enter, the chessboard disappeared. The participants could then press Enter to proceed to the next position or take a break. If the participant took a break and left the headrest support, a new calibration was performed.

Figure 1. The experimental setup during the memorization phase of the reconstruction task. A gaze-contingent window with a radius of 4.4° is visible on the computer screen.

Each participant reconstructed 30 different board positions, 6 for each window size. The different gaze-contingent window sizes were offered in a blocked manner. The entire randomization sequence for each participant can be found in the Appendix. The experiment took between 45 and 90 minutes per participant, excluding the completion of the consent form and pre-experiment questionnaire.

Dependent Measures

First, the horizontal (x) and vertical (y) gaze data were filtered. Specifically, periods during which vertical gaze data on the screen were unavailable, such as caused by eye blinks, were labeled as gaps. A margin of 100 ms was added before and after each gap, and the gaps were subsequently linearly interpolated. Next, the x and y data were median-filtered using a window length of 100 ms. Saccades were identified based on the speed of the gaze point and filtered using a Savitzky-Golay filter. A speed threshold of 30°/s was adopted, and the minimum fixation duration was set to 40 ms.

For the find-the-best-move task, the following measures were computed per participant:

- *Performance*
  - Number of puzzles completed.
  - Number of puzzles solved correctly.
- *Eye-tracking*
  - Number of fixations.
  - Saccade amplitude in degrees.
  - Median fixation duration in milliseconds (the median was used as this measure is robust to outliers)
  - Standard deviation of the horizontal fixation location coordinate in pixels.
  - Standard deviation of the vertical fixation location coordinate in pixels.

The five eye-tracking measures were first computed per puzzle and subsequently averaged over the participant's completed puzzles. Two novices completed only 6 puzzles, while the other participants completed 12 or more puzzles. Therefore, it was decided to repeat the analysis by using the first 6 puzzles only.

For the reconstruction task, the following measures were computed per participant:

- *Performance*
  - Proportion correct, i.e., the number of pieces that were placed correctly divided by the total number of pieces in the position to be reconstructed.
- *Descriptive*
  - Reconstruction time in seconds. This is the time it took to reconstruct the position, defined as the elapsed time from the start of the trial until placing the last piece. The maximum possible reconstruction time was 60 s.
  - Median pick-place time in seconds. This is the median time elapsed between picking up a piece and placing it on the board during the reconstruction phase.
- *Eye-tracking*
  - Number of fixations during the memorization phase.
  - Saccade amplitude during the memorization phase, in degrees.
  - Median fixation duration during the memorization phase, in milliseconds. The last, i.e., non-completed, fixation was not included in this computation.
  - Standard deviation of the horizontal fixation location coordinate in pixels during the memorization phase.
  - Standard deviation of the vertical fixation location coordinate in pixels during the memorization phase.

Reconstruction data for 5 of 450 trials were unavailable due to a software error, and eye-movement data for the memorization phase were unavailable for 1 of 450 trials. These trials were treated as missing data in the analyses. The magnitudes of differences between the three participant groups were assessed using Cohen's d.

Results

Find-the-Best-Move Task

Table 1a shows the mean and standard deviation of the number of puzzles solved for the three expertise levels. The number of puzzles completed (correctly) differed strongly between the three groups. Furthermore, experts made fewer fixations per puzzle than intermediates and novices, consistent with the fact that experts completed the puzzles faster.

Additionally, experts had a longer median fixation duration per puzzle than novices. Experts also had a smaller saccade amplitude and lower standard deviations of fixation locations than novices, indicating a more concentrated spread of fixations.

The pattern of results remained the same when selecting only the first six puzzles (all participants completed at least six puzzles); see Table 1b. The effects were also apparent when selecting only the first five fixations and the first five saccades (Charness et al., 2001), as can be seen in Table 1c. An exception was the median fixation duration, which did not differentiate clearly between the participant groups when computed for the first five fixations.

Table 1a. Mean (*SD*) of dependent measures for the three participant groups, and Cohen's *d* between the three pairs of participant groups.

Measure	**Experts (E)**	**Intermediates (I)**	**Novices (N)**	***d* E–I**	***d* E–N**	***d* I–N**
Number of puzzles completed	34.00 (7.48)	18.20 (4.32)	10.40 (4.16)	2.59	3.90	1.84
Number of puzzles correct	30.60 (8.65)	15.00 (3.67)	6.40 (3.36)	2.35	3.69	2.44
Number of fixations	21.50 (7.06)	49.00 (18.21)	82.23 (45.03)	-1.99	-1.88	-0.97
Median fixation duration (ms)	255.0 (36.3)	226.1 (25.6)	199.7 (21.7)	0.92	1.85	1.11
Mean saccade amplitude (°)	3.06 (0.47)	3.43 (0.58)	4.20 (0.50)	-0.69	-2.33	-1.42
SD fixation location hor. (px)	136.4 (20.0)	159.4 (16.6)	187.5 (20.5)	-1.25	-2.52	-1.51
SD fixation location ver. (px)	143.2 (17.8)	175.2 (30.4)	231.1 (19.0)	-1.29	-4.78	-2.20

$p < .05$ for $|d| \geq 1.46$, $p < .005$ for $|d| \geq 2.43$

Table 1b. Mean (*SD*) of dependent measures for the three participant groups, and Cohen's *d* between the three pairs of participant groups, when selecting the first six puzzles only.

Measure	**Experts (E)**	**Intermediates (I)**	**Novices (N)**	***d* E–I**	***d* E–N**	***d* I–N**
Number of puzzles correct (out of 6)	5.40 (0.55)	5.60 (0.55)	4.40 (2.07)	-0.37	0.66	0.79
Number of fixations	12.43 (2.86)	39.07 (20.94)	74.27 (48.68)	-1.78	-1.79	-0.94
Median fixation duration (ms)	260.0 (31.9)	229.7 (29.9)	197.2 (22.6)	0.98	2.27	1.23
Mean saccade amplitude (°)	3.43 (0.60)	3.86 (0.56)	4.36 (0.53)	-0.73	-1.63	-0.92
SD fixation location hor. (px)	148.4 (25.0)	174.0 (19.1)	198.7 (9.4)	-1.15	-2.67	-1.65
SD fixation location ver. (px)	156.2 (25.7)	191.3 (24.6)	232.9 (13.0)	-1.40	-3.76	-2.11

$p < .05$ for $|d| \geq 1.46$, $p < .005$ for $|d| \geq 2.43$

Table 1c. Mean (*SD*) of dependent measures for the three participant groups, and Cohen's *d* between the three pairs of participant groups, when selecting only up to the first five fixations and saccades per puzzle.

Measure	**Experts (E)**	**Intermediates (I)**	**Novices (N)**	***d* E–I**	***d* E–N**	***d* I–N**
Number of fixations (max. 5)	4.93 (0.10)	5.00 (0.00)	5.00 (0.00)	-1.02	-1.02	–
Median fixation duration (ms)	234.4 (31.4)	211.9 (20.9)	202.9 (22.7)	0.84	1.15	0.41
Mean saccade amplitude (°)	2.84 (0.51)	3.52 (0.69)	4.79 (0.42)	-1.11	-4.14	-2.24
SD fixation location hor. (px)	119.8 (15.2)	138.1 (19.6)	155.7 (21.1)	-1.04	-1.95	-0.87
SD fixation location ver. (px)	114.0 (15.0)	141.6 (38.1)	210.8 (23.6)	-0.95	-4.89	-2.18

$p < .05$ for $|d| \geq 1.46$, $p < .005$ for $|d| \geq 2.43$

Table 1 showed that experts had a lower standard deviation of fixation locations than intermediates and novices. These findings are illustrated for one puzzle in Figure 2 (all fixations) and Figure 3 (only fixations in a 1.5-s interval). More specifically, Figure 2 shows that experts not only made a small number of fixations; they also had a scan pattern that was closely tied to the correct move (c1–c6). In comparison, novices were more likely than experts to scan irrelevant pieces, such as the two rooks on the eighth rank. The same pattern was identified when selecting only the first few seconds of the data (Figure 3). An additional observation was that one expert was able to complete four puzzles with as few as three or four fixations. This is illustrated in Figure 4, depicting the expert player's fixations for one of the puzzles.

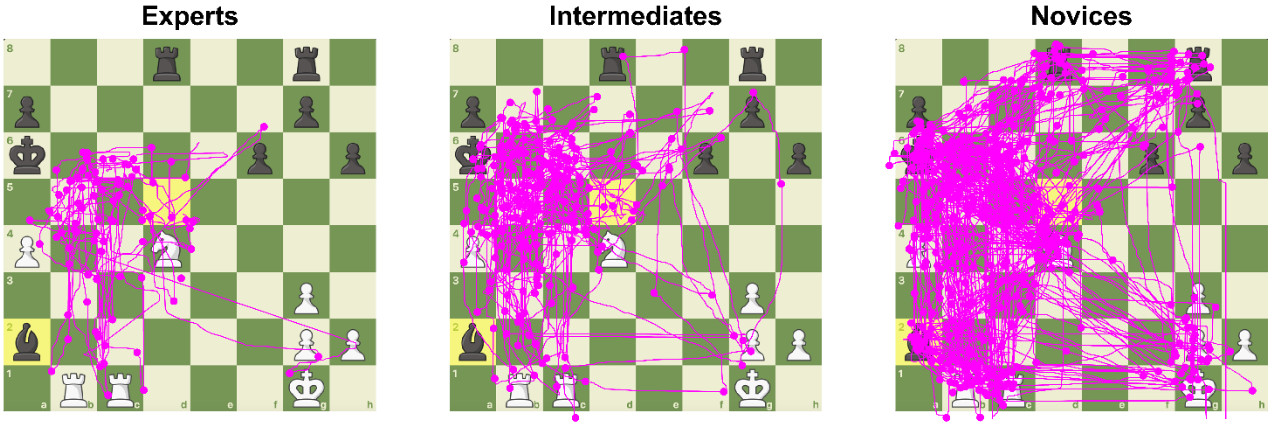

Figure 2. Participants' fixation locations and scan paths for Puzzle 6.

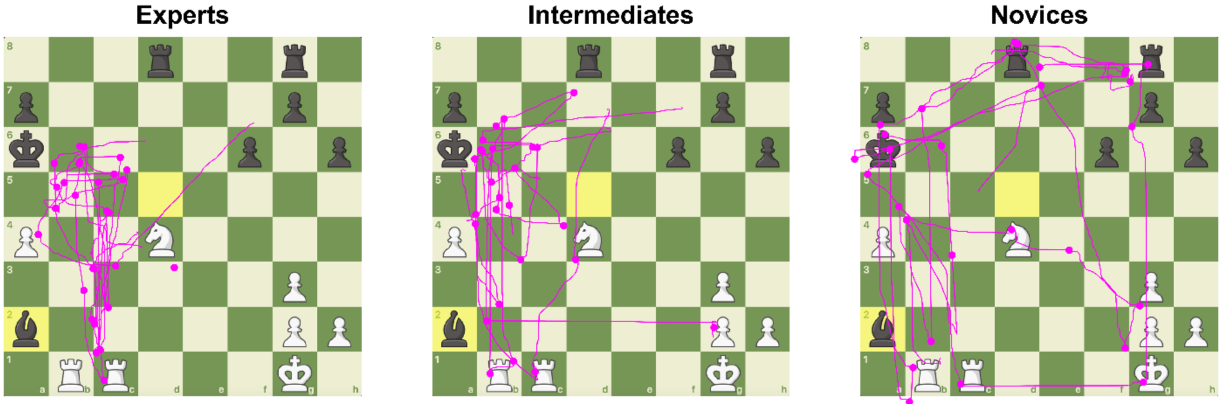

Figure 3. Participants' fixation locations and scan paths for Puzzle 6, depicting only the interval 0.5 s ≤ elapsed time ≤ 2 s.

Figure 4. An expert's fixation locations and scan paths for Puzzle 26. The expert placed four fixations and took 2.65 s to solve the puzzle. In this puzzle, e5–f7 is the only winning move.

Reconstruction Task

An automated analysis of the reconstructed positions showed that experts had better reconstruction accuracy than intermediates and novices (Table 2). Effect sizes between experts and novices were smallest for the smallest gaze window ($d = 1.35$) and stronger (d ranging from 2.81 to 3.56) for the larger window sizes and absence of the window.

These effects were corroborated by a repeated-measures ANOVA of the reconstruction accuracy with window size as a within-subject factor and expertise level as a between-subjects factor, showing a significant effect of window size, $F(4, 48) = 25.8$, $p < 0.001$, partial $\eta^2 = 0.68$, a significant effect of expertise level, $F(2, 12) = 10.85$, $p = 0.002$, partial $\eta^2 = 0.64$, and a significant window size × expertise level interaction, $F(8, 48) = 2.88$, $p = 0.011$, partial $\eta^2 = 0.32$.

Table 2. Mean (*SD*) of reconstruction accuracy for the three participant groups and five window sizes, and Cohen's *d* between the three pairs of participant groups.

Window radius	**Experts (E)**	**Intermediates (I)**	**Novices (N)**	***d* E–I**	***d* E–N**	***d* I–N**
2.2°	0.39 (0.13)	0.30 (0.10)	0.21 (0.14)	0.71	1.35	0.80
4.4°	0.74 (0.14)	0.42 (0.22)	0.34 (0.11)	1.76	3.22	0.47
6.5°	0.81 (0.14)	0.48 (0.20)	0.38 (0.13)	1.91	3.16	0.58
8.7°	0.81 (0.13)	0.51 (0.21)	0.37 (0.12)	1.74	3.56	0.81
Full	0.81 (0.17)	0.56 (0.15)	0.34 (0.15)	1.50	2.81	1.45

$p < .05$ for $|d| \geq 1.46$, $p < .005$ for $|d| \geq 2.43$

Results for the additional dependent measures are shown in Figure 5. It can be seen that the mean reconstruction time was similar across the three participant groups. However, experts tended to have a longer median fixation duration during memorization (therefore, a correspondingly smaller number of fixations) compared to intermediates and novices. In addition, experts had a more concentrated distribution of horizontal and vertical fixation location and a smaller saccade amplitude compared to intermediates and novices, similar to the results of the find-the-best-move task. The heatmaps in Figure 6 provide further evidence of the more concentrated and centralized attentional distribution of the experts compared to the intermediates and novices.

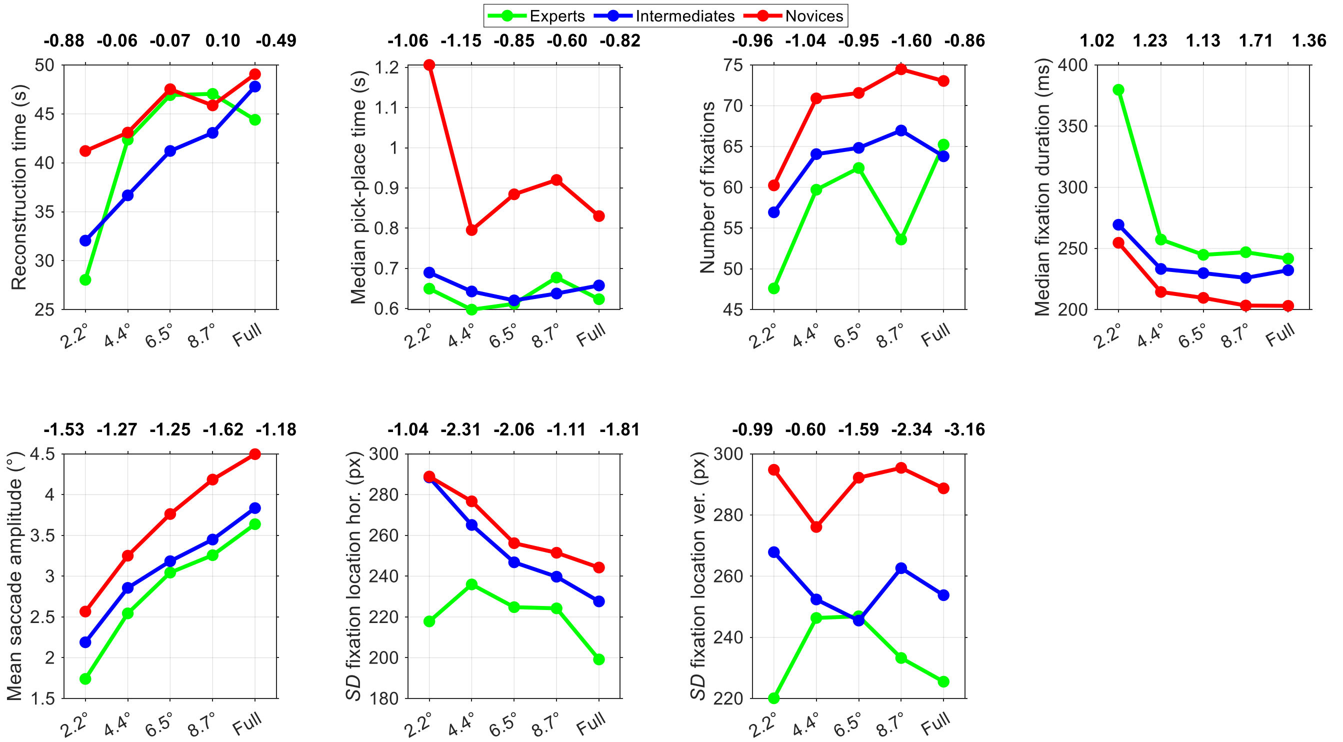

Figure 5. Means of the dependent measures for the three participant groups and five window sizes. The top of each figure lists Cohen's *d* between the scores for experts and novices. $p < .05$ for $|d| \geq 1.46$, $p < .005$ for $|d| \geq 2.43$.

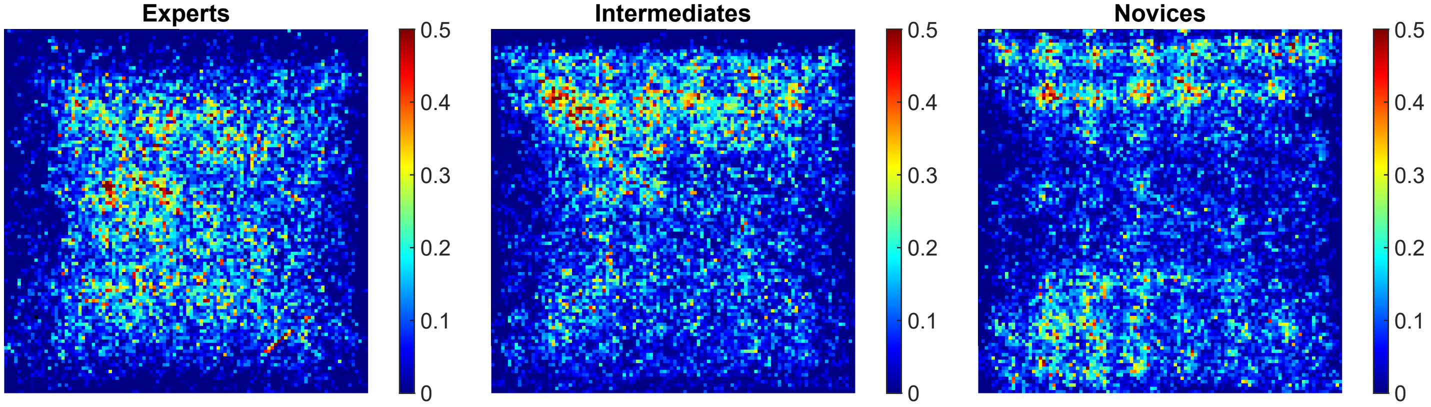

Figure 6. Heatmaps of gaze points for all trials of all window sizes of the memorization phase of the reconstruction task, aggregated per participant group. The heatmaps were divided into 10×10-pixel squares and normalized so that the total score of each heatmap equals 1000.

Discussion

The purpose of this research was to determine whether chess players rely more on peripheral vision than intermediate and novice players. In an experiment with players of three skill levels, we examined the effect of a gaze-contingent window while players were memorizing a chess position on the subsequent reconstruction of that position. We hypothesized that a small window size would cause highly rated chess players to lose their advantage in accurately reconstructing the chess positions, while for novices, the effect of window size would not be as pronounced.

The results were consistent with our hypothesis: Experts lost much of their advantage in reconstructing the board for the smallest window with a 2.2° radius. This suggests that experts were unable to perform the reconstruction task well when only foveal information was available (the foveal region can be defined as the area within 2.5° from the fixation point; Sakurai, 2015). For larger windows (4.4° radius or higher), the experts' performance was nearly on par with their full-view performance.

The heatmaps indicated a striking difference between experts and novices. Experts were more likely to glance near the center of the board, while novices were more likely to focus on the edges. The heatmap for novices also revealed a grid-like pattern, suggesting that novices encoded the board by focusing on individual pieces. These findings are consistent with the chunking theory and experts' reliance on peripheral vision.

Likewise, experts arrived at the best move using a limited number of fixations. Our findings provide empirical support for earlier claims such as those of Jongman (1968), who noted that "the basis for the analysis of the search-strategy of the chess-master is the fact that he proves able to select very quickly—if not immediately—those aspects which are of primary importance in the position in question" (Jongman, 1968, p. 157), or Tikhomirov and Poznyanskaya (1966), according to whom "the work of the eye is carried out in a limited range of positions, i.e., 'an orienting zone' " (p. 14).

Our study adds to the body of research that indicates that experts have a perceptual advantage in chess. Apart from Reingold et al. (2001) and Wang et al. (2016), previous research on eye-tracking among chess players has suggested a role of peripheral vision in chess based on eye movements (Bilalić et al., 2010; Charness et al., 2001; Simon & Chase, 1973), but without directly controlling participants' access to peripheral vision. In our study, the gaze-contingent window ensured that participants could not see the board or pieces outside a circle following the participant's gaze point on the screen.

It is noted that the present findings cannot be used to make claims about the size of the visual span of chess players. It is possible that experts not only made better use of peripheral (or parafoveal) vision but also used inferential processes, i.e., estimating the position of pieces from general chess knowledge while these pieces were not seen or remembered. Burmeister and Wiles (1996) reviewed a number of experiments in chess ("blind guessing" by De Groot, 1966; "pennies guessing" by Chase & Simon, 1973b) and performed similar experiments on the game of Go to illustrate that board reconstruction performance is governed by not only perception but is also achieved through inferences. By analogy, it is plausible that the second-smallest window size (4.4° radius) enabled experts to recognize chunks and interpolate any remaining pieces to perform at the same level as the full-view condition, while for the smallest window (2.2° radius), they were unable to recognize the relations/chunks present in the position.

In addition to providing support for our hypothesis, an adjacent finding was that while solving puzzles or memorizing board positions, experts had a significantly longer median fixation duration than novices (but not for the first five fixations). In other words, experts not only made fewer fixations (which, for the find-the-most-move task, can be explained by the fact that they solved puzzles faster), but they also fixated longer. Previous research either found no difference in fixation duration between experts and lower-rated players (Charness et al., 2001; Mezö et al., 2015; Reingold et al., 2001) or found longer fixation durations for experts, which is consistent with our work (Reingold & Sheridan, 2011; Sheridan & Reingold, 2017). It is possible that while novices searched the board for pieces and still encoded the position, experts engaged in problem-solving for a larger proportion of their fixations (Reingold & Charness, 2005; Sheridan & Reingold, 2017).

An interesting corollary was that a smaller gaze-contingent window size resulted in a longer median fixation duration and a shorter saccade amplitude, for all three groups. These findings align with studies on gaze-contingent spotlights of different radii in a visual search task (e.g., David et al., 2022; Nuthmann, 2014). A likely explanation is that peripheral vision is used to determine where to look next, and that participants are inclined to select target fixation locations within the gaze-contingent window (Ludwig et al., 2014; Nuthmann, 2014).

Conclusion

This study showed that when withholding access to peripheral vision, experts and novice chess players become more alike in terms of the accuracy with which they can memorize and reconstruct a chess position. Furthermore, while finding the best move or memorizing a board position, more skilled players tend to fixate longer, as well as on more concentrated regions on the board. These findings are consistent with the more extensive use of peripheral vision and the availability of larger chunks for experts compared to intermediates and novices.

From our results, it can be seen that differences in performance between participant groups hardly differed between the window sizes, except for the smallest window. Therefore, future research is recommended with a more fine-grained series of window sizes and with a larger number of participants. It would also be interesting to apply a shorter memorization phase or use windows with a fixed location (as opposed to a window that moves with the participant's eyes). This would prevent participants from re-fixating to new locations during the memorization phase and may thus allow for more precise estimates of the extent to which participants are able to infer pieces that they cannot have seen. Future research is also recommended into the extent to which chess relies on vision. It is known that experts can typically play blindfold chess at high levels, and that in some cases, not looking at the board can help think through deep lines (e.g., Cleveland, 1907; Hearst & Knott, 2009; Mechner, 2010). It would be valuable to gain a deeper understanding of the mental and visual representations that chess players have, both with and without access to visual information.

Supplemental Material

Raw data and scripts for reproducing the experiment and analysis are available at https://doi.org/10.4121/21816081

Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the *Journal of Expertise.*

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Appendix

Table A1. Randomization order for the trials of the reconstruction task.

	Position number (High, medium, small number of pieces for 1–10, 11–20, and 21–30, respectively)																													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Participant 1 (I)	26	16	6	1	11	21	2	7	12	27	22	17	3	28	23	18	13	8	9	14	24	4	19	29	25	20	5	30	10	15
Participant 2 (E)	23	28	13	8	3	18	19	29	4	24	9	14	1	26	21	16	6	11	15	10	20	5	25	30	7	27	2	17	12	22
Participant 3 (I)	3	18	8	28	23	13	9	4	24	19	29	14	7	2	12	17	22	27	6	21	16	1	11	26	25	10	5	30	15	20
Participant 4 (N)	18	8	23	13	28	3	29	19	14	9	4	24	7	17	12	22	27	2	15	5	20	30	10	25	1	6	26	11	21	16
Participant 5 (N)	17	2	7	22	27	12	20	30	5	15	10	25	9	24	29	19	14	4	8	28	13	23	3	18	11	26	6	21	1	16
Participant 6 (N)	20	10	15	5	30	25	3	18	13	23	8	28	11	16	6	21	1	26	27	22	7	17	12	2	9	19	14	4	24	29
Participant 7 (E)	18	28	3	8	23	13	15	30	10	5	20	25	24	14	9	29	19	4	12	22	17	7	2	27	6	11	26	16	1	21
Participant 8 (N)	21	11	6	16	1	26	29	9	4	14	24	19	28	8	23	18	13	3	22	27	12	7	17	2	10	25	5	20	15	30
Participant 9 (E)	25	15	30	20	10	5	12	7	17	22	2	27	1	16	26	6	21	11	24	14	29	4	19	9	23	28	18	8	3	13
Participant 10 (I)	25	30	10	15	5	20	19	4	24	14	9	29	3	23	28	8	13	18	22	12	7	2	17	27	21	1	6	11	16	26
Participant 11 (E)	9	29	4	19	24	14	30	10	25	20	15	5	26	21	6	11	1	16	22	12	17	7	27	2	3	23	13	8	28	18
Participant 12 (I)	22	7	27	17	2	12	8	3	28	13	23	18	29	19	24	14	9	4	15	30	5	20	10	25	21	26	11	1	6	16
Participant 13 (E)	1	21	26	11	6	16	20	15	10	5	25	30	29	24	4	9	14	19	2	22	27	17	7	12	13	23	8	18	3	28
Participant 14 (I)	27	12	22	7	17	2	23	3	28	8	18	13	15	30	10	20	5	25	21	26	11	1	6	16	29	9	4	19	24	14
Participant 15 (N)	16	11	26	6	1	21	27	22	12	2	17	7	5	10	30	15	20	25	9	14	19	29	24	4	8	3	23	18	28	13

	Window size (1 = smallest, 5 = largest)																													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Participant 1 (I)	5	5	5	5	5	5	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4
Participant 2 (E)	4	4	4	4	4	4	5	5	5	5	5	5	2	2	2	2	2	2	1	1	1	1	1	1	3	3	3	3	3	3
Participant 3 (I)	5	5	5	5	5	5	1	1	1	1	1	1	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	2
Participant 4 (N)	1	1	1	1	1	1	2	2	2	2	2	2	5	5	5	5	5	5	3	3	3	3	3	3	4	4	4	4	4	4
Participant 5 (N)	1	1	1	1	1	1	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	2	5	5	5	5	5	5
Participant 6 (N)	5	5	5	5	5	5	3	3	3	3	3	3	1	1	1	1	1	1	2	2	2	2	2	2	4	4	4	4	4	4
Participant 7 (E)	4	4	4	4	4	4	1	1	1	1	1	1	5	5	5	5	5	5	3	3	3	3	3	3	2	2	2	2	2	2
Participant 8 (N)	3	3	3	3	3	3	1	1	1	1	1	1	5	5	5	5	5	5	4	4	4	4	4	4	2	2	2	2	2	2
Participant 9 (E)	3	3	3	3	3	3	5	5	5	5	5	5	4	4	4	4	4	4	2	2	2	2	2	2	1	1	1	1	1	1
Participant 10 (I)	5	5	5	5	5	5	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	2	1	1	1	1	1	1
Participant 11 (E)	5	5	5	5	5	5	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4
Participant 12 (I)	4	4	4	4	4	4	5	5	5	5	5	5	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3
Participant 13 (E)	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	2	5	5	5	5	5	5	1	1	1	1	1	1
Participant 14 (I)	1	1	1	1	1	1	2	2	2	2	2	2	4	4	4	4	4	4	5	5	5	5	5	5	3	3	3	3	3	3
Participant 15 (N)	1	1	1	1	1	1	2	2	2	2	2	2	5	5	5	5	5	5	4	4	4	4	4	4	3	3	3	3	3	3

Table A2. Photos of the reconstruction task for the five gaze-contingent window sizes.