AN EYE MOVEMENT ANALYSIS OF CHESS PLAYERS ACROSS LEVELS OF EXPERTISE: AN ELECTROOCULOGRAPHY STUDY

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF INFORMATICS

OF

THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

ÖZGÜR ERKENT

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

THE DEPARTMENT OF COGNITIVE SCIENCE

SEPTEMBER 2004

Approval of the Graduate School of Informatics

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Özgür Erkent

ABSTRACT

AN EYE MOVEMENT ANALYSIS OF CHESS PLAYERS ACROSS LEVELS OF EXPERTISE: AN ELECTROOCULOGRAPHY STUDY

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September 2004, 108 Pages

The eye movements of expert and novice chess players were recorded by electrooculography (EOG) technique as they attempted to find the mate in fifteen tactically active simple chess positions. In the analysis part of the data gathered from EOG recordings, the effect of the drift, which is an important problem for EOG, was reduced. The processed data were converted into coordinates of the display on which the chess positions were demonstrated. In the test phase, the players were asked to fixate the white king which appeared on a different square on an empty chess board for one second. It was predicted on which square the subject fixated by the method developed. The predictions and the actual location of the white king were compared and the results revealed that EOG technique can be used reliably to track the eye movements of the chess players while they fixated on a chess board. It has been revealed that experts produced more fixations on the relevant squares than did the novices as the fixations were investigated. The difference between fixation duration was not significant across skill groups. The results provide evidence for an early perceptual encoding advantage for expert players attributable to chess experience.

Keywords: Electrooculography, Expertise, Chess Skill Differences, Eye Movements

ÖZET

SATRANÇ OYUNCULARINDA GÖZ HAREKETLERİ ANALİZİ: BİR ELEKTROOKÜLOGRAFİ ÇALIŞMASI

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Eylül 2004, 108 Sayfa

Usta ve az bilen satranç oyuncuları taktiksel olarak aktif, basit on beş pozisyonda mat bulmaya çalışırlarken göz hareketleri elektrookülografi (EOG) tekniği ile kaydedildi. EOG kayıtlarında elde edilen verinin analizi sırasında EOG için önemli bir problem olan kaymanın etkisi azaltıldı. İşlenen veri konumların gösterildiği monitör koordinatlarına çevrildi. Test aşamasında oyunculardan boş bir satranç tahtasında her seferinde değişik bir karede bir saniye süreyle ortaya çıkan beyaz şahı tespit etmeleri istendi. Geliştirilen yöntem kullanılarak deneğin hangi kareye baktığı tahmin edildi. Tahminler ve beyaz şahın bulunduğu kare karşılaştırıldı ve sonuçlar EOG tekniğinin satranç oyuncuları satranç tahtası üzerinde tespit yaparken göz hareketlerinin takip edilmesi için güvenilir bir şekilde kullanılabileceğini gösterdi. Tespitler incelendiği zaman ustaların ilgili kareler üzerinde acemilere göre daha çok tespitte bulunduğu ortaya çıkarıldı. İki grup arasındaki tespit süreleri arasındaki fark belirgin değildi. Sonuçlar usta oyuncuların satranç deneyimine atfen erken algısal kodlamada bir avantaja sahip olduklarına dair kanıt sunmaktadır.

Anahtar Kelimeler: Elektrookülografi, Ustalık, Satranç Hüner Farklılıkları, Göz Hareketleri

To My Family

ACKNOWLEDGEMENTS

I express sincere appreciation to Assist. Prof. Dr. SühaYağcıoğlu for his guidance and insight throughout the research. I also thank Prof. Dr. Pekcan Ungan, Dr. Ruhi Soylu, Prof. Dr. Gürkan Tekman and Hacettepe University Medical Faculty Biophysics Department members Nurhan Erbil and Barkın İlhan for their suggestions and comments. To my family I offer sincere thanks for their unlimited help throughout the whole duration of the preparation of the thesis.

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CHAPTER 1

INTRODUCTION

In cognitive science, chess offers an appropriate task environment to study the skilled performance (Reingold et.al. 2001; Gobet & Simon, 2000). As in any other field, to become an expert in chess requires several years of study and thousands of hours of practicing (Saariluoma, 1985). To know the rules of chess is not sufficient to become an expert. In skilled performance studies, players with high ratings or masters are considered as experts, and players with low or no ratings are considered as novices (Gobet & Jackson, 2002). The ratings are given by the International Chess Federation (FIDE) or local chess federations.

In a classic study, de Groot (1966) demonstrated chess diagrams taken from real games for 2-15 sec, then cleared the diagram. The players were asked to set the pieces as they were in the diagrams. The expert players were successful than novices in reproduction of the diagrams. Skill significantly affected the performance of the players. De Groot explained that the main differentiators of chess expertise was memory and perception, not the superiority in searching for good moves. In another classic study, Chase and Simon (1973a) repeated and developed the findings of de Groot. They represented the diagrams taken from real games for 5 sec and required the chess experts to reproduce these diagrams, the experts were sucessful than less skilled players again. However, when "random positions" were represented instead of positions taken from real games, the skilled players were not essentially better than less skilled players. These results mean that the high memory performance of skilled players cannot be related to their general superior memory systems or processes. Recently, in the study of Gobet and Simon (1996), it was shown that there is a small, but reliable advantage in recall for random positions. This small advantage is related with the occasional presence of positions taken from real games in random positions.

Chase and Simon (1973a) concluded that early perceptual organization and internal representation is the main reason for the superiority of the expert chess players in the recall of chess positions. The subsequent logical-deductive thinking process is not essential for chess expertise, but rather the immediate visual-perceptual process is essential. The initial perceptual phase and the search phase of the problem-solving process is separated in their study.

To study the early perceptual process of skilled performance which is closely related with the perceptual organization, verbal think-aloud protocols provide a large source of information. For example it was observed by de Groot (1965) that players use familiar patterns to find strong moves in "thinking-aloud" protocols. But a new research paradigm to ensure that stable inferences are drawn is necessary (Charness et.al. 2001). Although the measurement of eye-movements is an appropriate technique in chess-related tasks, it is surprising that this technique has been used only in a few empirical studies related to chess (Reingold et. al. 2001; Charness et. al. 2001; de Groot & Gobet, 1996; Ellis, 1973; Jongman, 1968; Tikhomirov &

Poznyanskaya, 1966). In the recent studies (Reingold et. al. 2001; Charness et. al. 2001; de Groot & Gobet, 1996), the eye movements are recorded with a camera, then the recorded film is analyzed frame-by-frame (image-processing technique is used for the analysis).

The eyes of an expert can encode at a glance the essence of the shortly shown stimulus material related to the domain of expertise. For example in the study of Kundel and Nodine (1975) the expert radiologists could name 70% of the abnormalities in the X-Ray films when the films were presented for 200 ms. Charness et. al. (2001) explain this: "Cruc ial to this process of rapid perception, particularly for visual displays that require multiple fixations for encoding, is the ability to encode large clusters of related information –that is, chunks- and to locate the most relevant areas, or identify the salient locations, on which to focus attention." In their study, the chess players at two levels –intermediate and experts- were asked to find the best move in combinative (tactically active) chess positions and their eye fixation patterns were monitored. They hypothesized that most of the first few seconds of fixations of expert players will be on empty squares (to be able to extract more information from the surrounding piece-occupied squares). It has also been hypothesized that when the expert players fixate on squares with pieces, more fixations will be on the salient pieces (pieces related with the position). In the study of Reingold et. al. (2001), eye movement-monitoring technique was used to hypothesize that an essential component of chess mastery is a perceptual advantage.

In their study, de Groot and Gobet (1996) reanalyzed the research of Jongman (1968) and presented that expert players fixate more on the edges of the squares (28.7% of fixations) with respect to less skilled players (13.7%). This shows some indication that experts can encode more than one piece in a single fixation. In this study it has also been noted that skilled players cover a larger area during their fixations. In another study Reingold et. al. (2001) used a 3x3 minimized chess board in a check detection task. They revealed that a great percentage of the fixations of the skilled players were between pieces when compared with less skilled players. Charness et. al. (2001) suggested and tested two specific predictions. First the expert players will fixate on empty squares when compared with intermediate players, second when the expert players fixate on the pieces a great proportion of these will be on salient pieces (pieces related with active position on the board). To test these two predictions, they used five tactically active simple positions taken from real games, and their results supported the predictions. The expert players can encode more than one piece at a fixation, but it may not be necessary that the fixation will be on an empty square. For example in Figure1.1, to be able to encode more than one piece at a fixation, the fixations would occur on non-empty squares.

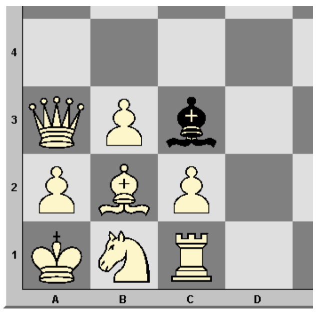


Figure 1.1 There are no empty squares between pieces. Fixations would occur on non-empty squares to be able to encode more than one piece at a fixation.

CHAPTER 2

ELECTROOCULOGRAPHY

There are two methods to record the eye movements: video-based oculography (VOG) and electrooculography (EOG). In VOG, usually an infrared (IR) light is projected to the eye of the subject and the images of the eye are taken (Figure 2.1). These images are sent to the computer and then processed by an image processing software. The location of the pupil is computed with respect to projected IR light and it is predicted where the subject is fixating on.

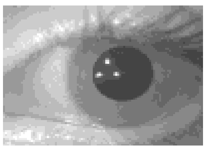


Figure 2.1 The movements of the eye are recorded by a camera. The projected light on the eye can be seen.

EOG is an electrical method of recording eye movements. Electrodes are attached to the skin near the eye using a conductive gel between the electrode and the skin. To record the vertical movements of the eye, electrodes are placed just above and below one of the eyes. To record the horizontal movements, they are placed to the right of the right eye and to the left of the left eye, and a fifth electrode is placed on the forehead to provide for a neutral ground. (Figure 2.2) When the depth of the fixation is required, a sixth electrode should be placed between two eyes for binocular recording. When the eyes move in the vertical direction –the subject looks up or down-, a potential difference is recorded by the vertical pair of electrodes (v-pairs). When they move in the horizontal direction –the subject looks right or left-, a potential difference is recorded by the horizontal pair of electrodes (h-pairs). These electrical potentials (cornea-retinal potential, 10-30mV: the cornea being positive) are generated by the permanent electrical dipole which exists between the cornea and the ocular fundus (Figure 2.3). This dipole sets up an electrical field in the tissues surrounding the eye. As the eye rotates, the field vector rotates correspondingly . Therefore, eye movements can be detected by placing electrodes on the skin in the area of the head around the eyes (Gips and Olivieri, 1996) since the alteration in the potential is proportional to the amount of rotation of the eye. Since there are two channels –vertical and horizontal- this is called a two-channel recording.

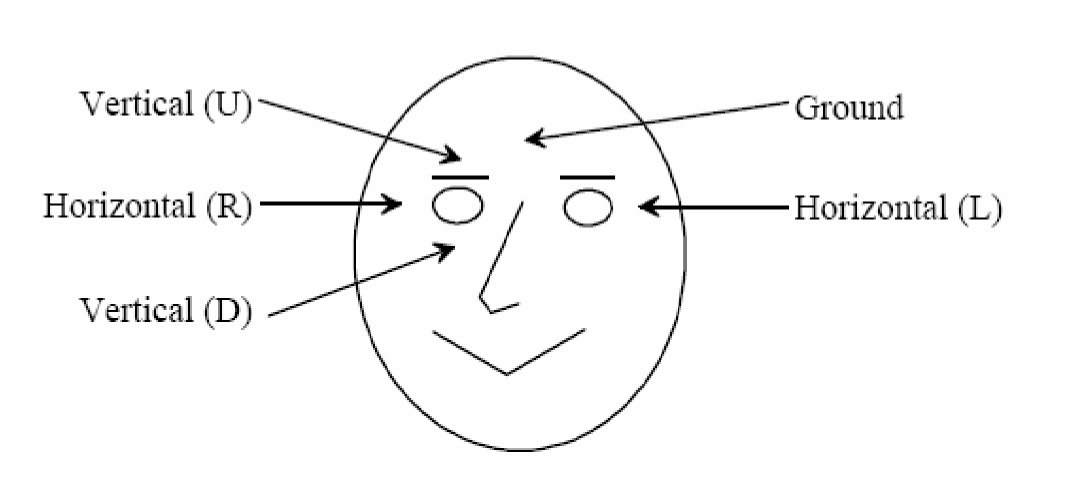


Figure 2.2   The placement of electrodes

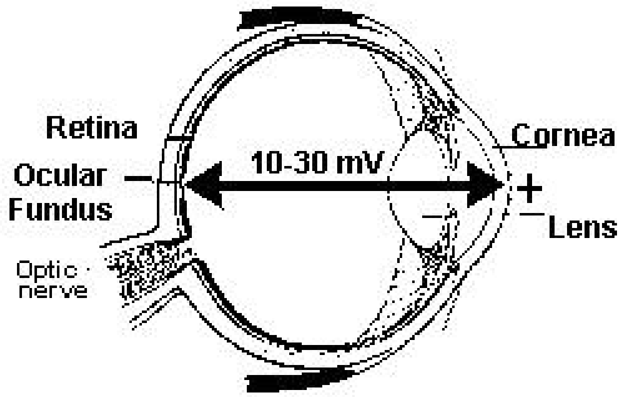


Figure 2.3 Electrical potentials are generated by the permanent potential difference which exists between the cornea and the ocular fundus (cornea-retinal potential, 10-30mV: the cornea being positive)

EOG system is used in different areas. Human-computer interaction is one of the main areas where it is used. (Majaranta, Räihä, 2002). A few examples are iDict (a gaze-assisted translation) (Hyrskykari et. al. 2000), Eye Typing (Majaranta, Räihä, 2002), a Semi-Autonomous Robotic Wheelchair (Yanco and Gips, 1997) and Eagle Eyes (a project developed for people with disabilities) (Gips et. al. 1996)

There are advantages and disadvantages of both of the techniques described above. The spatial resolution of video-based oculography is higher than EOG and it is free from the baseline drift problem (described below) that is the main concern in EOG. However, temporal resolution of a VOG system is limited with the frame acquisition rate (frames per second) of the camera which is generally 100 fps maximum. The temporal resolution of an EOG system on the other hand, is limited with the sampling rate (samples per second) of the analog to digital converter, which has very high values compared with the fps of the camera. Video-based oculography is much more expensive than EOG. This is the main reason why an EOG system was preferred in this study.

There are a number of artefact sources which contaminate the EOG and degrade the signal quality. Some precautions can be taken to keep these effects at minimum. One such artefact is a result of the interaction between the subject's skin and the electrode. The impedance between the skin and the electrode should be as low as possible. To clean the skin of the subject where the electrodes will be placed, a cleaning media like alcohol or a commercial skin-preparing material is used. The conductive gel may dry by time, if this is the case, it should be reapplied. Non-polarizable material like Ag-AgCl electrodes are preferred to prevent the offset potential between the gel-metal interface. Movement of the electrodes or perspiration may alter the impedance. The electrodes should be fixed firmly and the room temperature should be regulated.

The surrounding electrical fields can be another noise factor. Therefore the subject should be as far as possible from the mains supplies. If possible, experiments should be conducted in an electrically shielded chamber. Alternatively, since the frequency spectrum of EOG lies between 0-20 Hz, 50 Hz line interference can eliminated by lowpass filtering. (Marmor, Zrenner, 1993) There are also other noises, such as eye blinks of the subject. These eye blinks must be detected and removed from the EOG, or the time intervals during when the eye blinks occur should be marked as "not suitable" and discarded from the analysis.

The initial rest potentials of the subjects may be different, this may exceed the input limits of the system. This potential difference is increased/decreased by using offset adjustment. If the voltage difference alteration rates of the subjects are different, this may lead signals to exceed the limits of the analog-to-digital (A/D) system. To be able to overcome different alteration rates across different subjects, an amplifier with multi-optional amplifying ratio can be used.

Muscle contraction causes electromyographic activity and disturbs the EOG. The subject should be required not to squeeze her/his teeth or contract neck muscles and not to blink frequently. Since the eye movements of the subject are required, their heads should be kept stable by some means of fixation while the positions are shown on a display screen. The brightness of the monitor should not be high, since this causes the eyes of the subjects to tear in the experiments and gives discomfort.

Another known problem of EOG is drift. The signals may drift slowly by time when the subjects are fixating at a point. The amount of drift can change from subject to subject. This is generally a slow process and it takes some minutes before a significant drift is observed. In short periods of time, e.g five to ten seconds, the drift is quite negligible. This problem can be overcome by hardware design up to some degree. There are some designs cancelling the drift automatically on the fly but these designs are rather complex and cannot relied upon. A safer way to cancel the drift is to use manual offset adjustment between the experiments. Remaining drift can also be compensated by numerical techniques after the data is acquired.

One important problem in digital data acquisition systems is aliasing. Aliasing is the apperarence of low frequency signals that are not present in the original signal. It occurs due to the inadequate sample rate of the analog to digital (A/D) converter.

According to the Nyquist criterion (Orfanidis, 1996), analog data must be sampled at a rate twice the highest frequency present in the spectrum of the original signal. The spectrum of the EOG lies between 0-20 Hz and it must be sampled at a minimum rate of 40 samples per second in order to prevent aliasing. The higher the sampling rate the better but higher rates mean lager data storage requirements. In practice, analog data is lowpass filtered at a reasonable frequency (e.g 100 Hz for EEG) and A/D sampling rate is adjusted to 4-5 times this value to guarantee that aliasing does not occur.

Median filtering can be applied to the data stored in the computer. Median filtering is a nonlinear data smoothing technique introduced in 1971 (Tukey, 1971). The median of *n* numbers $x_1,x_2,...,x_n$, for n odd, is $x_{(n+1)/2}$ (the number in the middle of the series). It has some advantages over other filtering methos which are important for EOG data analysis: It can preserve the sharp edges of the data, however a low-pass filter can blur such edges. If the noise is spiky, it is sufficient in suppressing the noise (Gu et. al., 2000). Furthermore Gu et.al. (2000) reported that median filter can remove the eyeblink artefact in the data (Figure 2.4).

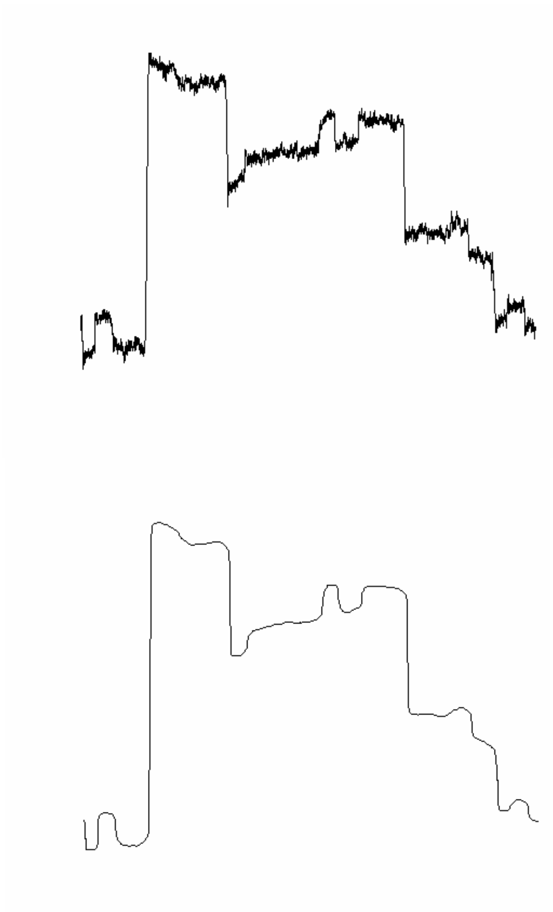


Figure 2.4 Median-filter on sample eye movement signal.

The duration of the fixations can also be found. Since fixations are what happen in between two saccades, the duration for a fixation is the time interval in between these two saccades. The saccades are fast movements of the eyes. If the subjects are not asked to follow a slowly moving object-that is they move their eyes voluntarily-, their eye movements create saccades and these can be seen as the sharp edges in the signal, therefore they are easy to identify. (Figure2.5)

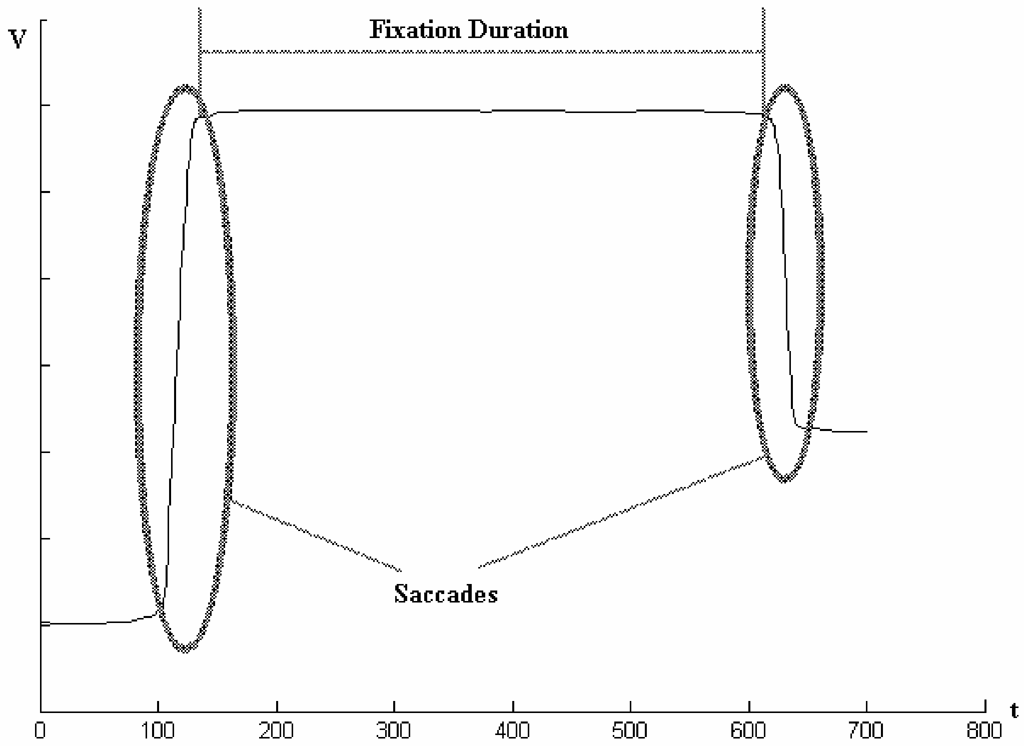


Figure 2.5 Fixation time is the duration between two saccades. In this figure the fixation time is approximately 500 ms.

CHAPTER 3

THE AIM OF THE PRESENT STUDY

In the present study, it is hypothesized that first few fixations of expert players will more likely be on the squares related with the position when compared with the less skilled players, and EOG technique can be used to track eye movements of chess players. In order to examine the difference of early perceptual processes across different skills, two groups of chess players (expert and novice) were asked to find the mate in tactically simple three different groups of chess positions. Each group of positions consisted of five diagrams. In the first group, the positions were taken from a game or they were modified so that there was essentially no difference between the modified position and the position taken from a game. The moves that are necessary to mate did not change and the material balance of both sides were same with the original one. Only the location of a pawn was changed or one pawn for both sides were included in the positions. In the second group of positions, a novel piece was inserted into the diagram, and it was related with the position. In the third group of positions the novel piece (same with the one in the second group) was not related with the position (Figure 3.1). It is known that novel popout is an attentional phenomenon in visual stimulus (Strayer and Johnston, 2000) and fixations cannot be directed to one location and attention to another (Hoffman and Subramaniam, 1995). The oculomotor readiness hypothesis (Klein, 1980) which describes the relationship between attention and rapid eye movements suggest that movements of both attention and saccades are mediated by the same neural circuitry. In their study Hoffman and Subramaniam (1995) found that there is a link between attention and rapid eye movements when subjects are free to orient their attention as they wish. The result is contrary to the hypothesis which claim that attention and saccades reflect independent processes. So the subjects are expected to be affected by the appearence of the novel piece if they concentrated on the board in the first group of positions as the novel piece is expected to affect subjects' attention, and as their attention will be affected, the fixations will also bew affected. The role of the novel piece can be summarized as a tool to detect the concentration of the subjects to the boards. When the novel piece is on the board, the proportion of players' fixations on salient squares or the fixation duration of the players are expected to be affected. Only one novel piece is placed on the board. The novel piece is placed on a salient sqaure or a non-salient square. As it is not known whether the subject fixates with a greater proportion on salient or non-salient squares, both kind of positions, the positions with the novel piece on a salient square and the positions with a novel piece on a non-salient square, are shown.

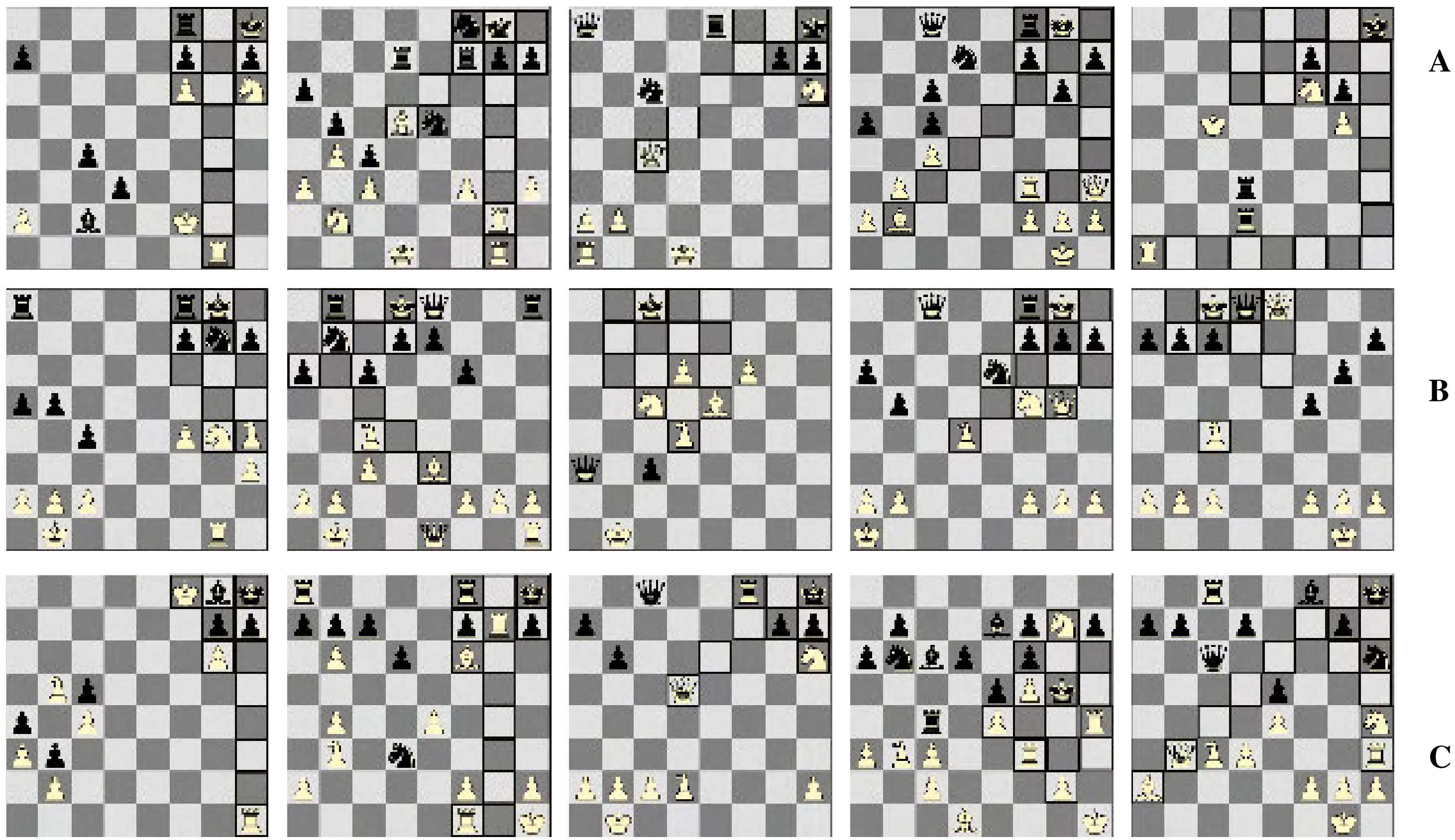


Figure 3.1 The fifteen positions of the experimental procedure used in the find-mate task. The salient squares are highlighted with a bold frame. Group A: There is no novel piece in the positions. Group B: There is a novel piece on salient square. Group C: There a novel piece on non-salient square.

To study the effects of the early perceptual phase on the skill differences, the first 1-2 seconds of fixations are important (Charness et. al., *2001*). First 1-2 seconds correspond to approximately first five fixations. If more than first five fixations are investigated, the skill differences can be attributed to the problem solving phase rather than the perceptual phase. Thus, first five fixations of the players on the boards who tried to find the mating moves were investigated. The fixations were classified as "in the salient square", "out of the salient squares" and "could not be investigated". The salient squares were squares that were included in the mating process. They can be empty or full. But it is not tested if a greater proportion of fixations of the expert players are on the empty squares when compared with novice players, as it is shown in Figure1.1, the necessary squares to encode more than one piece at a fixation may not always be the empty squares, squares occupied by a piece may be more appropriate to fixate on to encode more than one piece at a fixation.

The fixation patterns for different tasks on a chess board can be different (Charness et. al., *2001*). Patterns in check-detection task, or a memorizing chess position task can be different than each other. To simulate the early perceptual phase of a chess player's eye fixations in a game, a move-choice task was selected. Since only the first few fixations of the players were analyzed, no reaction was required. To control the concentration level of the players, positions with a novel piece were used. In each move-choice task, there was a mate for white, and the players were asked to find or try to find the mating moves. The positions were chosen from the exam questions of credited chess course given at Middle East Technical University (METU). The positions were not random, they were taken from a game, or modified, but there was essentially no difference between the original position and the modified position.

If drift problem of the EOG technique could be solved, and a spatial resolution that is sufficient to analyze the chess diagrams represented to the subjects can be obtained, then EOG can be used to track eye movements of the subjects. Since EOG will be used to detect where the player is looking at on a board for the chess-related task, it is important to know what the limitations for the squares of the board are. i.e. what can the spatial resolution of the system be. In the eagle eyes system, the subject can type on a keyboard on the screen by using his/her eyes only. (Gips and Olivieri, 1996) If one square of the chessboard is taken as a unit for spatial resolution, then the spatial resolution of the system used in the study of Gips and Olivieri (1996) is said to be 5x7, vertical by horizontal; which implies that the eye movements of a player while perceiving a position on a 5x7 chess board can be recorded with EOG. In this study, an 8x8 chess boards was used. In the pre-experiment study, it was observed that it can be predicted where the subject is fixating on the board. For this purpose, a chess board was presented on the screen and a king was shown on a square. The subject was required to fixate on the king. In the post-analysis, it was observed that the location of the fixation of the subject can be predicted.

CHAPTER 4

METHOD

4.1 Participants

Seventeen chess players (9 experts, 8 novices) participated in the experiment as volunteer subjects. Four of the subjects were female, thirteen were male. The ages of the players ranged from 18 to 35. The expert players had a national tournament experience, three of them were national team players and the rest were the players of METU Chess Team. The novices did not have any tournament experience. All participants had normal vision.

4.2 Materials

The display (an LCD monitor NEC MultiSync LCD 1535VI, 14”) showed chessboards subtending a visual angle of 45° vertically and horizontally. The chess pieces were approximately 4° in diameter. There were three group of positions and each of them consisted of five positions. The first group was shown one after another, but the second and third group of positions were mixed. The first group of positions included five chess positions which were selected from the exam questions of credited chess course at METU. All of the positions in the first group were taken from real games or they were modified, but there was essentially no difference between the modified and the original position. In the second group of positions, the boards included a novel piece related with the position. In the third group the novel piece was not related with the position. In the second and the third group the positions were essentially alike real game positions, but included a novel piece. The rules of the novel piece is a mixture of the knight and the bishop. It can jump one piece over other pieces diagonally. The shape of the novel piece can be seen in the Figure 4.1. It was recognized by the subjects. Its shape is not as any other piece, and it is different from any other piece as much as any piece is different from another. Two positions were shown to the players for practice. Both of the positions included the novel piece (Figure 4.2). All of the pieces were recognized by the subjects. In all of the positions there was a mate for white. The mates were simple and the positions were tactically active. Before the groups of positions were represented to the subjects, for the test phase of the EOG technique boards with a white king were shown (Figure 4.3). The subjects were required to fixate on the white king. For calibration process, a point in the middle of the screen was shown at every 5 seconds, and 4 points at the top, bottom, left and right of the screen were represented at the beginning of the experiment (Figure 4.4).

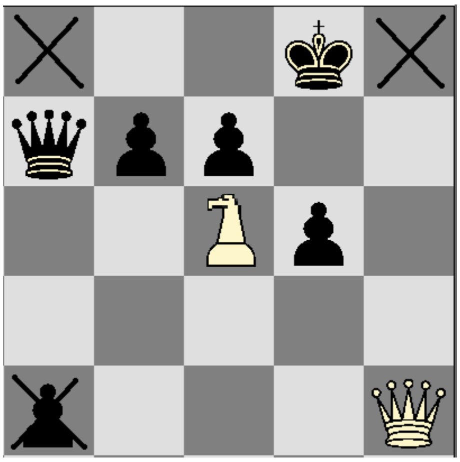


Figure 4.1 The novel piece is in the middle of the board. The squares it can move to are marked with a cross. It can jump over any piece. It can capture a piece only if the piece is in the target square that the novel piece moves to. The novel piece cannot move to a square that is occupied by its own piece (For example, in the figure shown it cannot move to the square occupied by the white queen.)

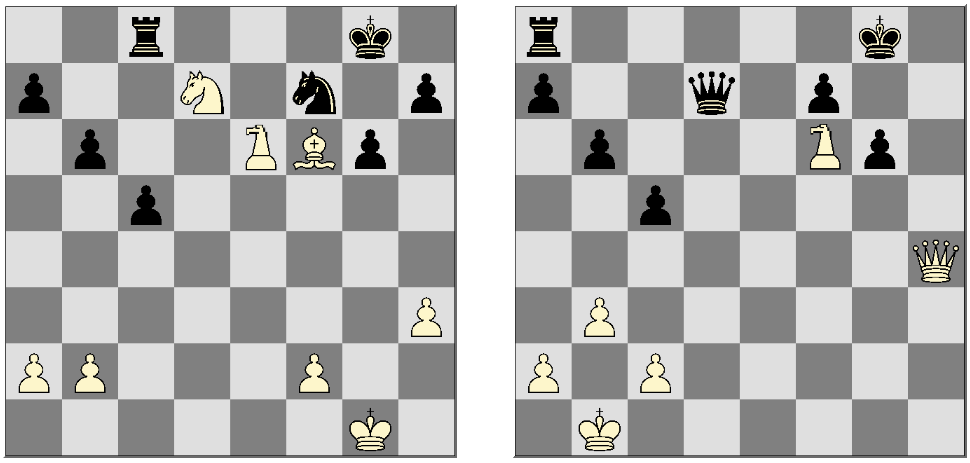


Figure 4.2 Positions shown to the subjects for practice.

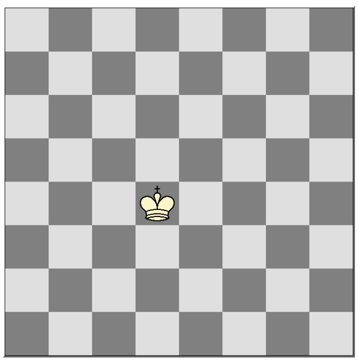


Figure 4.3 The white king on the board. The subjects were required to fixate the white king.

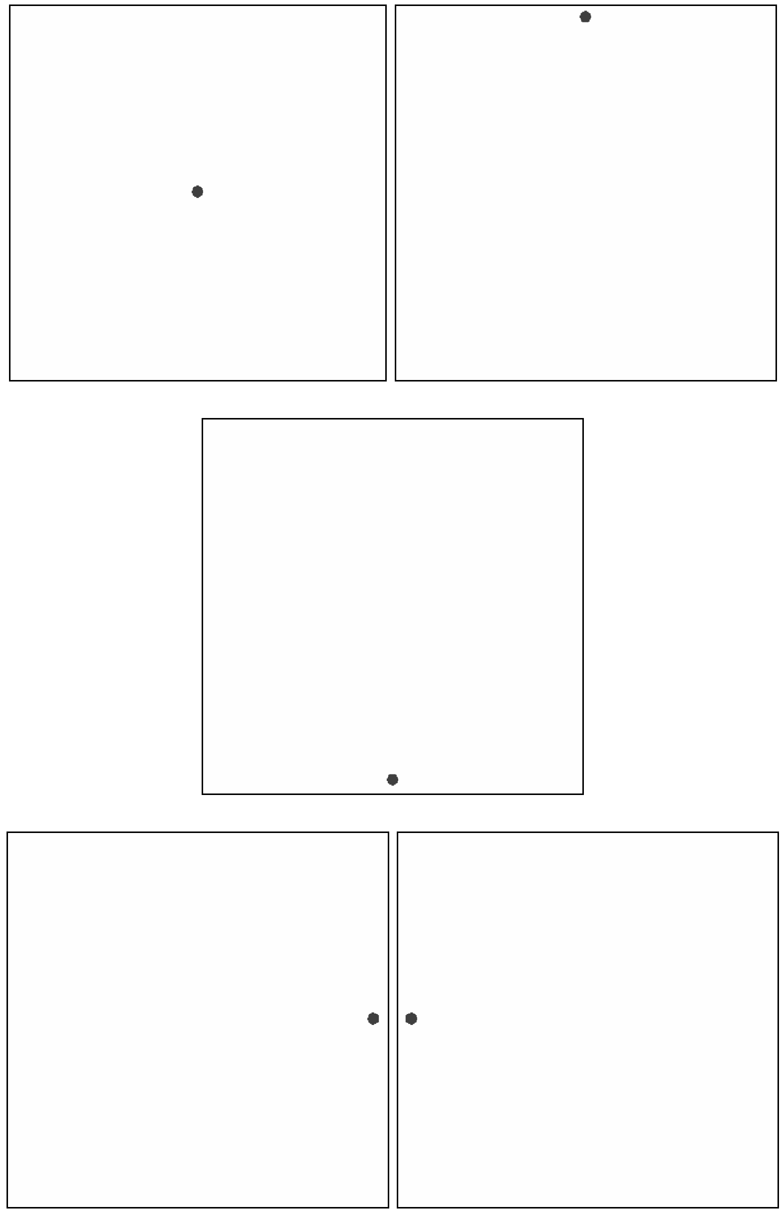


Figure 4.4 The points presented to the subjects for calibration.

4.3 Apparatus

Eye movements were measured with an EOG system developed at the Hacettepe University Medical Faculty Biophysics Department. The schematics of the amplifier can be seen in the Figure 4.5. The system is essentially a DC differential amplifier with two channels. The amplifier was powered by a pair of 12V batteries to eliminate 50 Hz interference and to provide for safety against electrical shocks.

Addinitionally, the input stage was decoupled from the subject by using a pair of Zener diodes and a 1 Kohm resistor for each of the inputs. The preamplification stage consists of an IC instrumentation amplifier (BurrBrown INA101) with a fixed gain of 40. Laser trimmed resistors in the differentiation stage of this IC provides for a common mode rejection ratio (CMRR) of over 80 dB which is quite difficult to achieve using discrete operational amplifiers. Also included in the preamplification stage is an offset adjustment circuit capable of providing for an offset voltage of ± Vs/400 mV where Vs is the supply voltage. This offset capability mainly enables cancellation electrode offset potentials and of undesired drift of baseline dc level. The initial baseline potentials of the subjects could be shifted up to values of ± 30 mV using this offset adjustment. In a few cases when this measure failed, electrodes were changed or reapplied. The second stage of the amplifier has an adjustable amplification which gives overall amplification factors of x700, x900, x1300 and x1600. The second stage also includes an 100 Hz analog lowpass filter (Butterworth, 1st order). Output of the amplifier is fed to a 12 bit A/D converter Advantech PCL-718 operating at 500 samples per second acquisition rate. An additional amplification of x100 was available at the input of the A/D converter. A/D converter was driven by a Linux based PC (Pentium II 500 MHz) with qEOG acquisition software developed by Ilhan (2003).

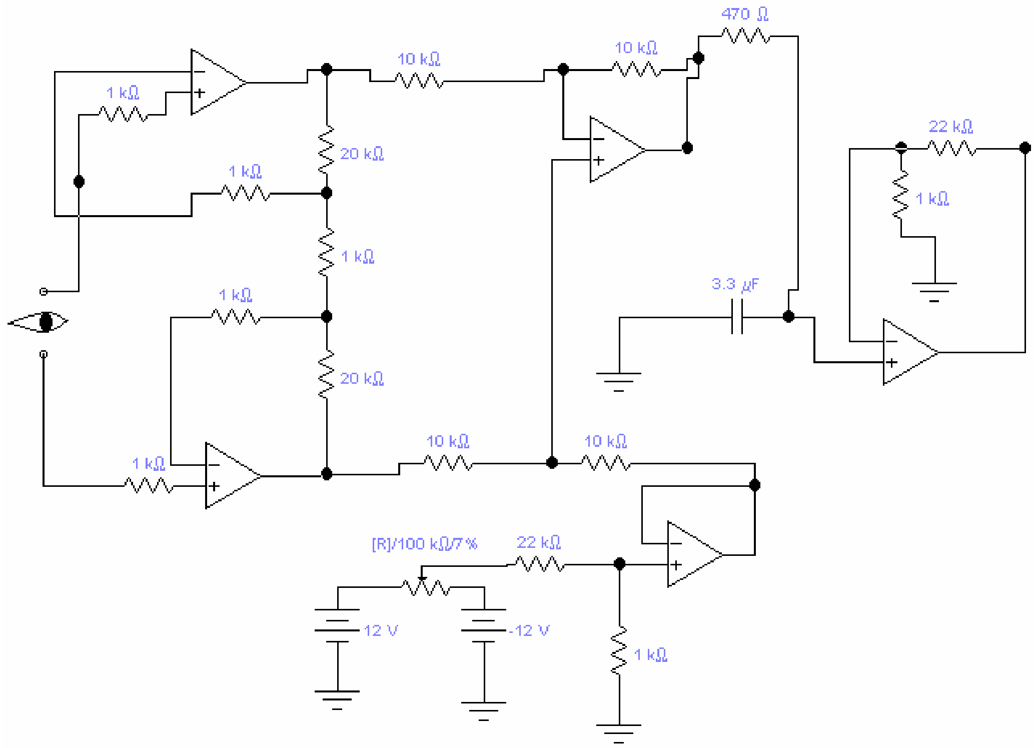


Figure 4.5 Schematics of the card used in the EOG amplificatory for one channel. In the figure the channel is used for vertical eye movement recording.

4.4 Procedure

Experimental procedure started with the presentation of the calibration points. On a black screen a grey point was shown at the top, bottom, right and left of the screen respectively for 1 second periods. In this calibration phase, in between the presentation of each point, a point was shown in the middle of the screen for 1 second and the subjects were required to fixate on that central point. In the test phase the white king was represented in 25 different squares, each for 1 second and the subjects were required to fixate on the white king. In between every 5 representations of the white king, the point in the middle of the screen was shown for 1 second. In the position phase, 15 positions were represented for 5 seconds each and the players were asked to find the mating moves. In between every position, a point was shown in the middle of the screen for 1 second and the subjects were asked to fixate this point. The first 5 positions did not include any novel piece, but the next 10 positions included the novel piece whether related with the position or not. No reaction was required from the players. A total of 69 slides were shown to the subjects during the whole experiment. The experiment setup can be seen in the Figure 4.6.

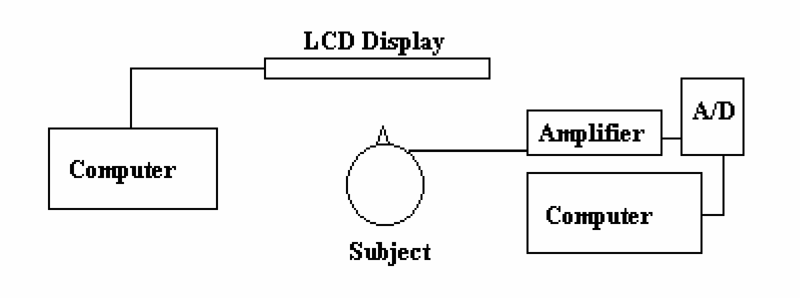


Figure 4.6 The experiment setup. The slides shown on the LCD display are controlled by a computer and the data is stored in another computer.

4.5 Data Analysis

The data gathered from the EOG system is stored in the computer. The data does not give information about the coordinates of the eye fixations directly. In this study firstly the data was filtered and then the effect of the drift on the data was suppressed. Later, this processed data was converted to the eye fixation coordinates.

In the present study the median filter for 149 points was used (sampling frequency was 500 Hz). It has been observed that when the number of points increase, the noise is suppressed more successfully, however the edge preserving property of the median filter is lost. Therefore 149 points has been found as an optimum by trial-error. Although the eye-blinks were suppressed, they did not dissappear (Figure 4.7), the durations which the eye-blink occurs is identified and marked as ‘unidentified fixation’. A typical eye -blink artefact pattern can be found in the Figure 4.7. The sharp edges, which are important for fixation-time analysis have been preserved in median filtering. As it can be seen in Figure 2.4, the noise at high frequencies have been suppressed by median-filter.

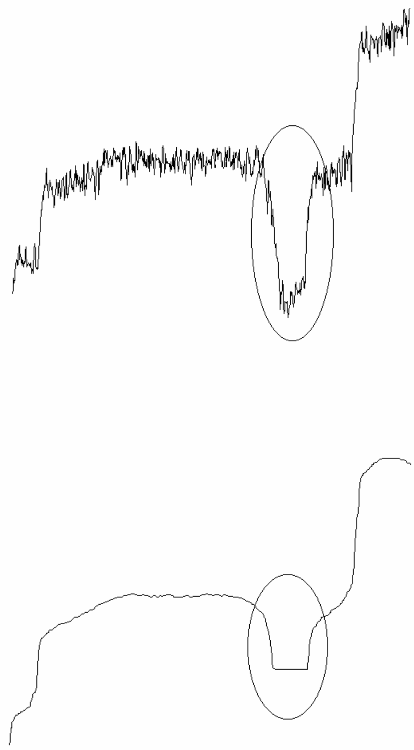


Figure 4.7 Eye blink artifact suppression on sample eye movement signal.

The effect of drift is an other artefact which should be removed. To remove drift, during the experiment the subject was required to fixate on the point which appeared in the middle of the screen at every 5 seconds. The mean voltage difference values should be same both horizontally and vertically during fixation on the same point, however drift causes the signal to have a slope. To remove the effect of drift, the slope which is a result of the drift is calculated:

x = mean value of the data during the fixation of the subject in the middle of the screen before the stimulus is displayed

y = mean value of the data during the fixation of the subject in the middle of the screen after the stimulus is displayed

a = start of the time interval when the subject fixates in the middle of the screen before the stimulus is displayed

b = end of the time interval when the subject fixates in the middle of the screen before the stimulus is displayed

c = start of the time interval when the subject fixates in the middle of the screen after the stimulus is displayed

d = end of the time interval when the subject fixates in the middle of the screen after the stimulus is displayed

$s=(x-y)/((a+b)/2-(c+d)/2)$; (slope of the drift)

When the drift whose slope is known extracted from the data, the effect of the drift is minimized (Figure 4.8).

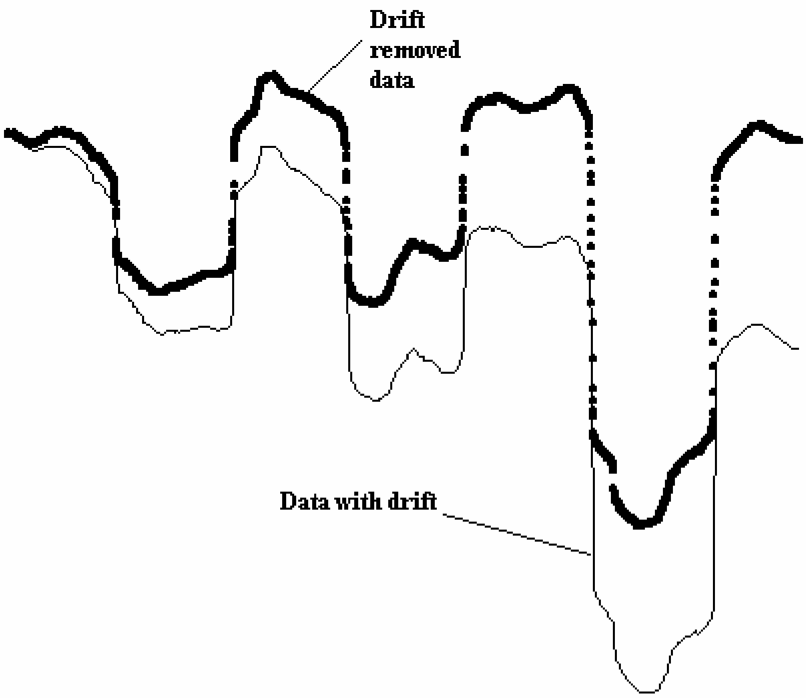


Figure 4.8 Effect of the drift can be seen in the figure. The bold line is the signal which the effect of drift is reduced.

When the artefacts and noise are reduced in the data, data can be converted into the coordinate system of the display to investigate the eye fixations. The following procedure was applied to predict the fixations. Figures in the appendix show the eye fixations of the subjects in test phase and the experiment phase. All of the predictions –even the ones which were identified as 'could not be investigated'- were included in the figures. The fixations of the subjects were indicated by red points. The board is empty if the fixation could not be investigated. The results of fixation predictions for 16 participants were found to be sufficient, however the results of fixation predictions for the subject CI was found to be insufficient. The reason may be the high sweating of the subject's face related to high temperature in the room where the experiments were carried out. A detailed explanation for the investigation in the test phase can be found in Figure 4.9, 4.10 and 4.11.

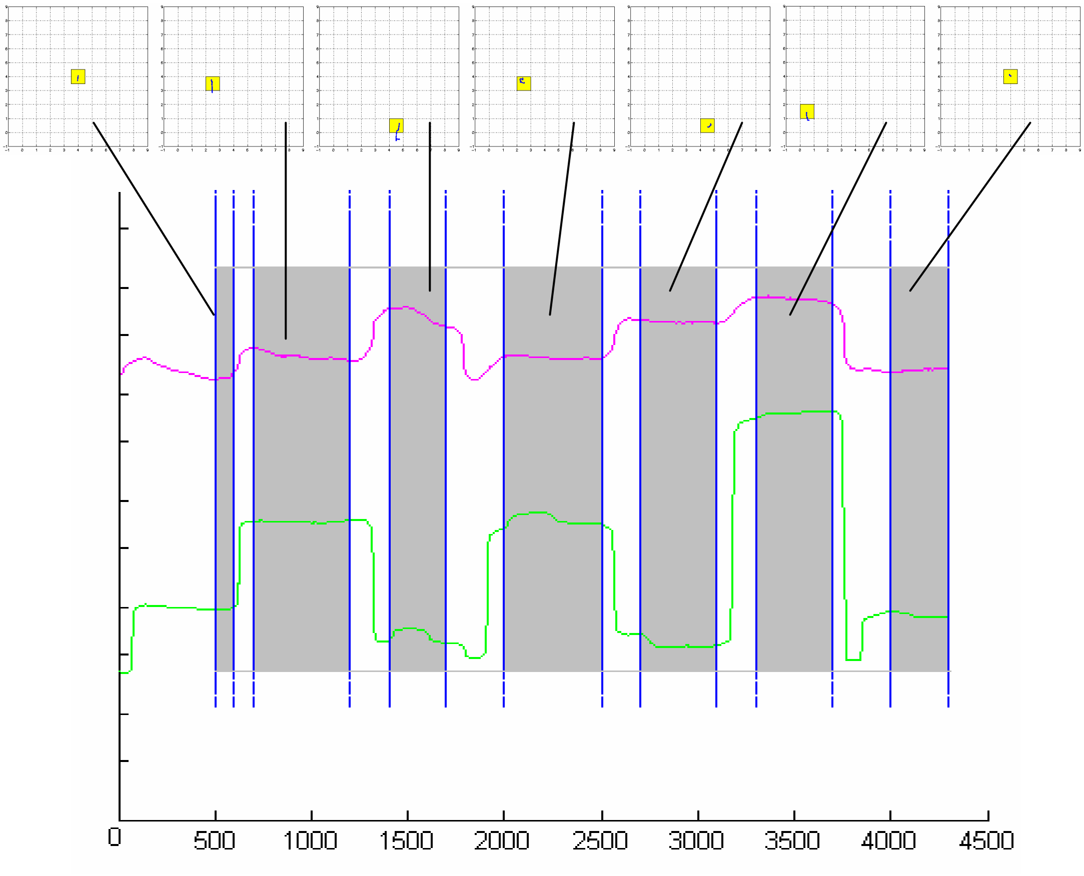


Figure 4.9 The figure shows the eye movement signals of the subject DA during the test phase between the positions 27-33. As this is the test phase, the fixation times were not measured. The shaded area shows the duration for the prediction of the fixation's location. On the upper side of the figure the predictions and the actual location of the white king are compared. The white king's square is shaded. In the last and the first position, the subject fixates the point in middle of the screen.

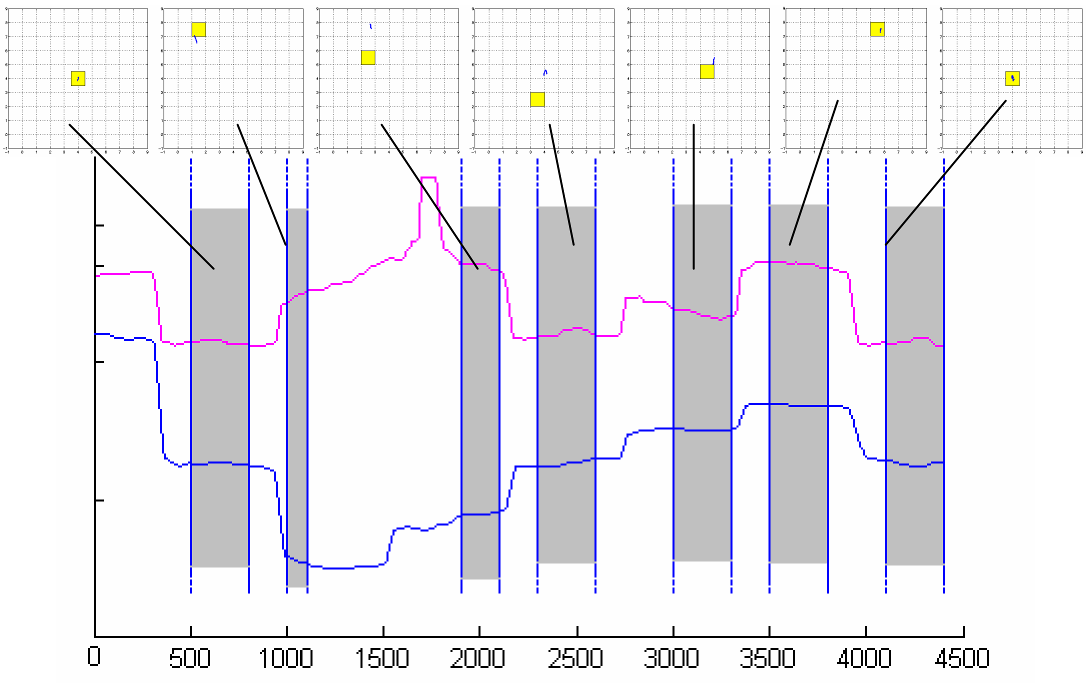
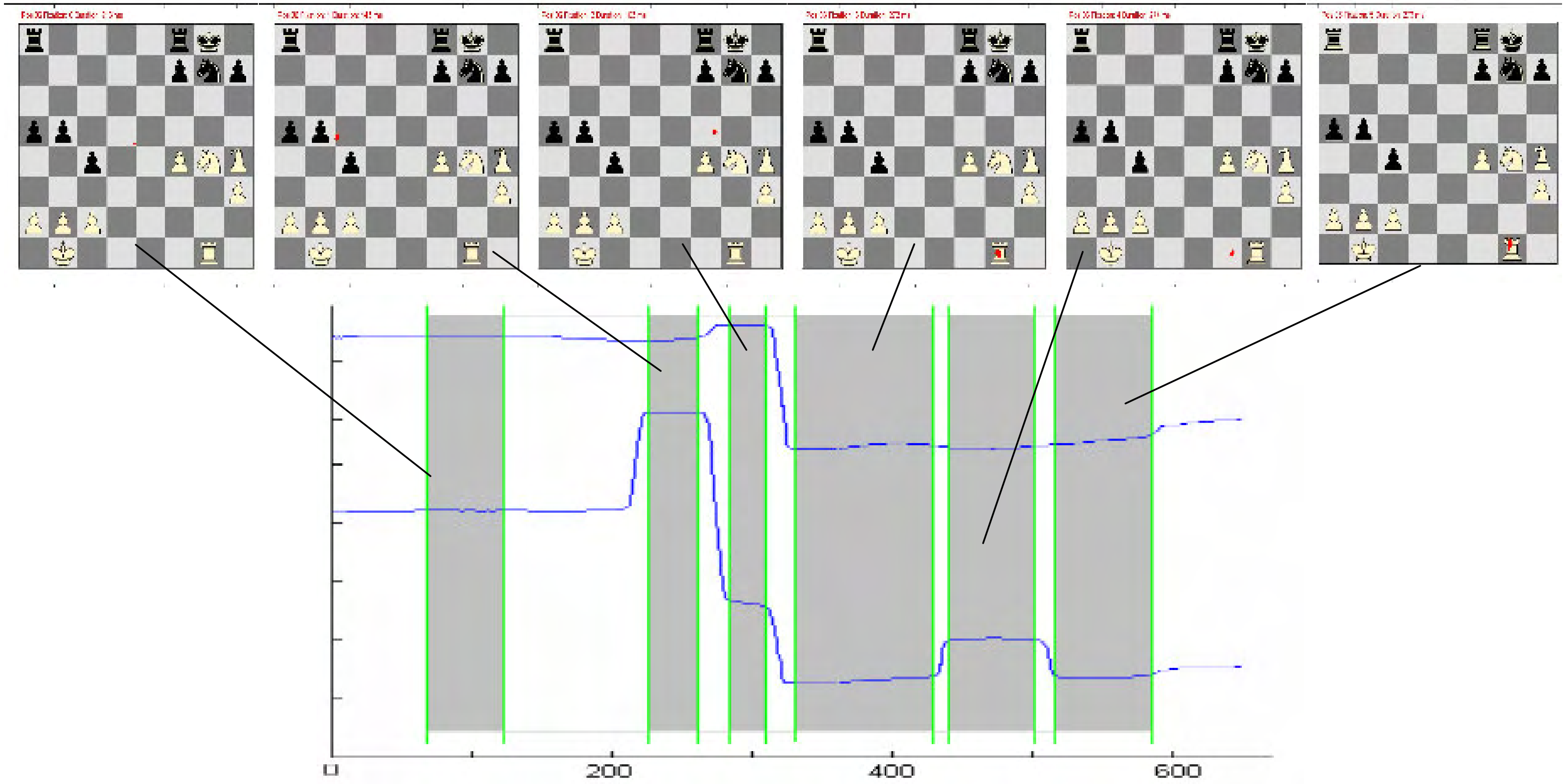


Figure 4.10 The figure shows the eye movement signals of the subject BI during the test phase between the positions 15-21. As this is the test phase, the fixation times were not measured. The shaded area shows the duration for the prediction of the fixation's location. On the upper side of the figure the predictions and the actual location of the white king are compared. The white king's square is shaded. In the last and the first position, the subject fixates the point in middle of the screen. The eye blink artifact affects the surrounding signals for this subject, resulting in a false prediction for the fixations around the eye blink. In the analysis, such data was identified as 'not investigable' and these fixations were not taken into analysis.



Figureure 4.11 An example EOG signal converted into board coordinates. The shaded areas are fixation durations. The d data are taken from the subject NE during finding the mate for the sixth position.

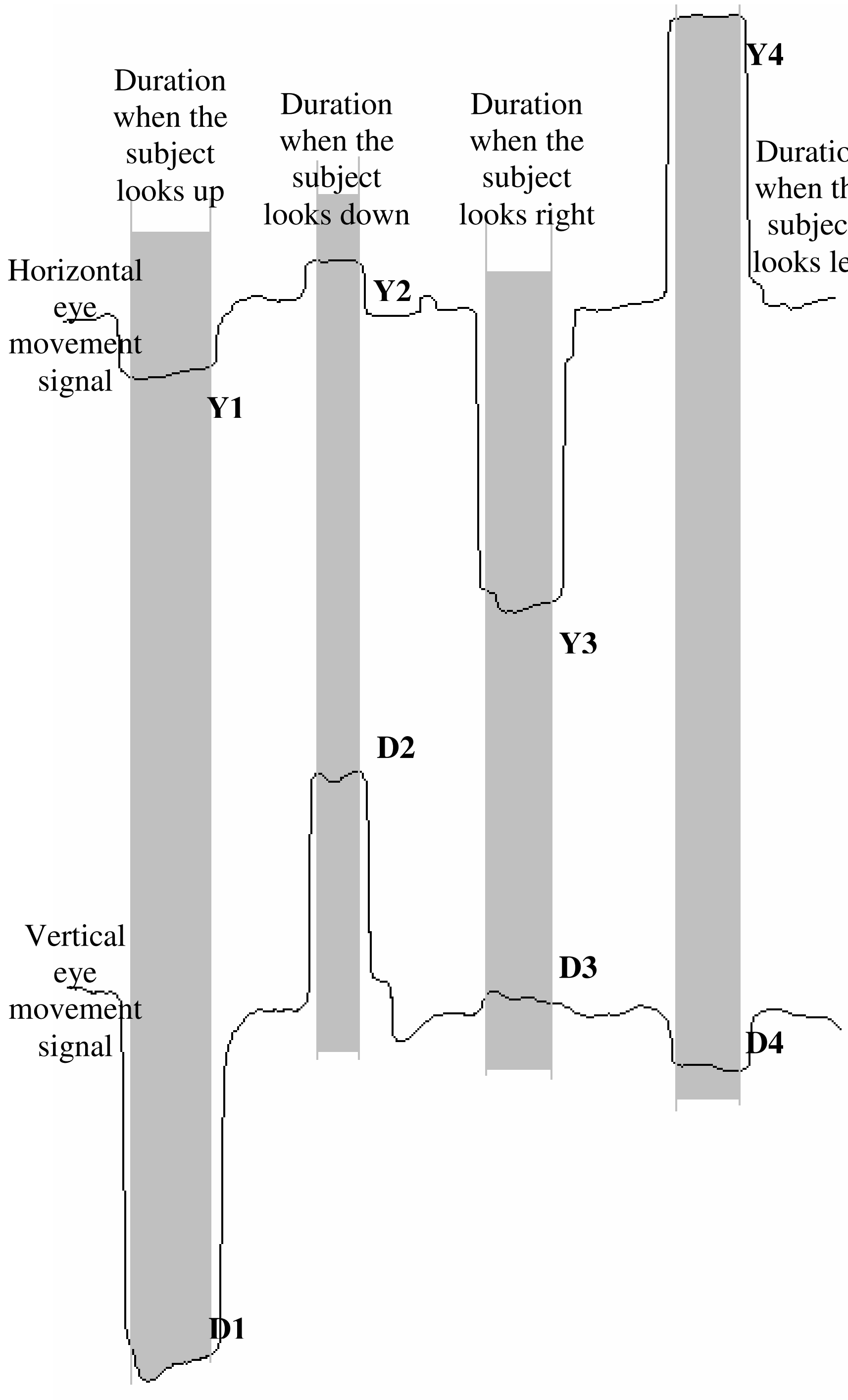


Figure 4.12 Effect of vertical eye movement signals on horizontal eye movement signals, and effect of horizontal eye movement signals on vertical eye movement signals.

In the experiments, it has been observed that the horizontal movement signals of eyes affect the signals of vertical movements, and the vertical movement signals of eyes affect the signals of horizontal movements. In the Figure 4.12 the lines at the top indicate the horizontal movement and lines at the bottom indicate the vertical movement. (Y for horizontal and D for vertical) D1, D2, D3, D4, Y1, Y2, Y3 and Y4 are mean values of voltage differences when the eyes move up, down, right and left respectively. To be able to process actual data, it is necessary to find the coefficients of signals that affect each other.

X: Actual Vertical Movement Voltage Difference

x: Ideal Vertical Movement Voltage Difference (not affected by horizontal movement signal)

Y: Actual Horizontal Movement Voltage Difference

y: Ideal Horizontal Movement Voltage Difference (not affected by vertical movement signal)

a: Coefficient of horizontal movement effect on vertical movement signal

b: Coefficient of vertical movement effect on horizontal movement signal

$Y = y + ax$

$\underline{X = x + by}$

Then $x = (X - bY)/(1 - ba)$

And $y = Y - ax$

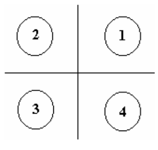


Figure 4.13 The screen divided into four regions

The screen can be thought as shown in the Figure 4.13. The coefficients of four regions are different from each other. For example if the subject looks at right and up then this means that the coefficients for the 1st region will be used. The coefficients can be found for 4 regions.

For the 1st region: $a = Y1/D1$; $b = D3/Y3$;

For the 2nd region: $a = Y1/D1$; $b = D4/Y4$;

For the 3rd region: $a = Y2/D2$; $b = D4/Y4$;

For the 4th region: $a = Y2/D2$; $b = D3/Y3$;

Given X and Y values, it can be found four different solution sets for (x,y). Each of them is in another region. They can be called as (x1,y1), (x2,y2), (x3,y3), (x4, y4).

If the subject looks at the first region, then

$(x1*D1>0\ \&\ y1*Y3>0)$

shall be true, assuming that if the subject looks up, the voltage difference is positive for vertical movement and if the subject looks right, the voltage difference for horizontal movement is positive. Then, using the same convention;

If the subject looks at the 2nd region: $(x2*D1)>0\ \&\ (y2*Y3)<0)$

If the subject looks at the 3rd region: $(x3*D1)<0\ \&\ (y3*Y3)<0)$

If the subject looks at the 4th region: $(x4*D1)<0\ \&\ (y4*Y3)>0)$

shall be true, and the ideal data set (x,y) can be found. Since (x,y) data set is the voltage difference, it must converted into the coordinates on the screen.

D1: Voltage difference for vertical movement signal when the subject looks at the maximum up.

D2: Voltage difference for vertical movement signal when the subject looks at the maximum down.

Y3: Voltage difference for horizontal movement signal when the subject looks at the maximum right.

Y4: Voltage difference for horizontal movement signal when the subject looks at the maximum left.

The point at center of the screen can be accepted as (0,0) point.

The point at the top of the screen can be accepted as (0,1) point.

The point at the bottom of the screen can be accepted as (0,-1) point.

The point at the right of the screen can be accepted as (1,0) point.

The point at the left of the screen can be accepted as (-1,0) point.

Since (x,y) values are known, it is known at which region the eyes are looking, then the coordinates to where the eyes are looking on the screen can be found. Figure 2.10 shows a detailed explanation of the procedure.

C: Horizontal Coordinates of the screen where the eyes are fixating

R: Vertical Coordinates of the screen where the eyes are fixating

If looking up: $R = x/D1$

If looking down: $R = -(x/D2)$

If looking right: $C = y/Y3$

If looking left: $C = -(y/Y4)$

CHAPTER 5

RESULTS

For each player the first five fixations were computed to investigate the spatial distribution of fixations produced by subjects during the early perceptual phase of attempting to find the mating moves. The three groups of positions were investigated. The squares were classified as "the salient square" and "non -salient square". The salient squares are related with the position where the non-salient squares are not.

Analysis of multivariate analysis of variance (MANOVA) was carried out to investigate the proportion of fixations across two skill groups and the effect of the novel piece and the level of significance was taken to be 0.05 ($p<0.05$). For the purposes of this analysis the average percentage of the first five fixations on salient squares to the first five fixations on non-salient and salient squares were computed for three different groups of positions. Fixation order and type of position were within-participants independent variables and skill level was a between-participants independent variable. Multivariate test showed a significant main effect of fixation order, $F(4,11) = 5.035$ (Figure 5.1). Univariate tests showed that the linear component was significant, $F(1, 14) = 9.563$, $MSE = 0.025$. The interaction of skill and fixation order was found to be significant in the multivariate test, $F(4,11) = 3.586$ (Figure 5.2). The proportion of fixations on salient squares was significantly different across expert and novice chess players, $F(1,14) = 8.720$, $MSE = 0.021$ (Table 5.1).

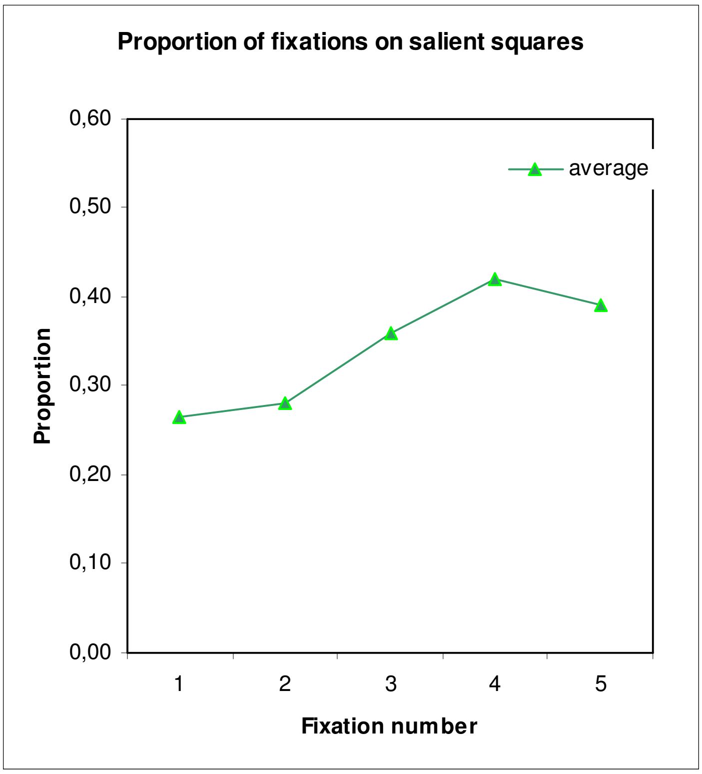


Figure 5.1 Proportion of the first five fixations on the salient squares for all the subjects

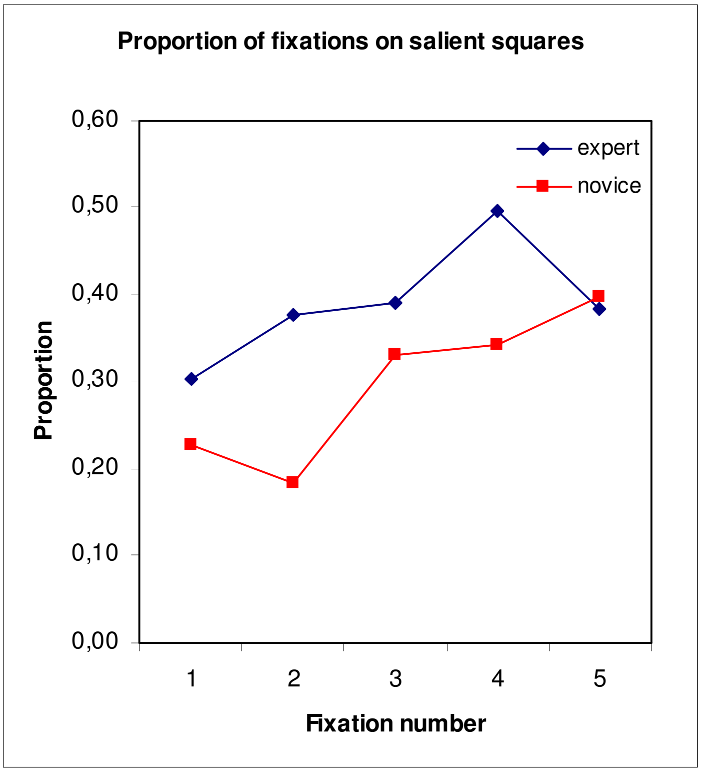


Figure 5.2 The change in the proportion of fixations for two skill groups

Table 5.1 Mean of proportion of fixations on salient squares

Expertise	Mean of proportion of fixations on salient squares
Expert	0.391
Novice	0.296

The fixation times were also analyzed using MANOVA. The average fixation durations of players in positions with a no novel piece, with novel piece on a salient square and with a novel piece on non-salient square were computed for the purposes of this analysis. As in the analysis of the proportion of fixations on salient squares fixation order and type of position were within-participants independent variables and skill level was a between-participants independent variable. Instead of proportion of fixations on salient squares, fixation times were used. There was not a significant difference between skill groups as their fixation durations are compared, $F(1,14) = 1.968$, $MSE = 5287.917$. The interaction of position types and fixation order was found to be significant in the multivariate test, $F(8,7) = 5.910$ (Figure 5.3). Univariate tests showed that the linear component was significant between the position Type1 (positions with no novel piece) and Type2 (positions with a novel piece on a salient square), $F(1, 14) = 6.990$, $MSE = 8237.059$, and the order 4 component was significant between the position Type1 (positions with no novel piece) and Type3 (positions with a novel piece on a non-salient square), $F(1, 14) = 5.177$, $MSE = 17506.753$.

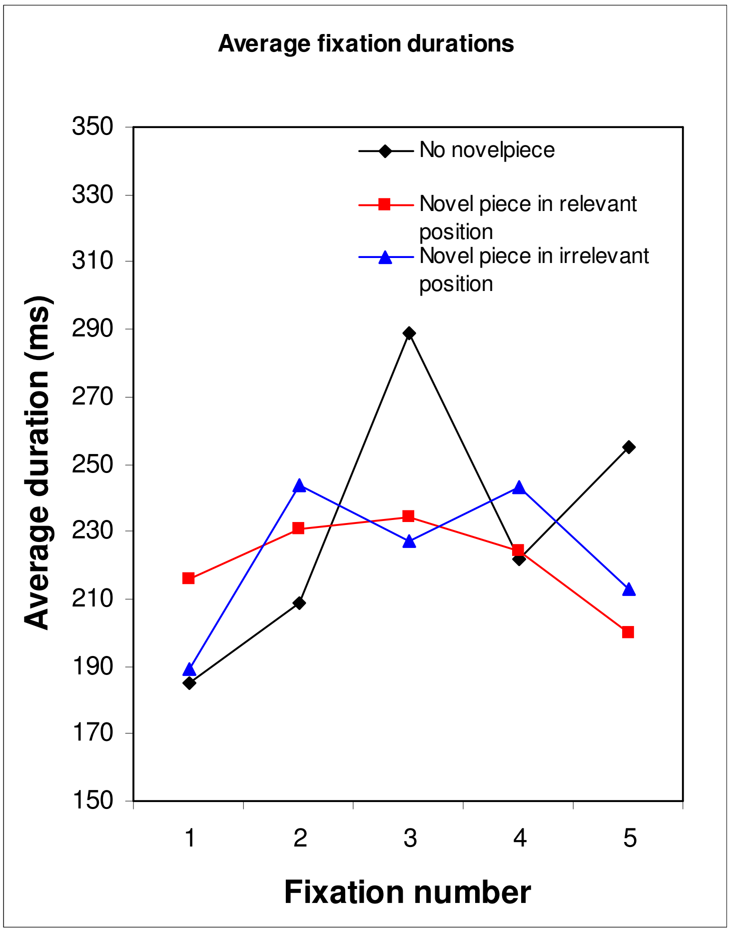


Figure 5.3 Change in fixation time between fixations across three group of positions

CHAPTER 6

CONCLUSION

6.1 Discussion

The proportion of fixations on salient squares changes with the fixation order. The proportion of fixations on salient squares increase in the later fixations. The reason can be that players direct attention and fixations to salient squares after first fixations to find out more information about the pieces on the salient squares. There is a difference in the change of proportion of fixations for two skill groups. The novice group has a linear increase in their fixation proportions. The fixation proportion of experts decrease after the fourth fixation. The experts may be searching for other pieces that are salient with the position after they find out the relations of the pieces, and the novices may be continuing to find out the relations between pieces on salient squares.

As the fixation times between skill groups are comparable, a significant difference is not observed, this result is consistent with the findings of Reingold et. al. (2001). However there was a difference in the change of fixation time between fixations across three different groups of positions. In the positions with no novel piece, the subjects have the longest duration on the third fixation. Then there is a sharp decrease in the durations.On the third fixation, the subjects can be finding out the realitonship between the pieces, therefore they may be fixating on the third fixation for a long time. However in the positions with a novel piece on a salient square, no fixation has such a long duration. The fixations of the subjects were affected by the novel piece, so they did not fixate as long as they did in the positions without a novel piece. In the positions with a novel piece on a non-salient square again there was not a fixation time as long as the one in the position without a novel piece. The fixations of subjects were affected by the novel piece. There was not a reaction expected from the subjects during the experiment, therefore the novel piece was an object to detect the alertness of the subject, and it has been observed that when a novel piece was inserted onto the board, the fixation duration of the subjects changed which indicated that the subjects were affected by the novel piece. If the subjects were not alert in the first group of positions, where there was no novel piece, then they would not be expected to be affected by the appearance of the novel piece.

6.2 Conclusion

In the experiments the experts produced a greater proportion of fixations on salient squares than novices which is consistent with the hypothesis that first few fixations of expert players will more likely be on the squares related with the position when compared with the less skilled players. This shows that an important percentage of expertise in chess is based on perceptual mechanism. Thus, the results in this study are consistent with Charness et. al. (2001), Chase & Simon (1973b) and Gobet & Simon (1998) that an advantage in the early perceptual phase is an essential component in chess skill.

Further study for the investigation of the role of early perceptual organization in skill differences in chess expertise can be carried out between blind chess players. As they "see" the pi eces by touching them, a new methodology can be developed to observe their "fixations" on pieces. To perform multiple chess -related tasks as full chessboard memorization and chessboard check detection with blind chess players would be beneficial for the theory development in the expertise studies.

In the present study a mate-find task is applied. The mate-find task is an ecologically valid task as the move-choice task applied in Charness et. al. (2001), however the tasks such as partial chessboard detection, full chessboard memorization lack the ecological validity of mate-find and move-choice tasks.

It has been shown that EOG technique can be used to record and track eye movements in chess related tasks. The early perceptual phase advantage of the experts to the novices can be investigated by the analysis of the spatial distribution of early fixations (first five fixations). Future work can be made to reduce the drift by hardware design and electrode selection. To convert the eye fixation signals into display coordinates in real time, a software can be developed which works in consistency with the designed hardware. The offset adjustment and amplification can be set by the software.

Further studies which require eye-movement recording and tracking can be made by the EOG technique. The early fixation strategies of experts in other areas can be observed to investigate the role of early perceptual encoding advantage. In this study the eye movement recordings with EOG technique provided evidence for the importance of the initial encoding process in chess expertise as players attempted to find the mate in a chess game.

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APPENDIX

DATA RELATIVE TO CHAPTER 4

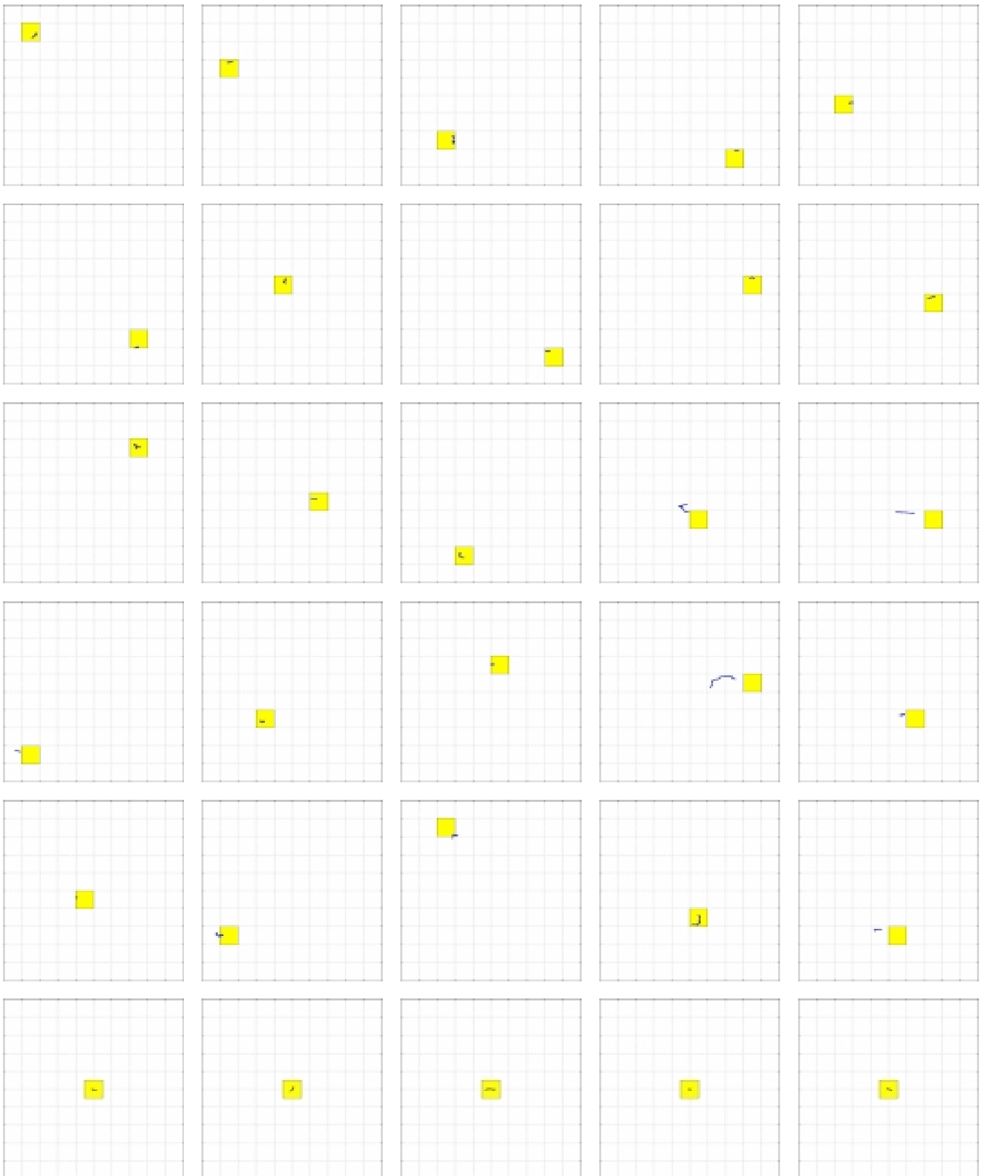


Figure A.1 Test phase of subject AK

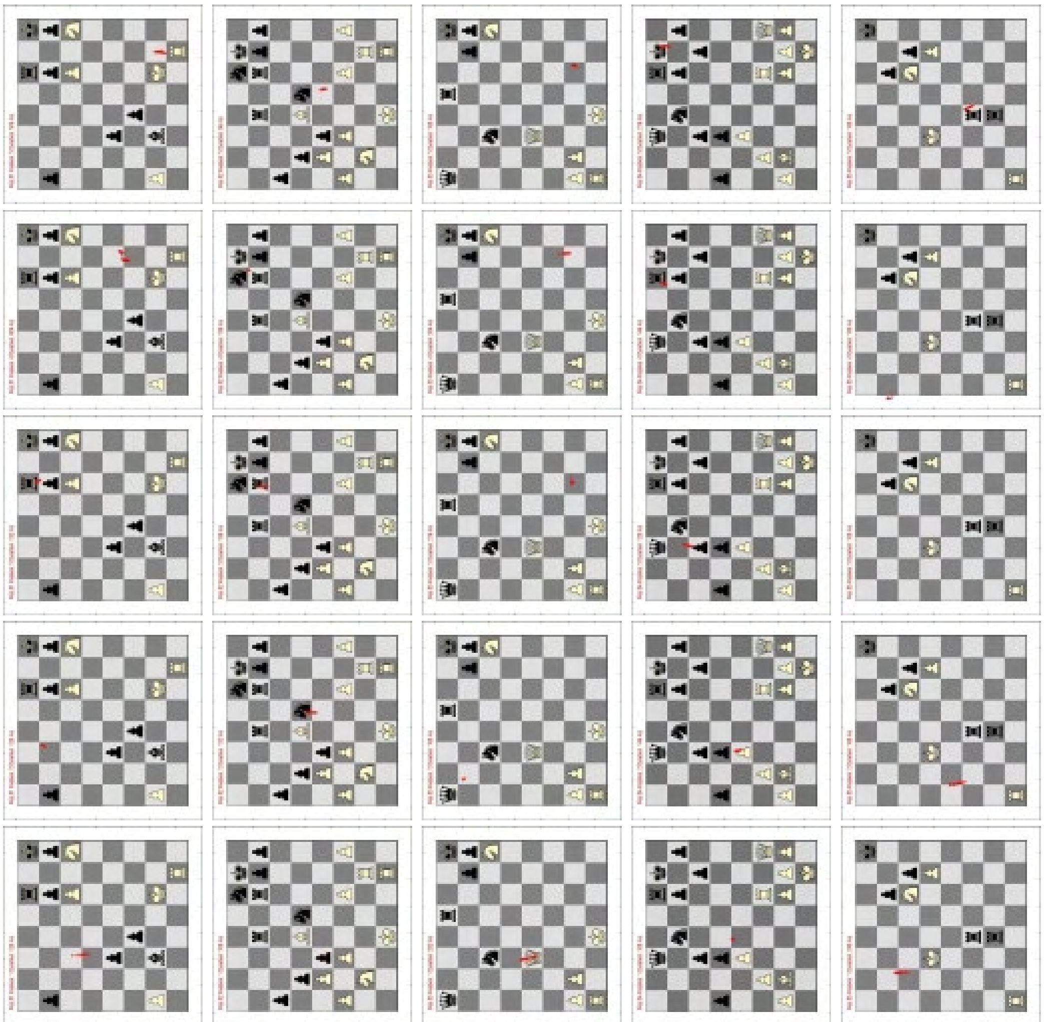


Figure A.2 First five fixations of subject AK on first group of five positions

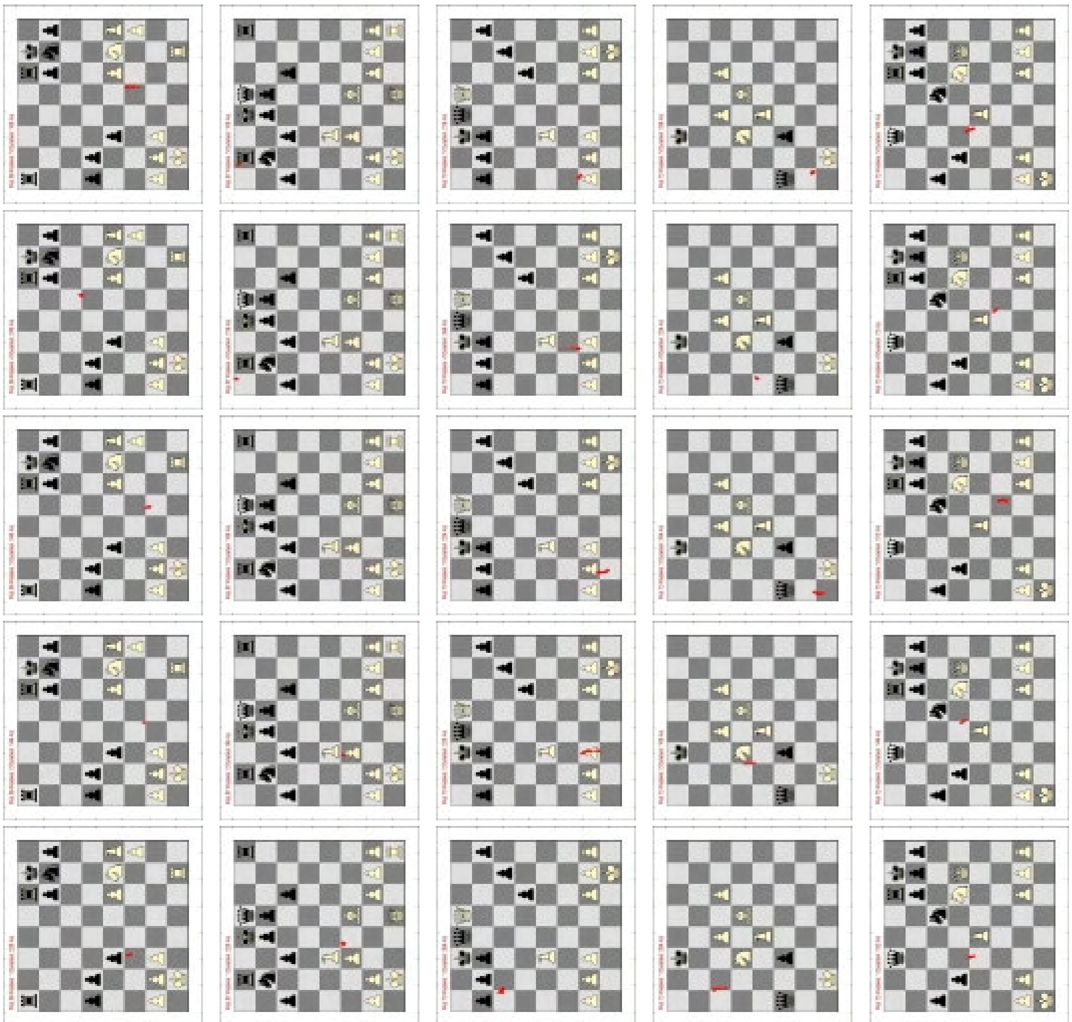


Figure A.3 First five fixations of subject AK on second group of five positions

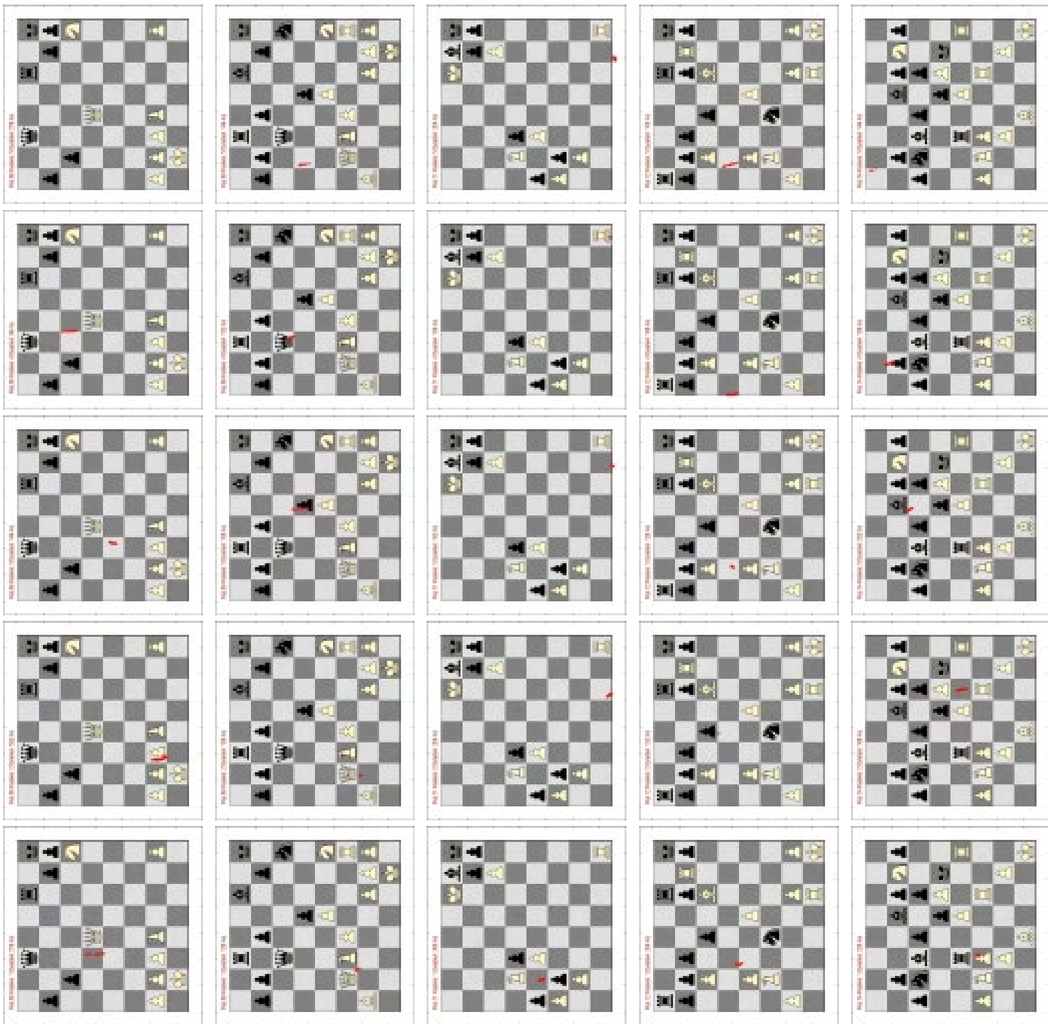


Figure A.4   First five fixations of subject AK on third group of five positions

Figure A.5 Test phase of subject BI

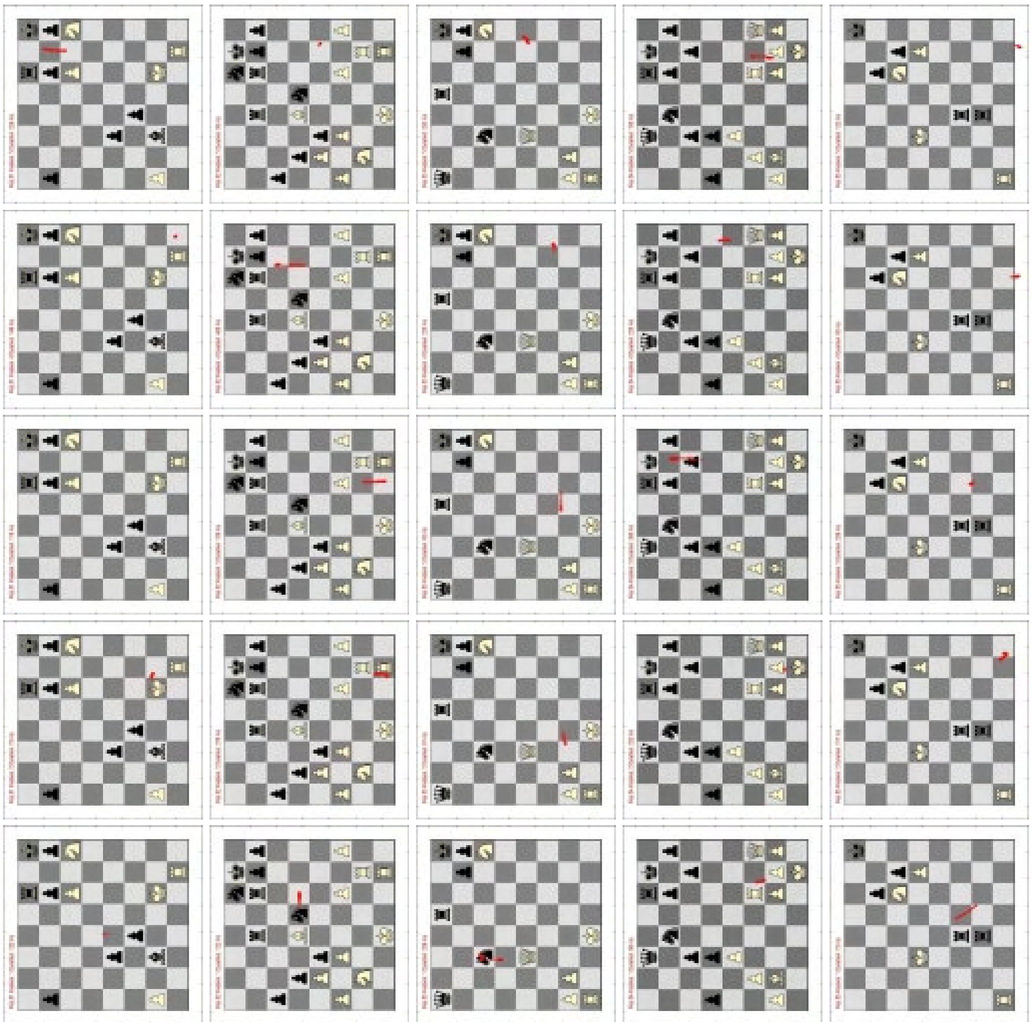


Figure A.6 First five fixations of subject BI on first group of five positions

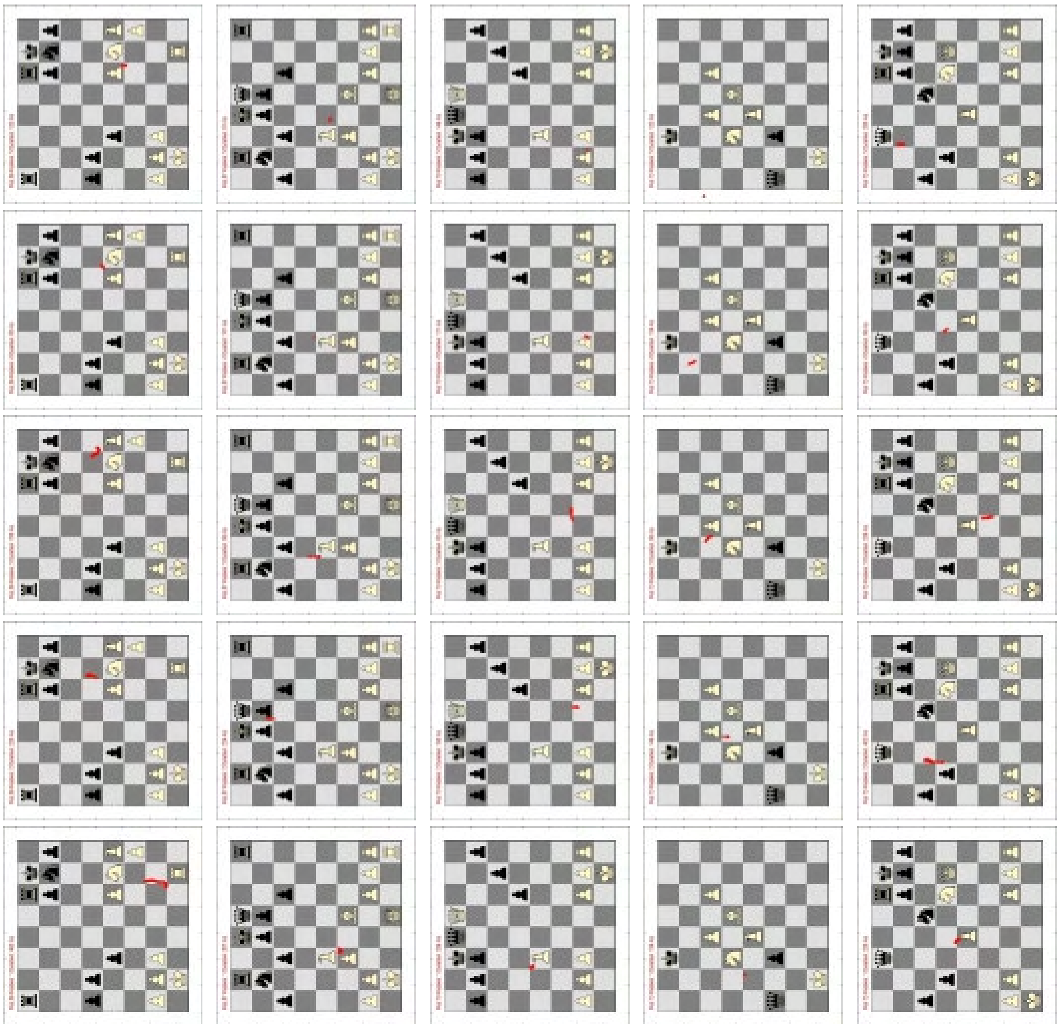


Figure A.7 First five fixations of subject BI on second group of five positions

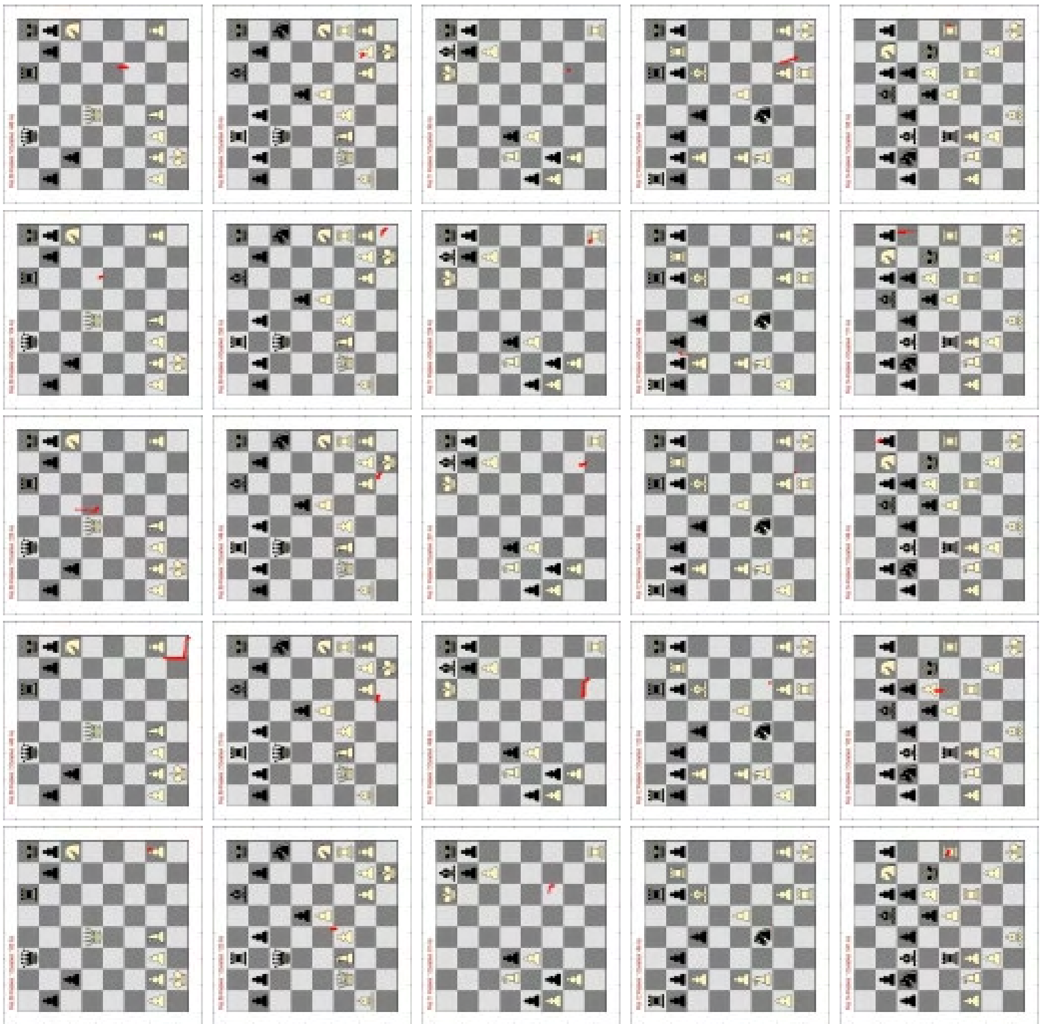


Figure A.8   First five fixations of subject BI on third group of five positions

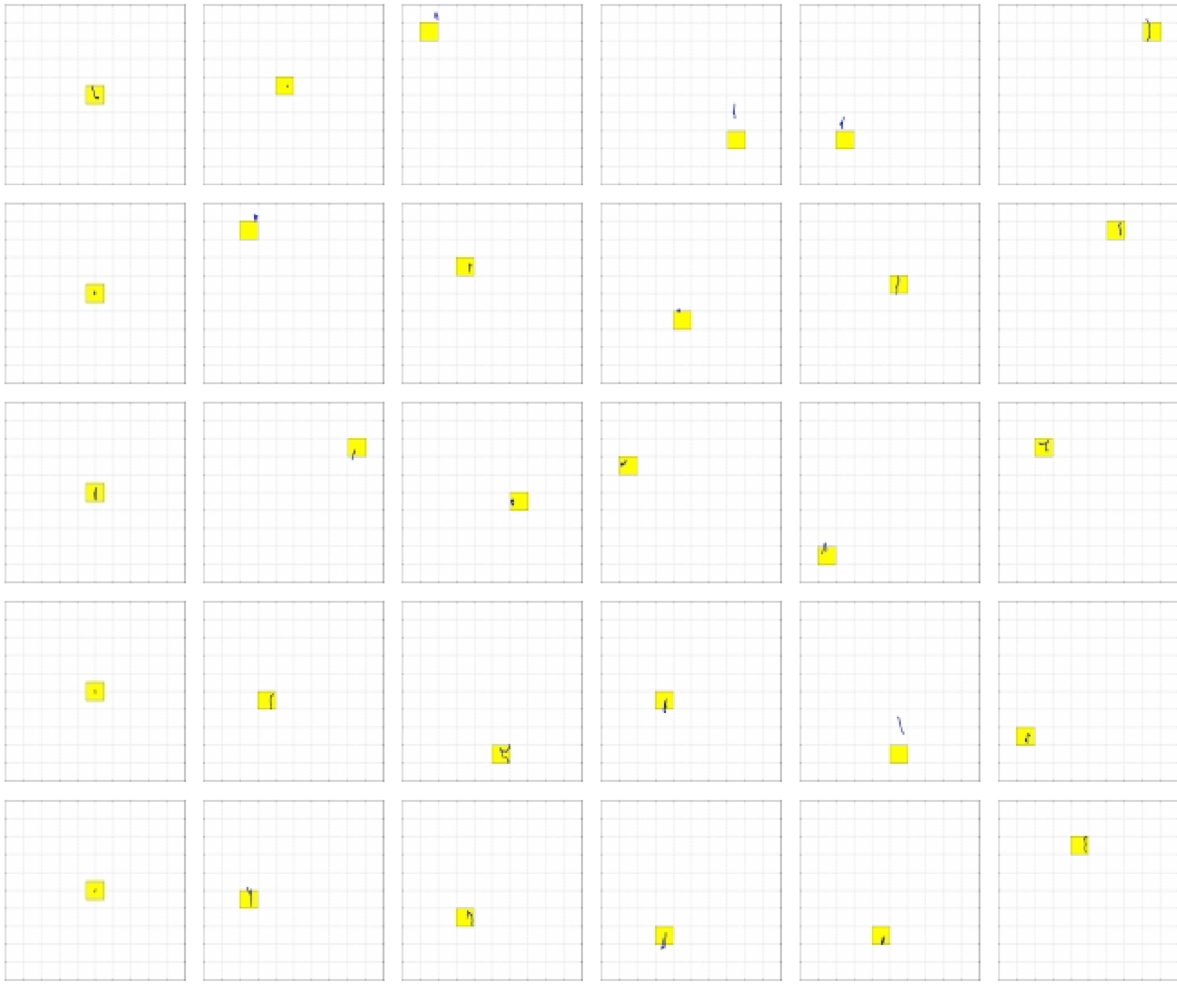


Figure A.9 Test phase of subject CS

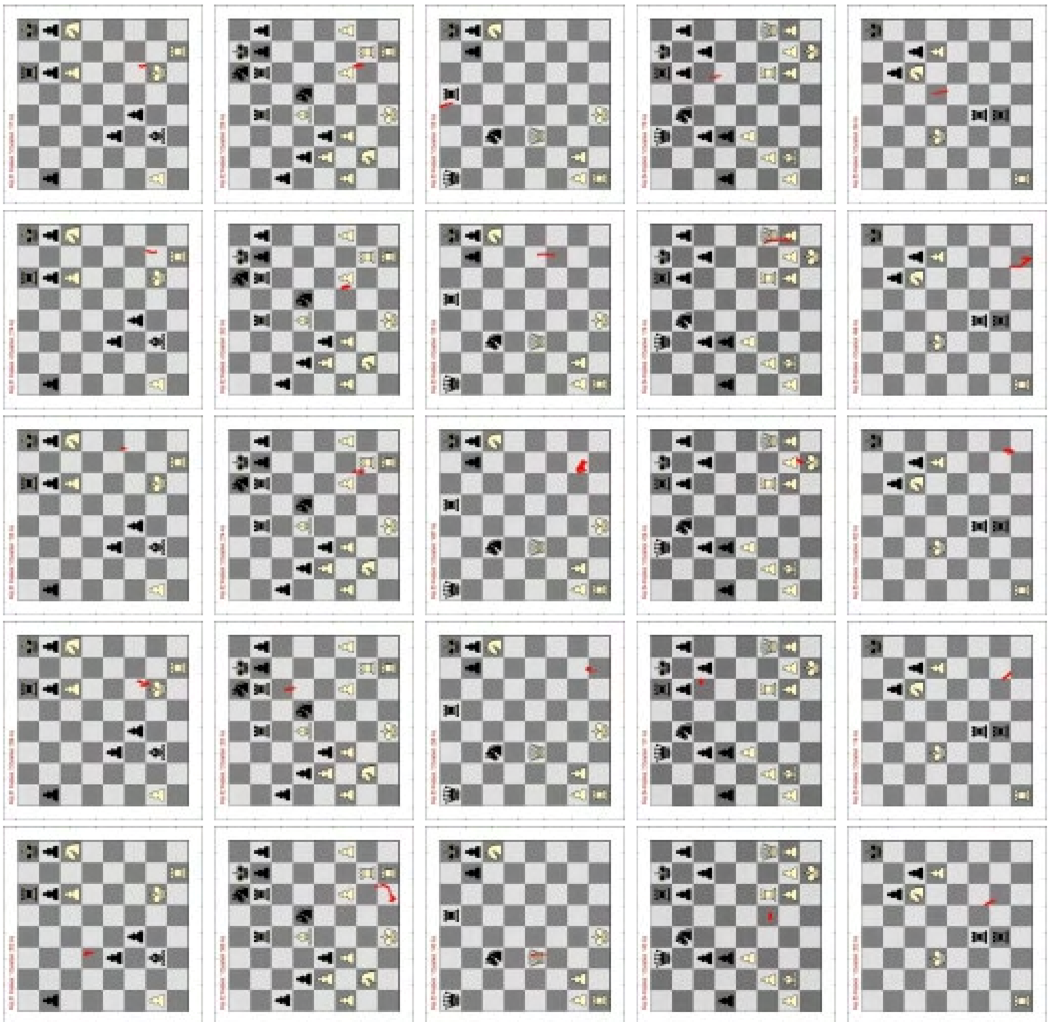


Figure A.10 First five fixations of subject CS on first group of five positions

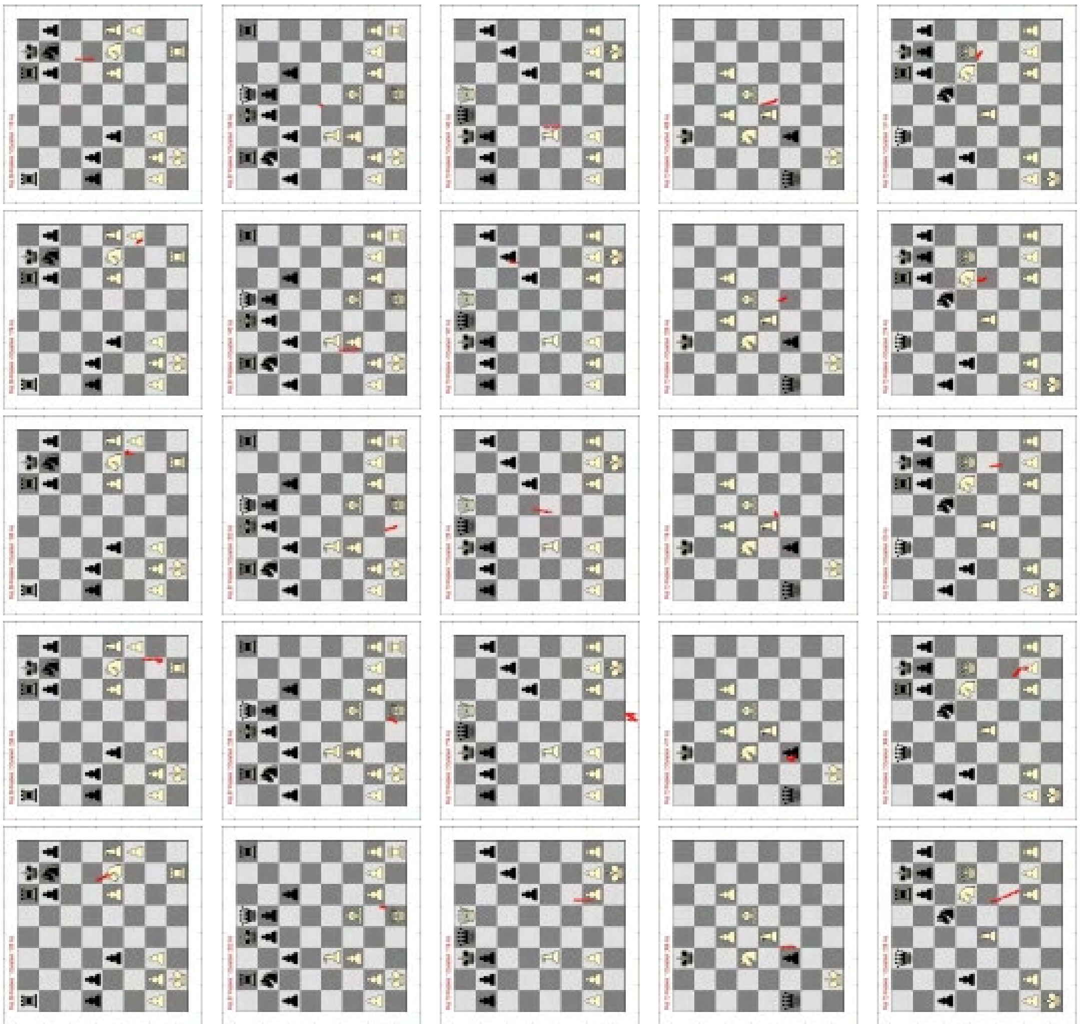


Figure A.11 First five fixations of subject CS on second group of five positions

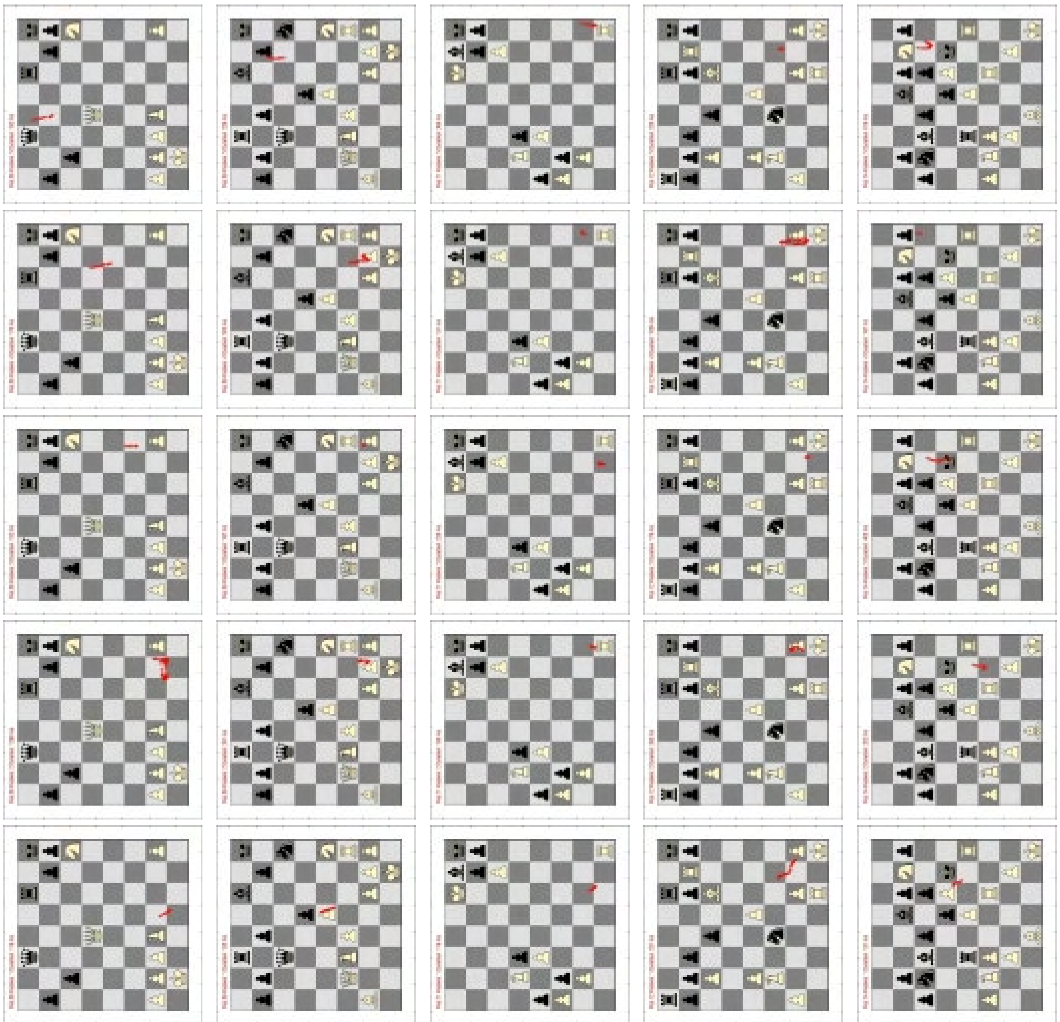


Figure A.12 First five fixations of subject CS on third group of five positions

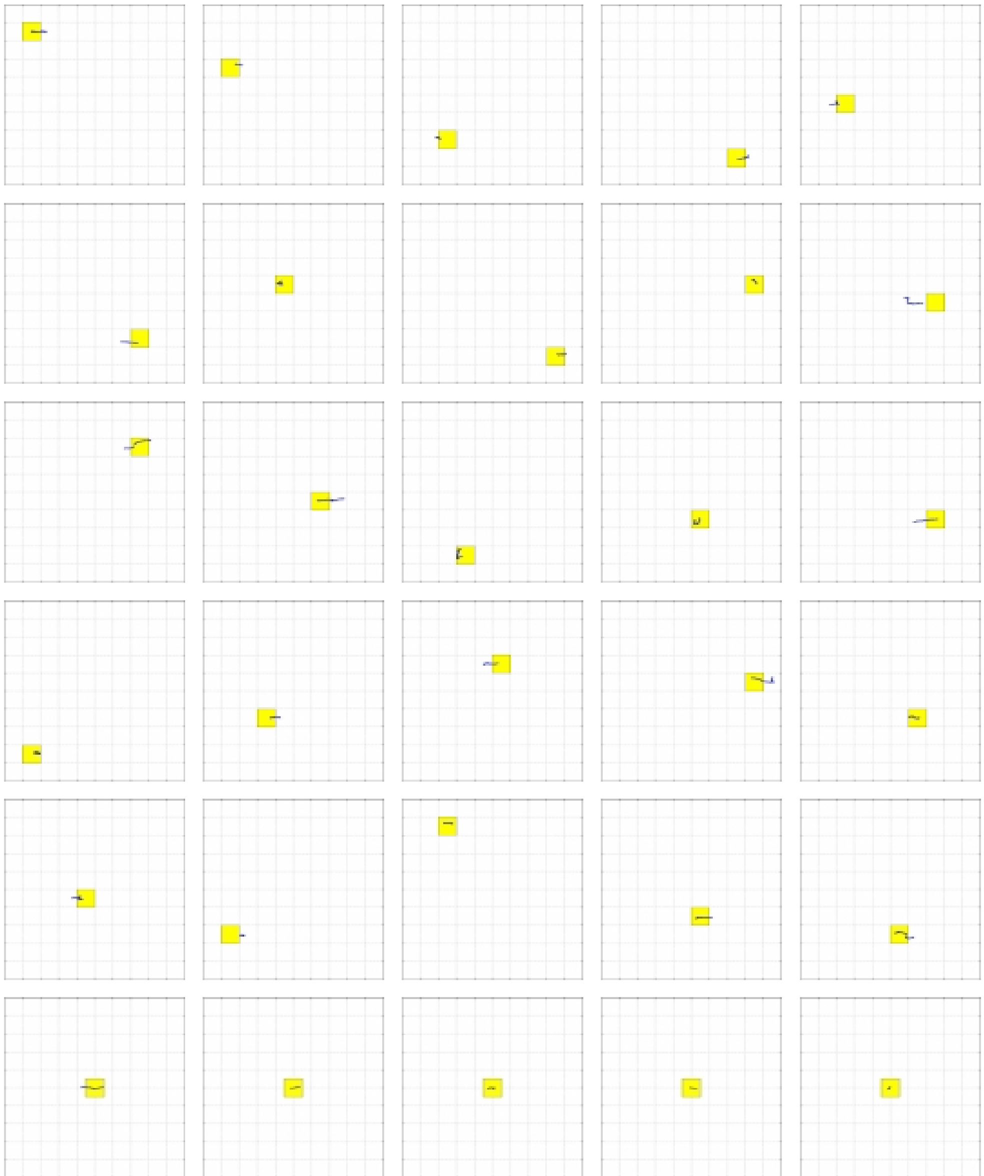


Figure A.13 Test phase of subject DA

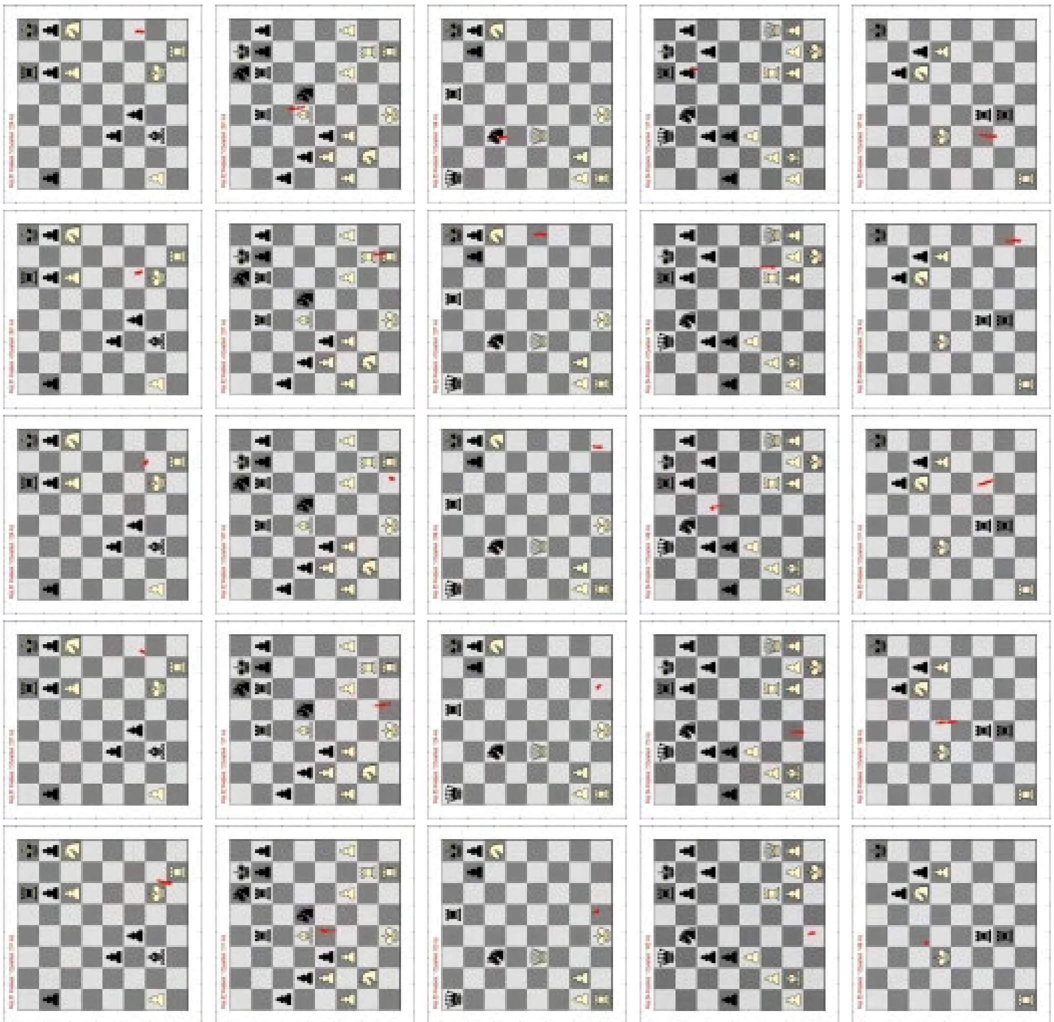


Figure A.14   First five fixations of subject DA on first group of five positions

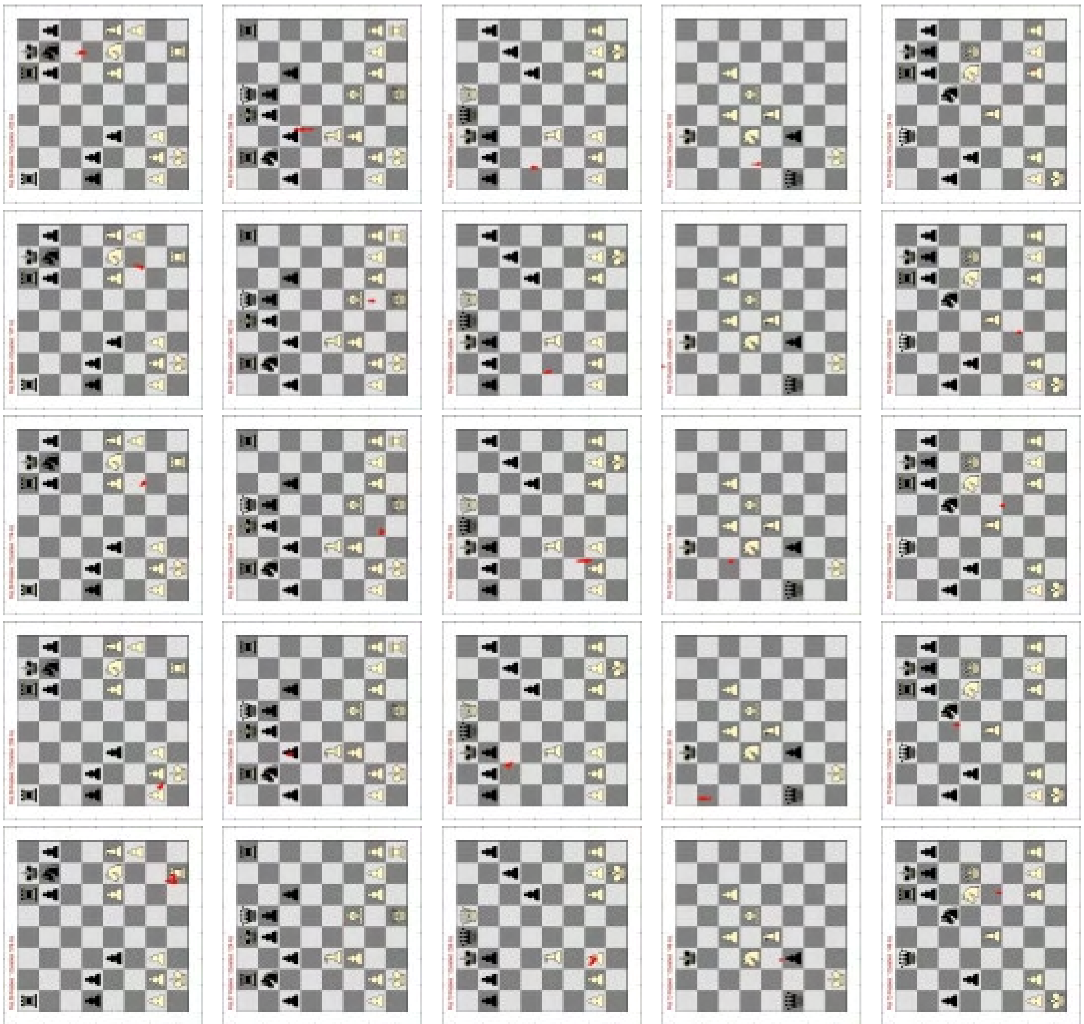


Figure A.15 First five fixations of subject DA on second group of five positions

Figure A.16 First five fixations of subject DA on third group of five positions

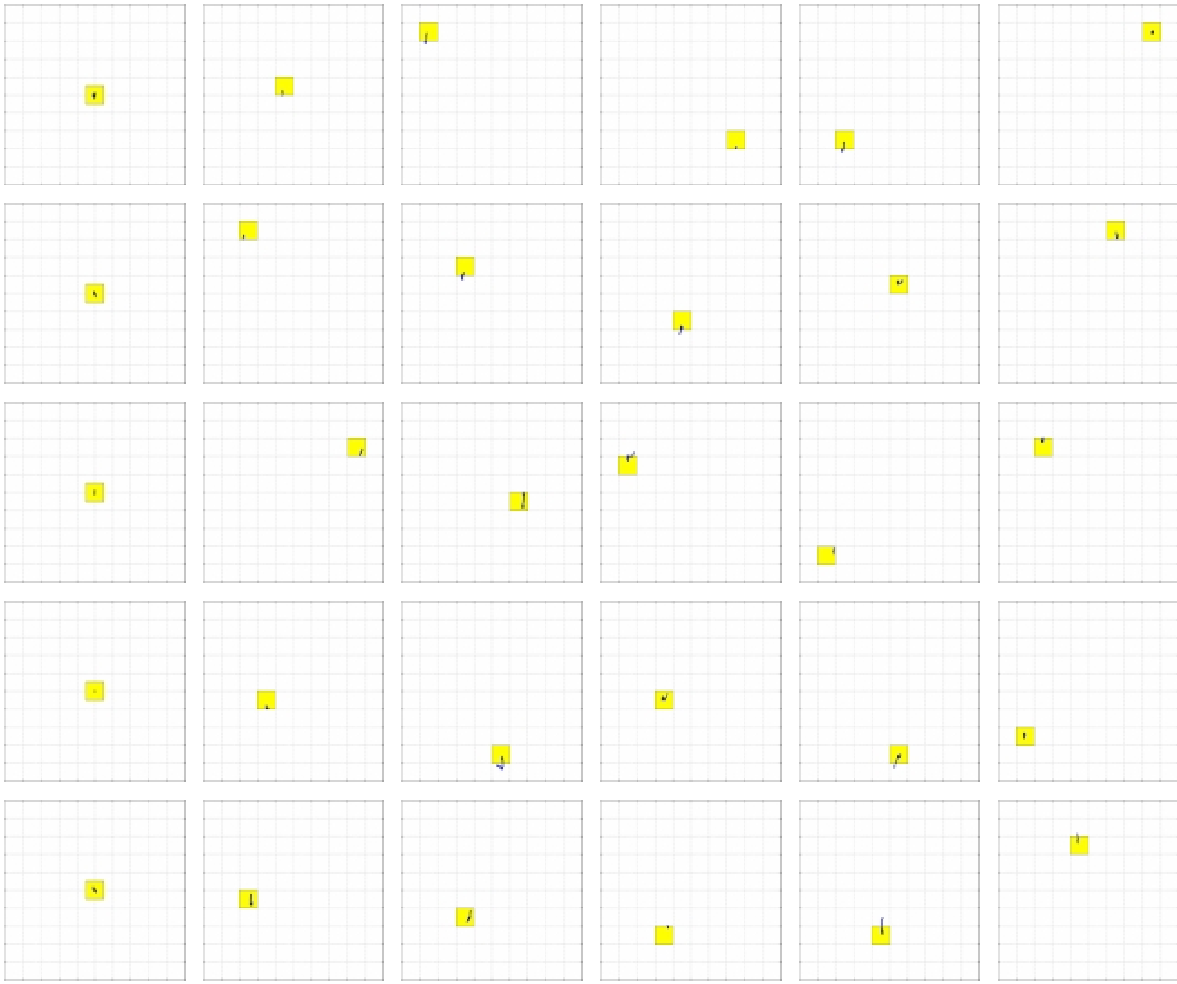


Figure A.17 Test phase of subject EA

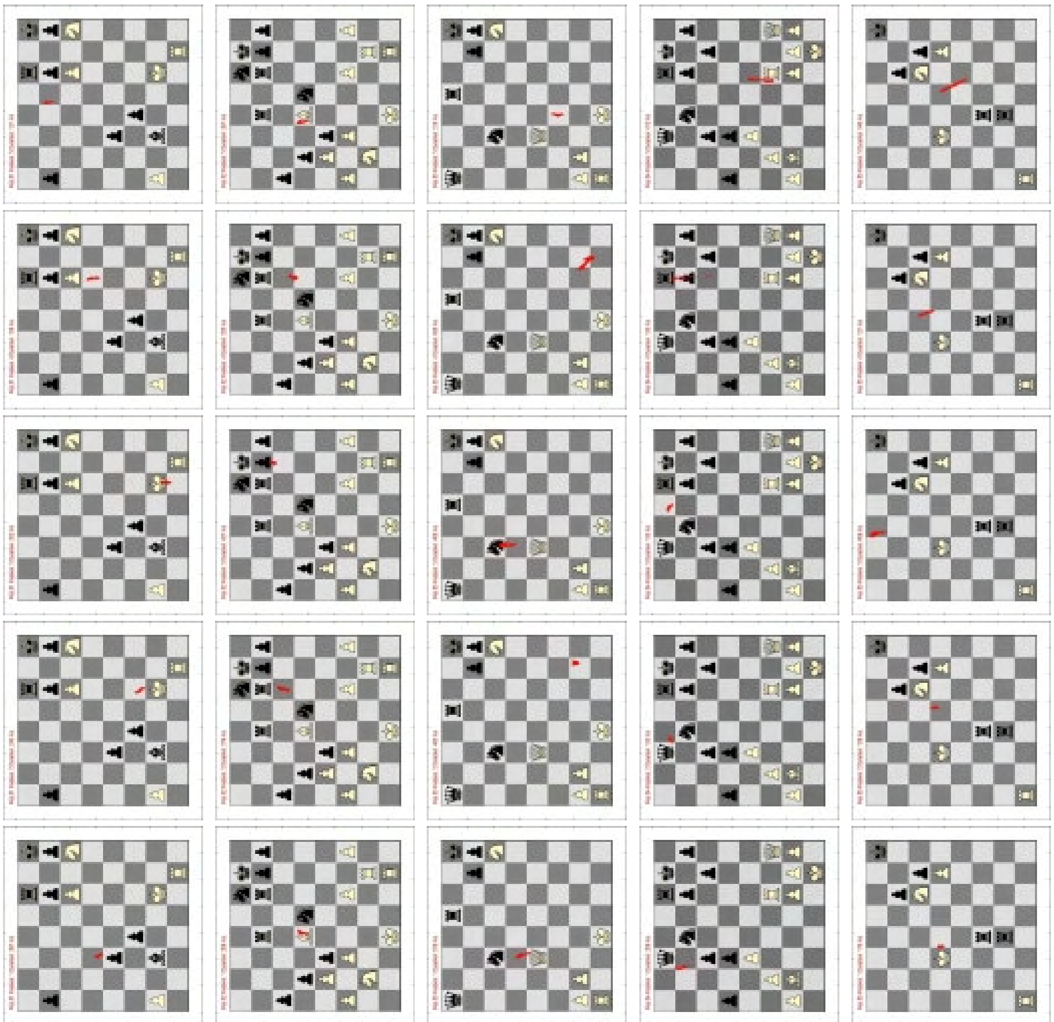


Figure A.18 First five fixations of subject EA on first group of five positions

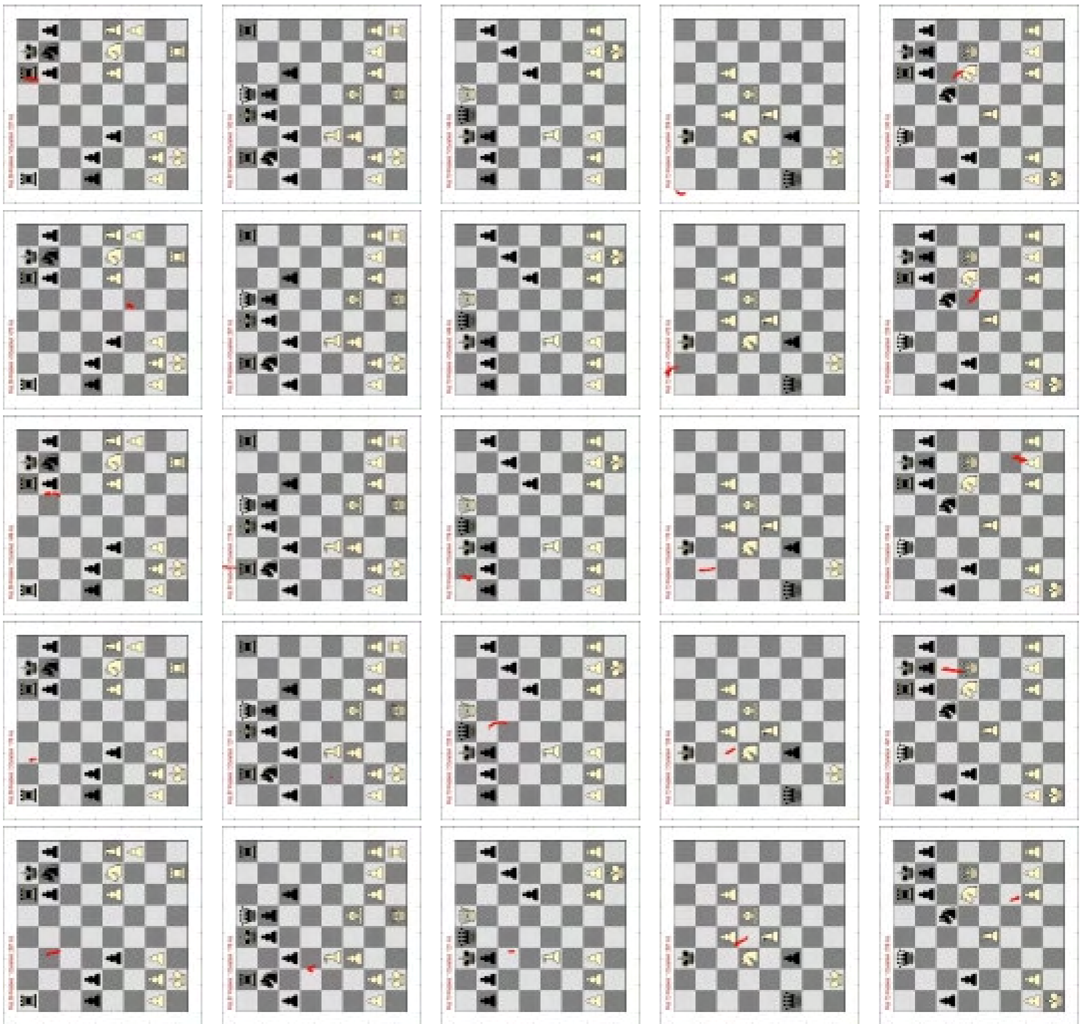


Figure A.19 First five fixations of subject EA on second group of five positions

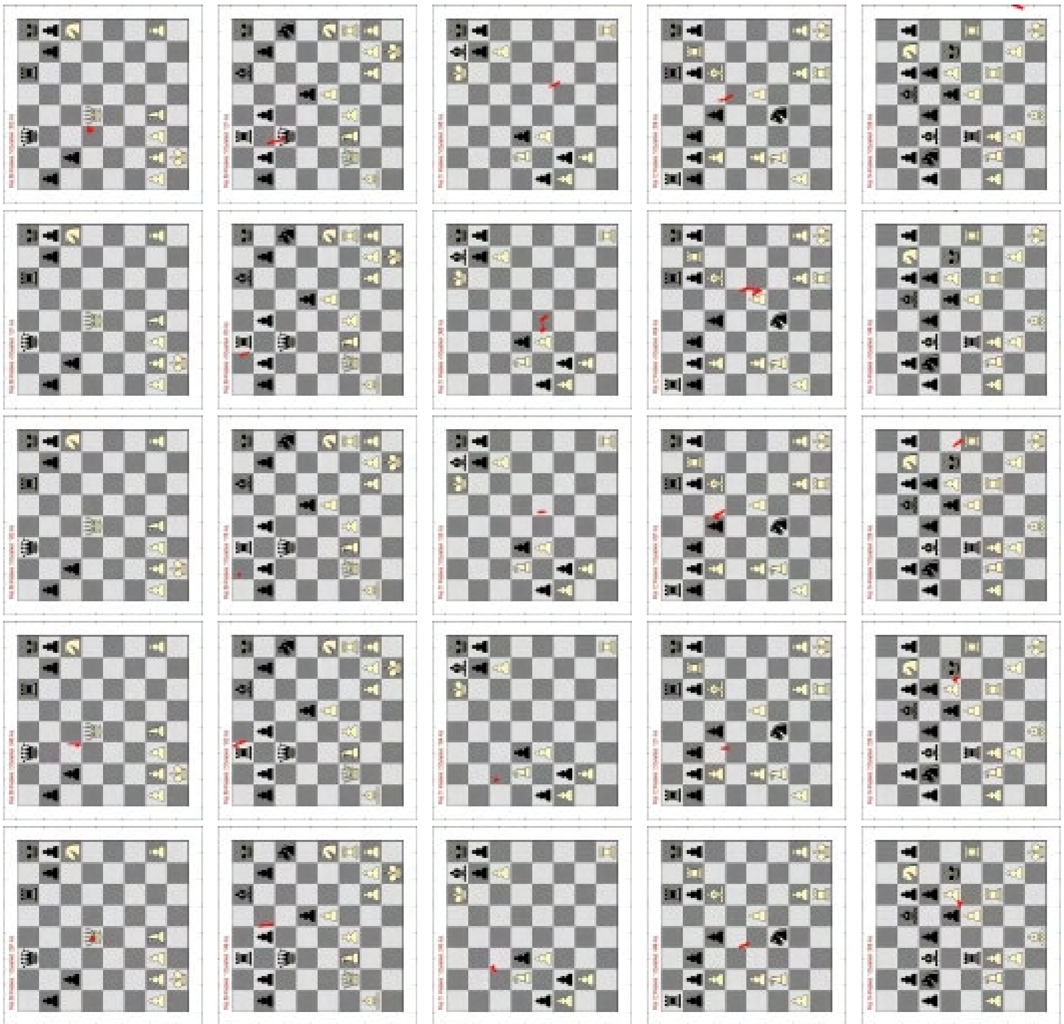


Figure A.20 First five fixations of subject EA on third group of five positions

Figure A.21 Test phase of subject IA

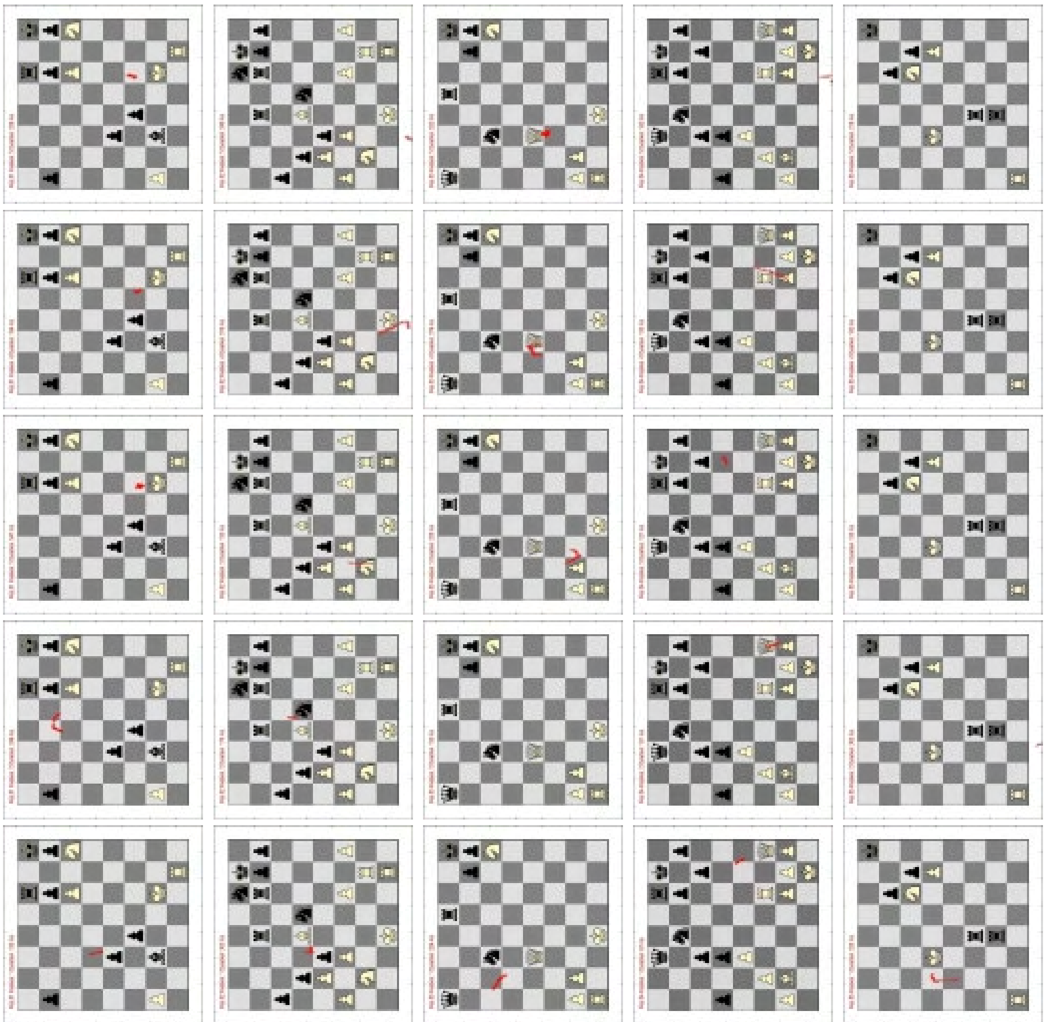


Figure A.22 First five fixations of subject IA on first group of five positions

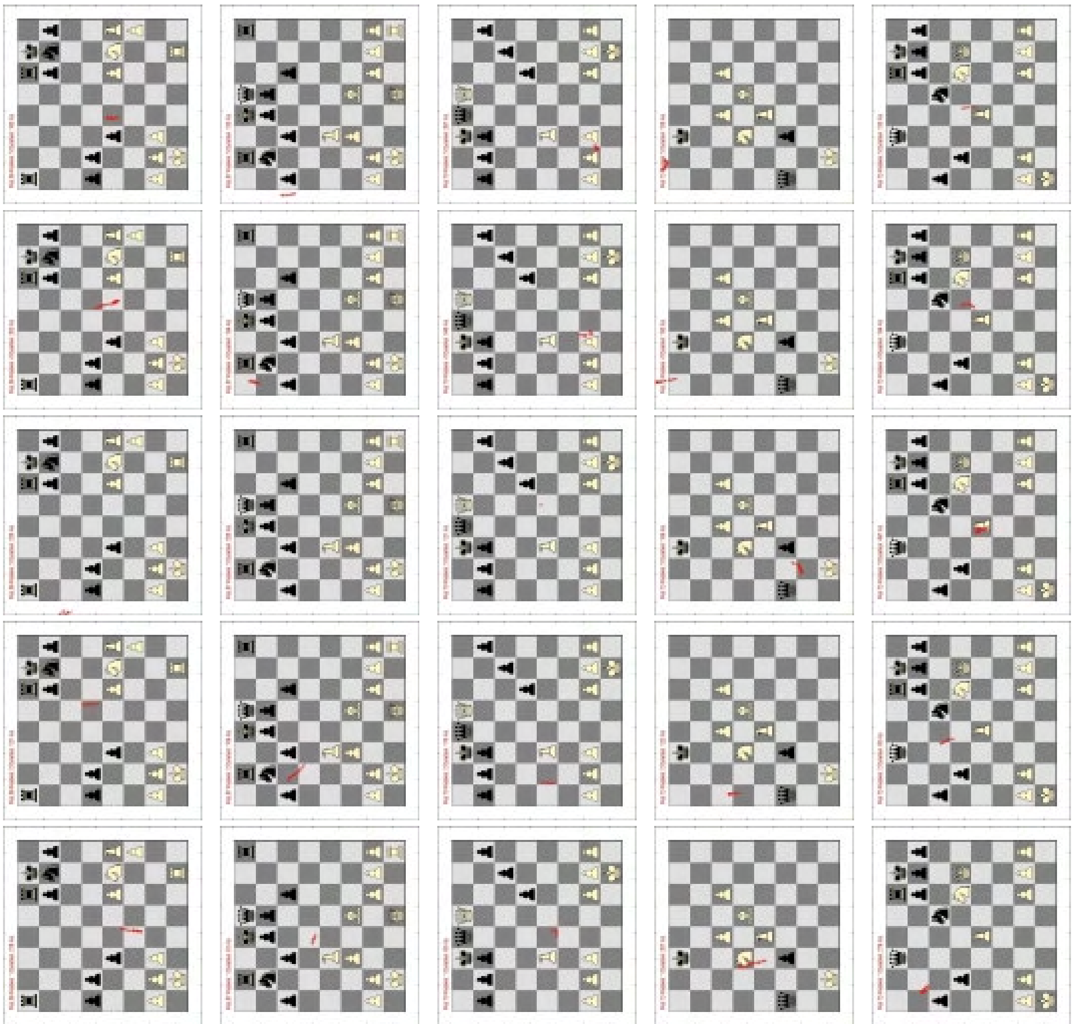


Figure A.23 First five fixations of subject IA on second group of five positions

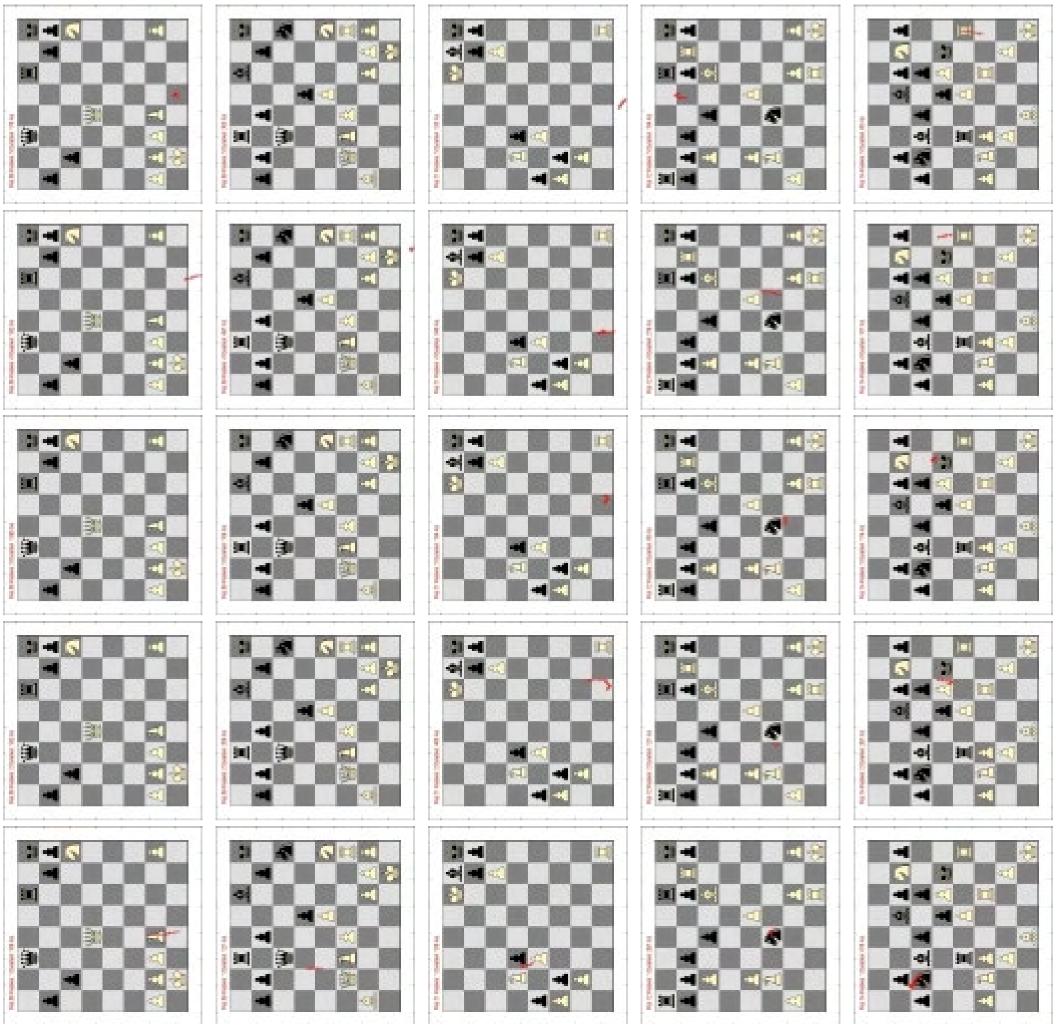


Figure A.24 First five fixations of subject IA on third group of five positions

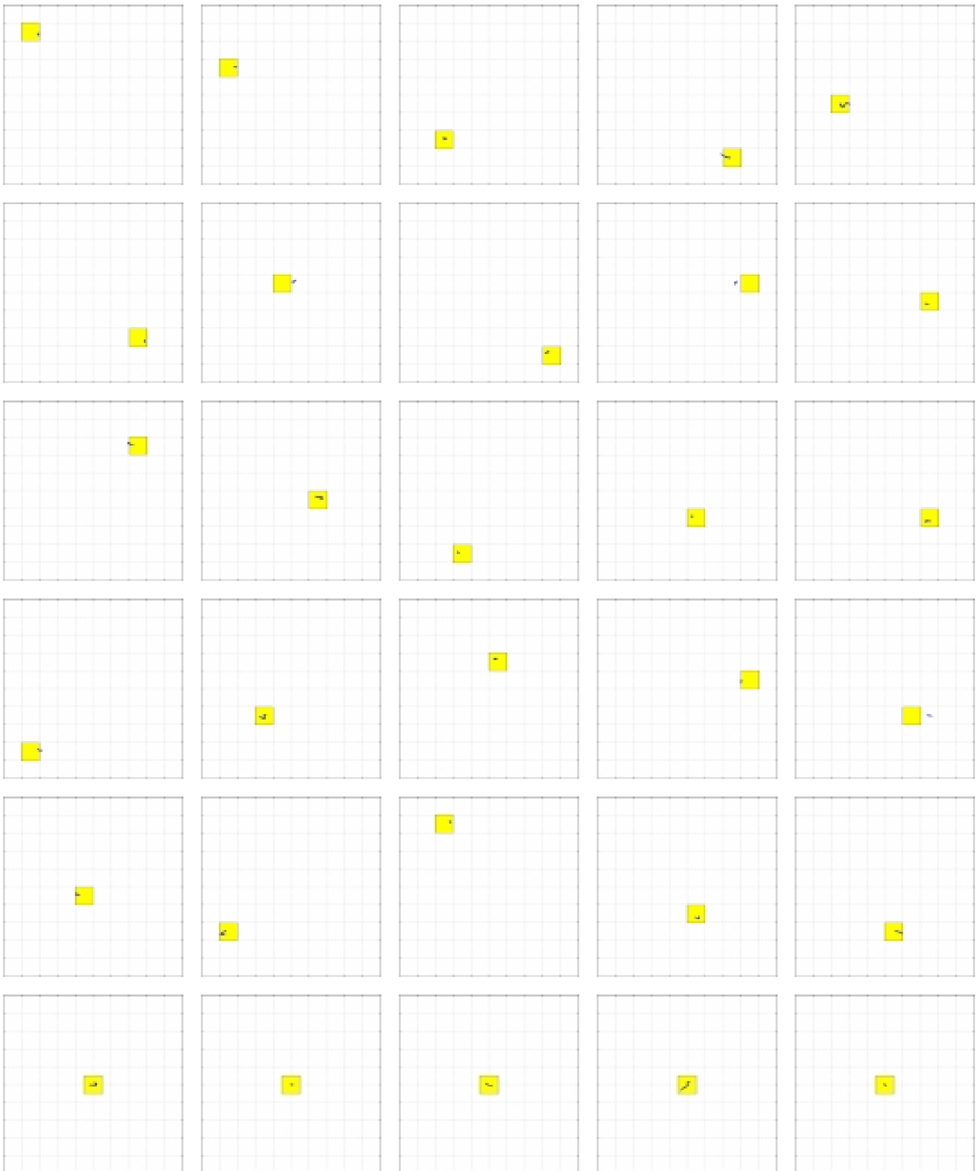


Figure A.25 Test phase of subject MK

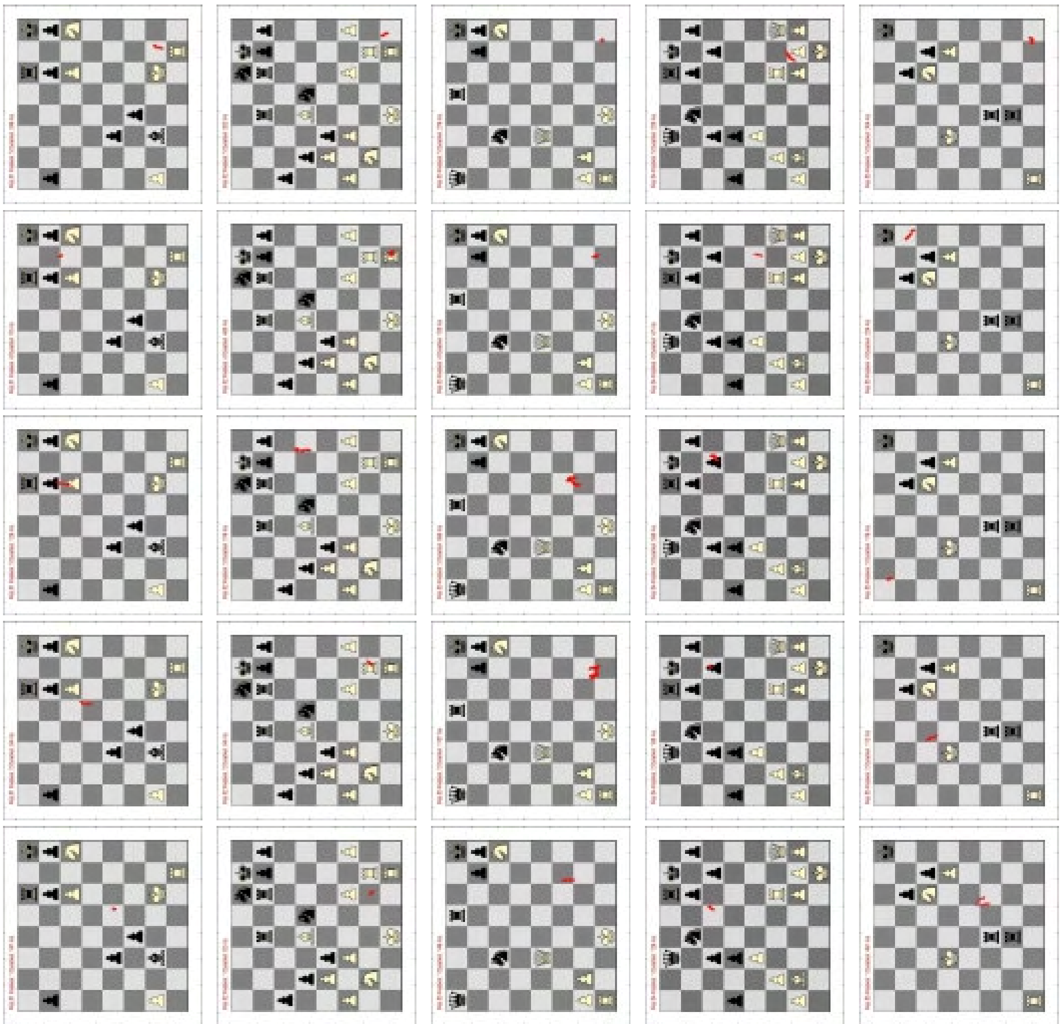
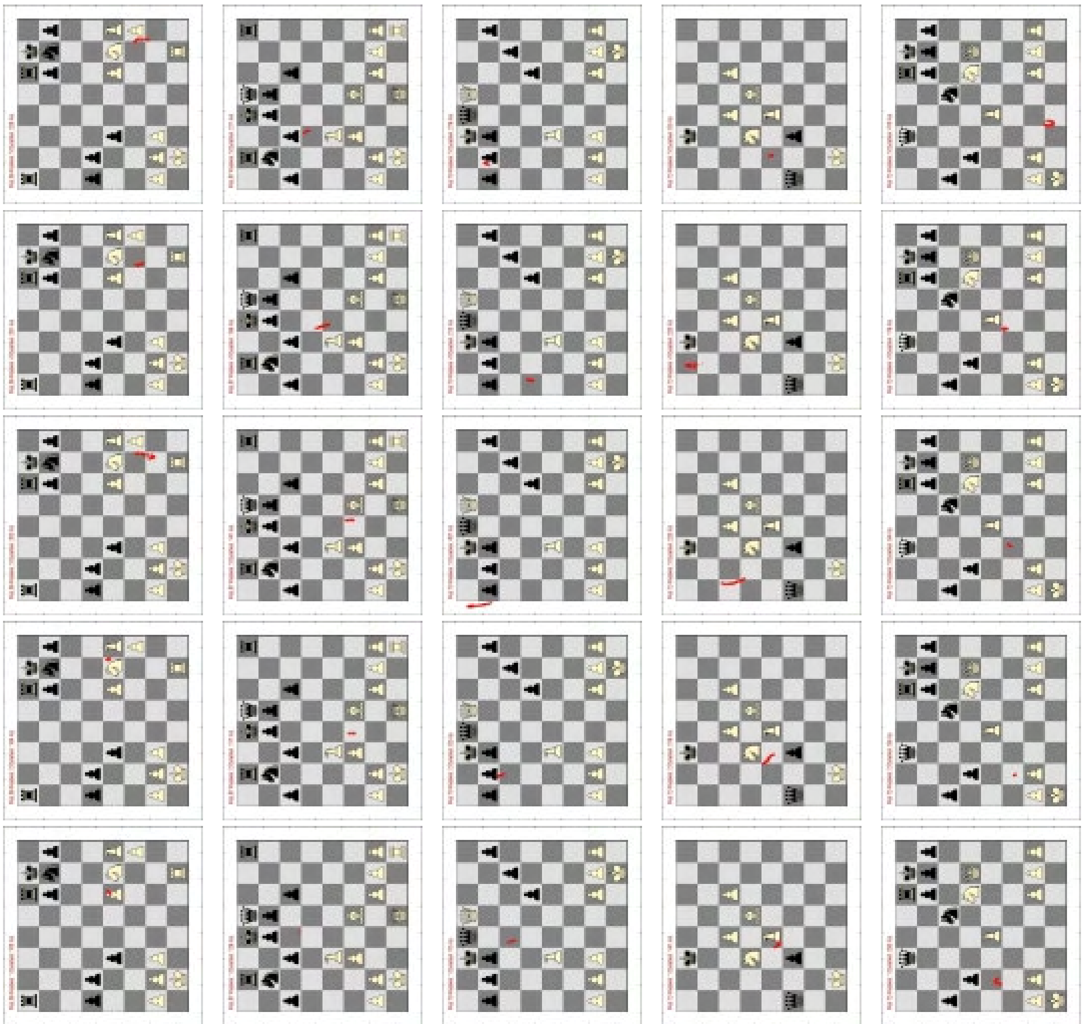


Figure A.26 First five fixations of subject MK on first group of five positions



FigureA.27 First five fixations of subject MK on second group of five positions

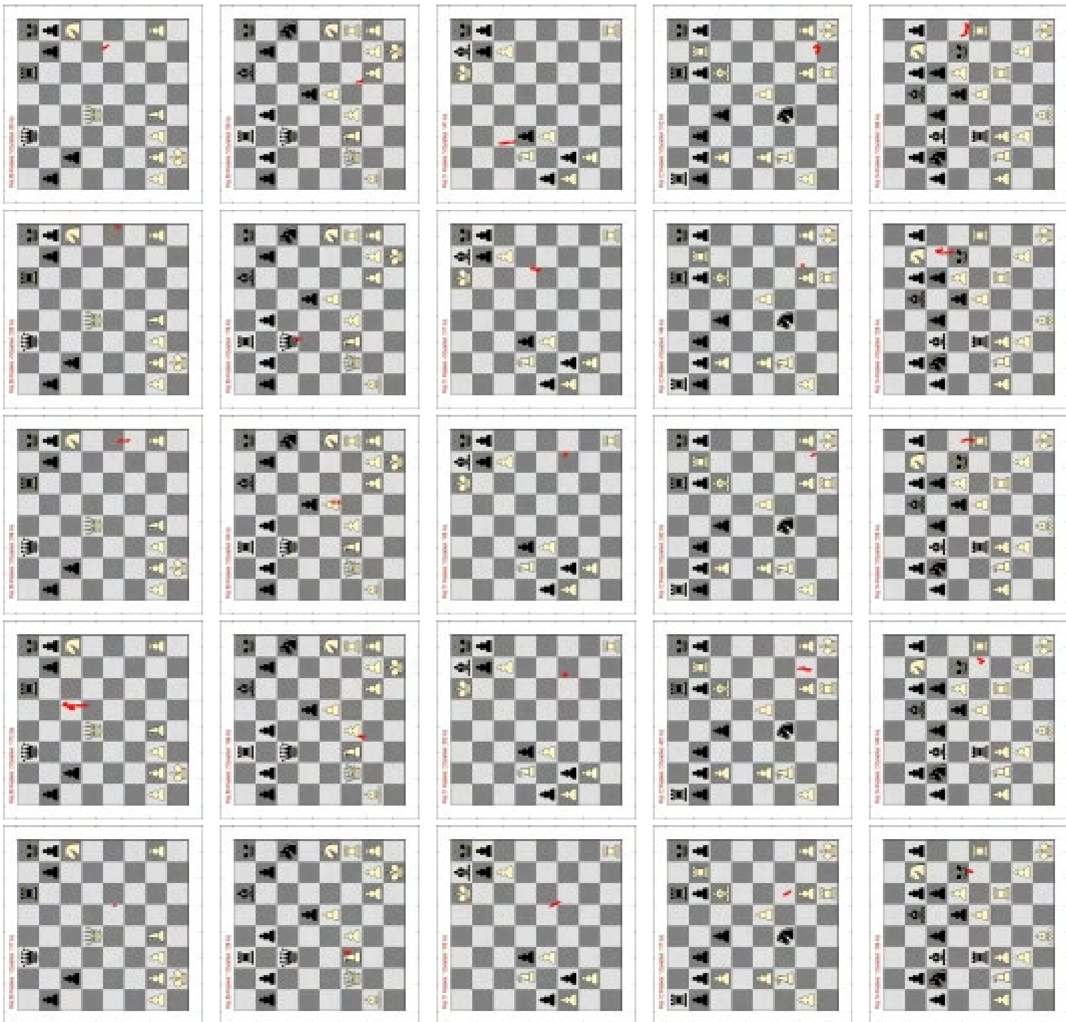


Figure A.28 First five fixations of subject MK on third group of five positions

Figure A.29 Test phase of subject NE

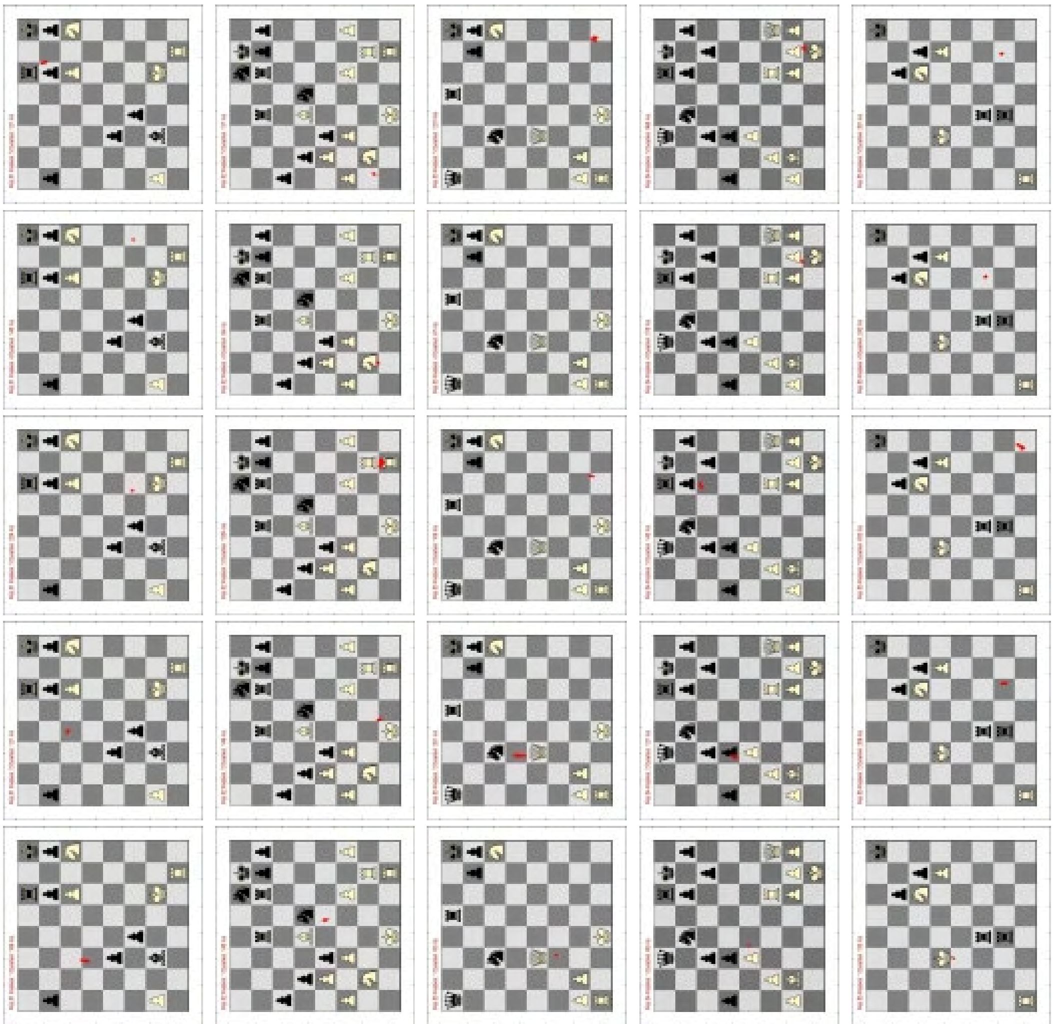


Figure A.30 First five fixations of subject NE on first group of five positions

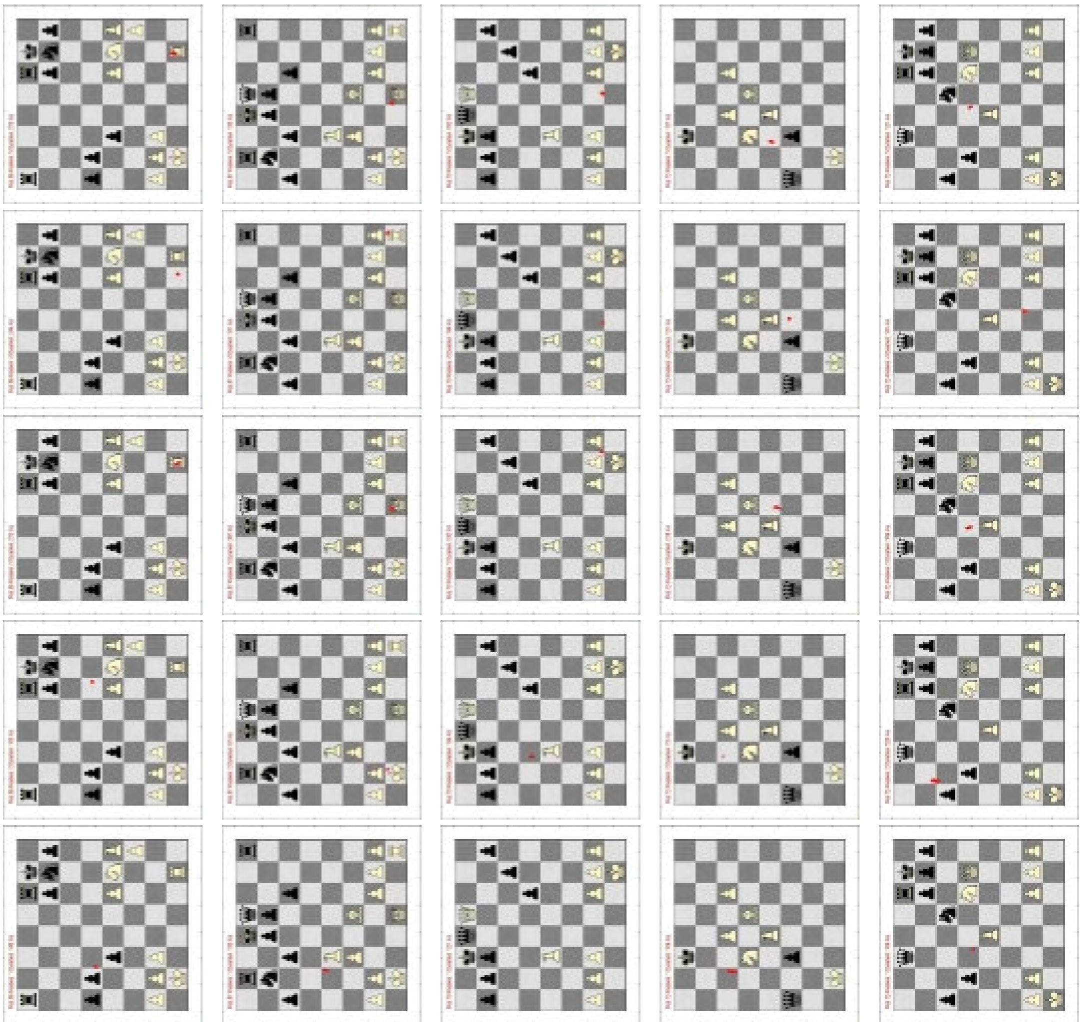


Figure A.31 First five fixations of subject NE on second group of five positions

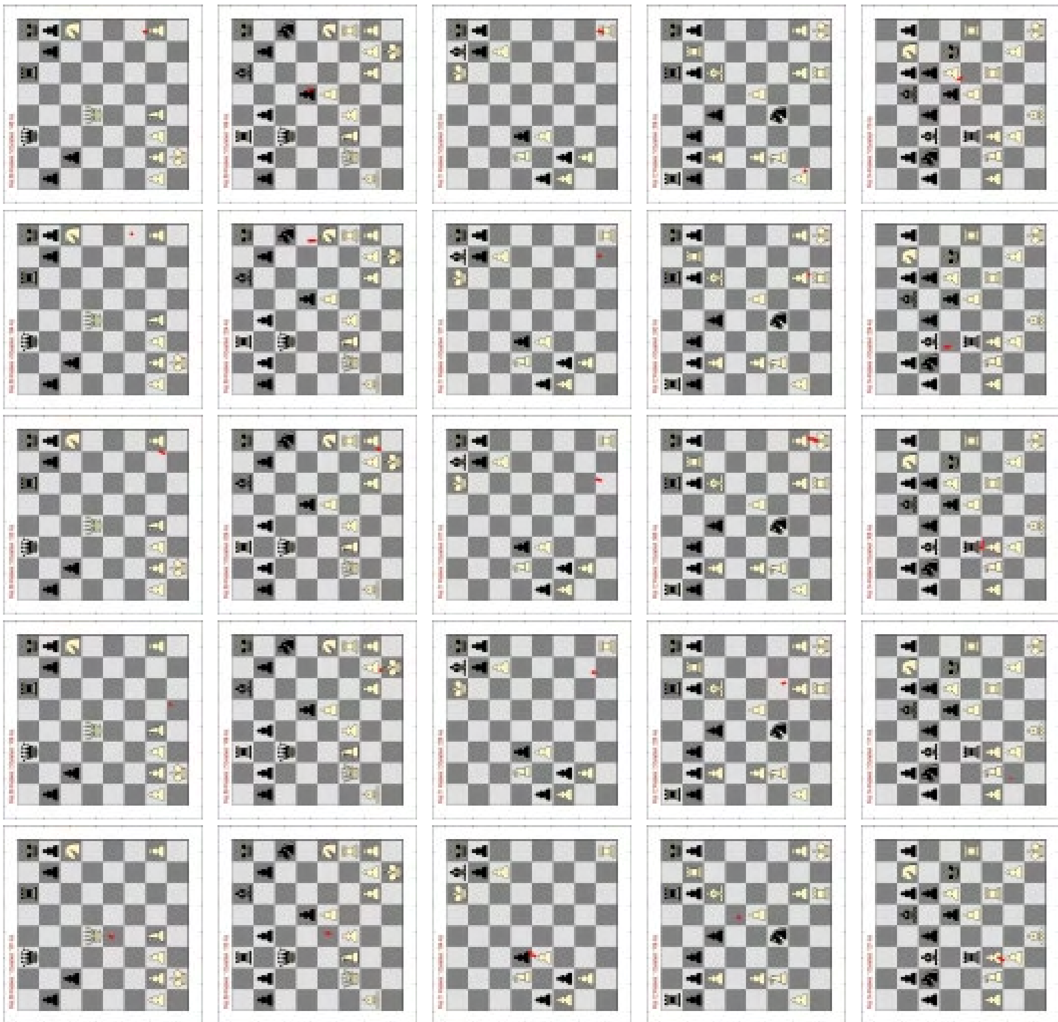


Figure A.32 First five fixations of subject NE on third group of five positions

Figure A.33 Test phase of subject OD

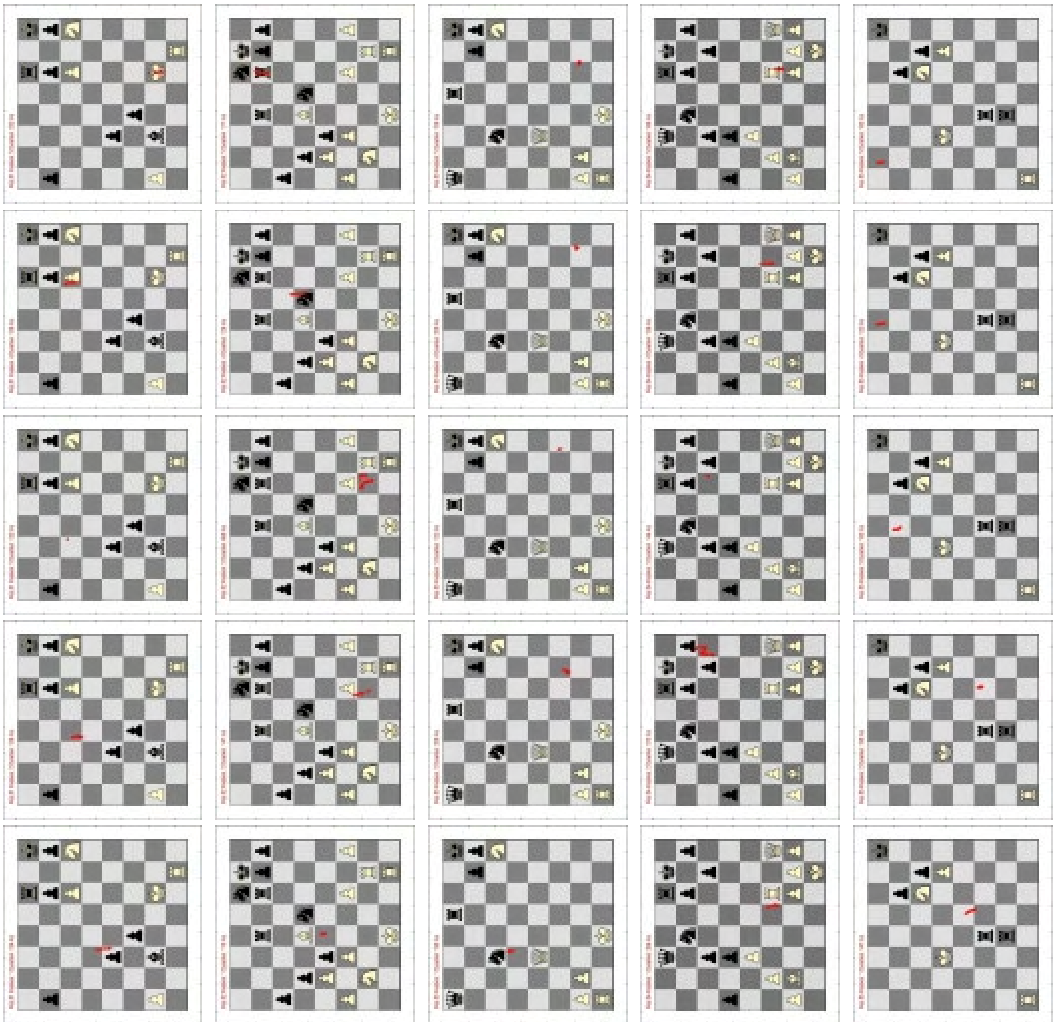


Figure A.34 First five fixations of subject OD on first group of five positions

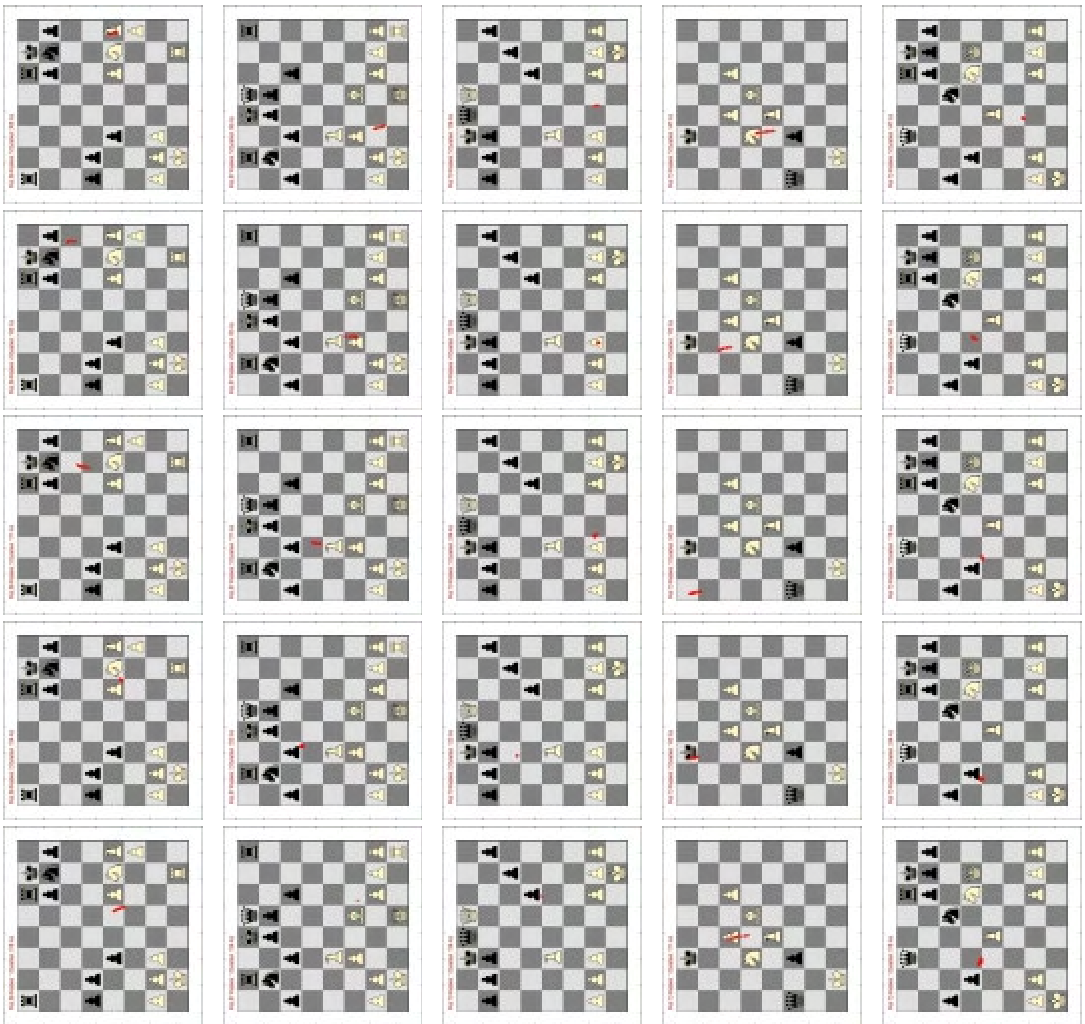


Figure A.35 First five fixations of subject OD on second group of five positions

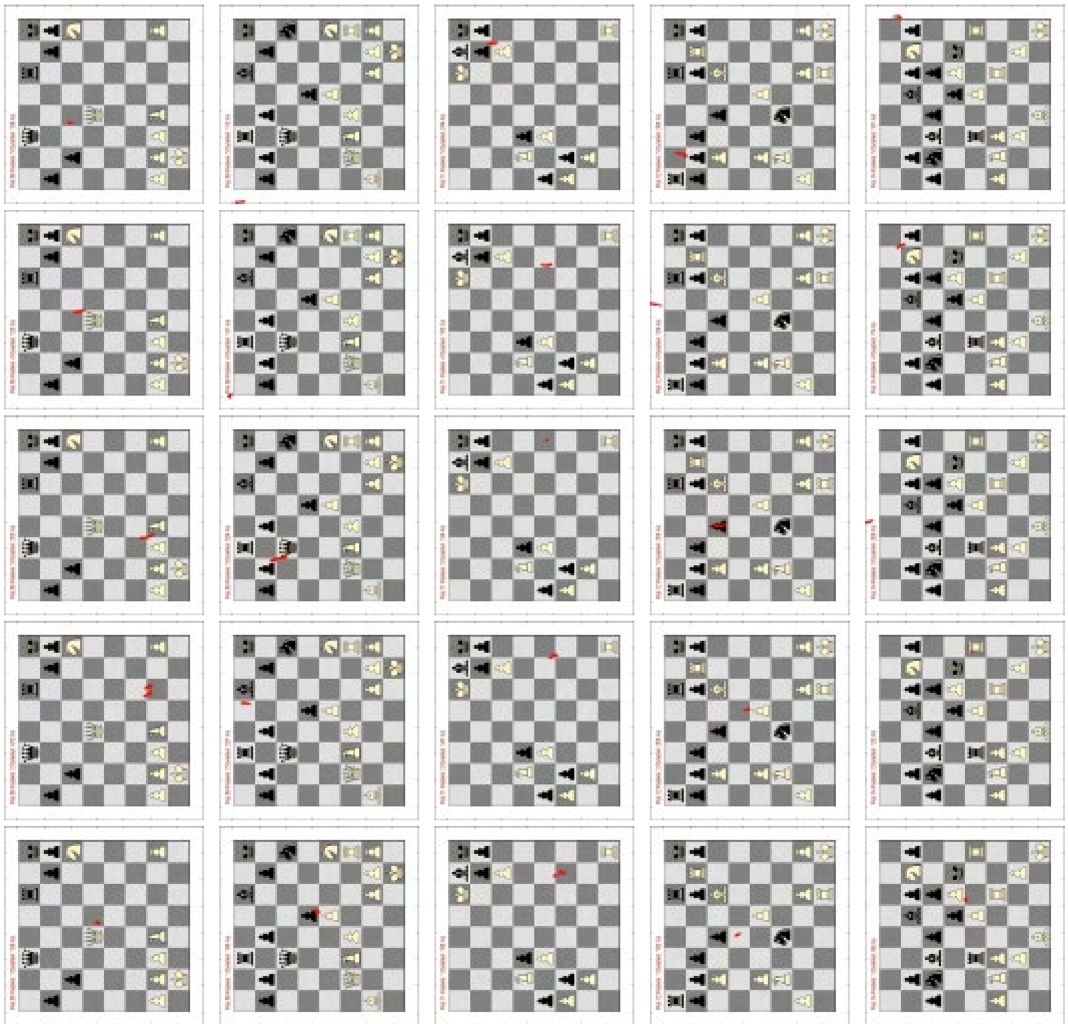


Figure A.36 First five fixations of subject OD on third group of five positions

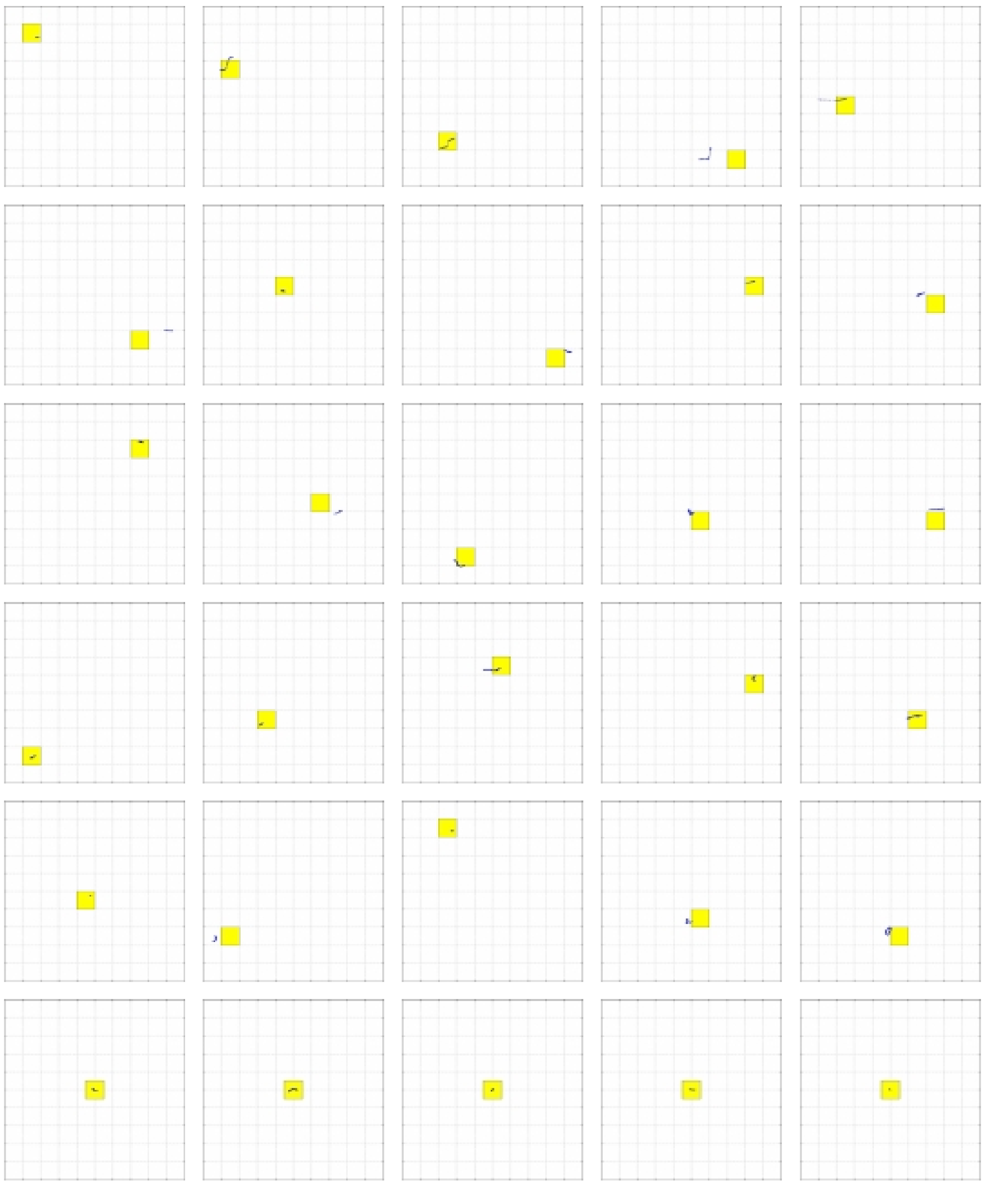


Figure A.37 Test phase of subject OA

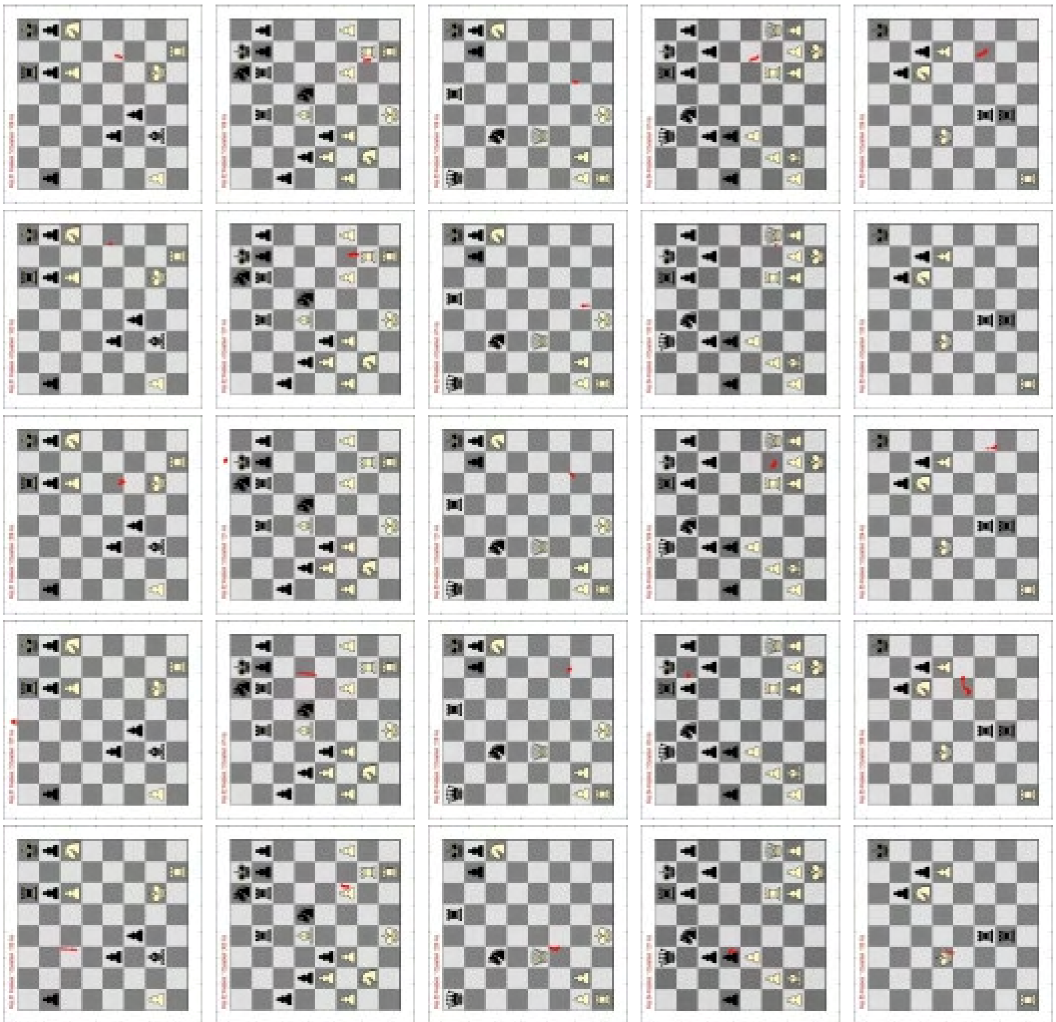


Figure A.38 First five fixations of subject OA on first group of five positions

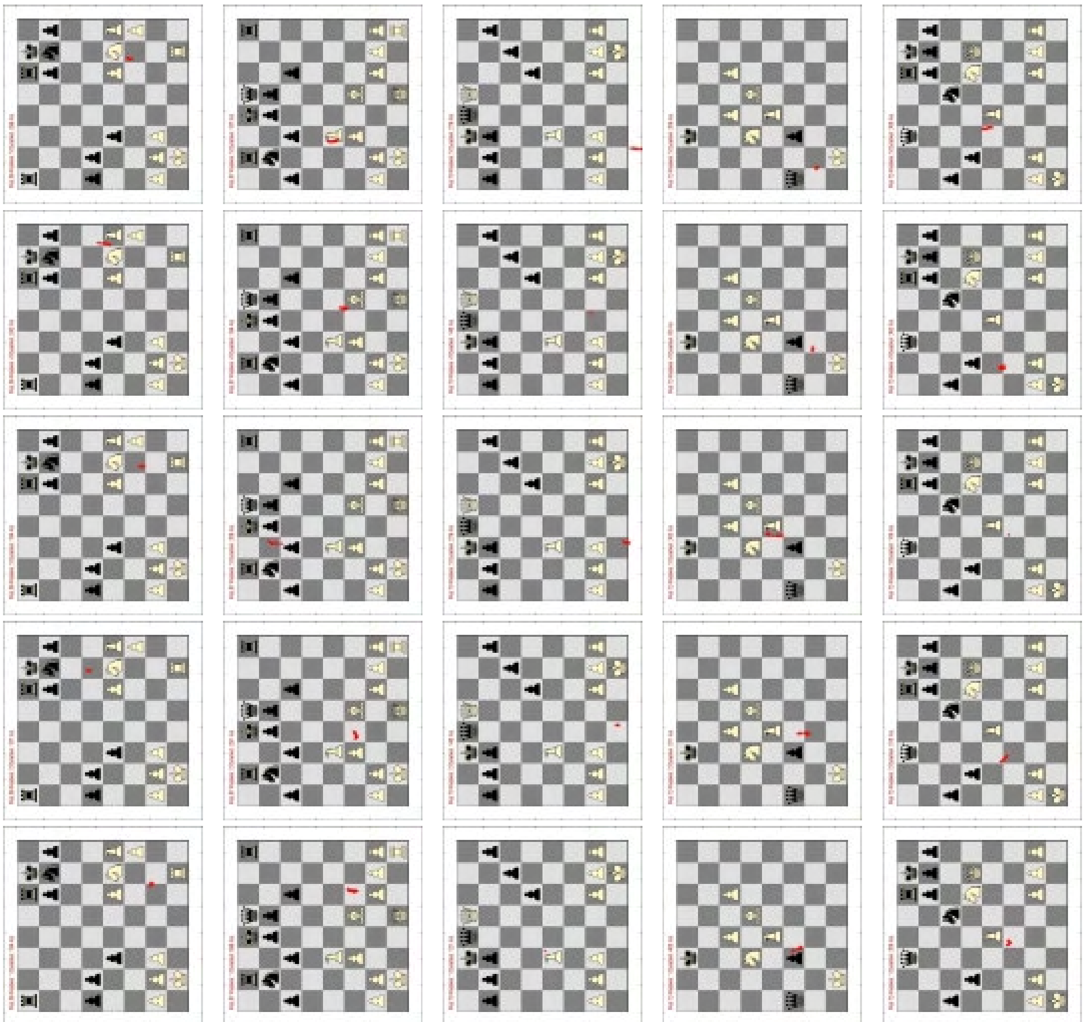


Figure A.39 First five fixations of subject OA on second group of five positions

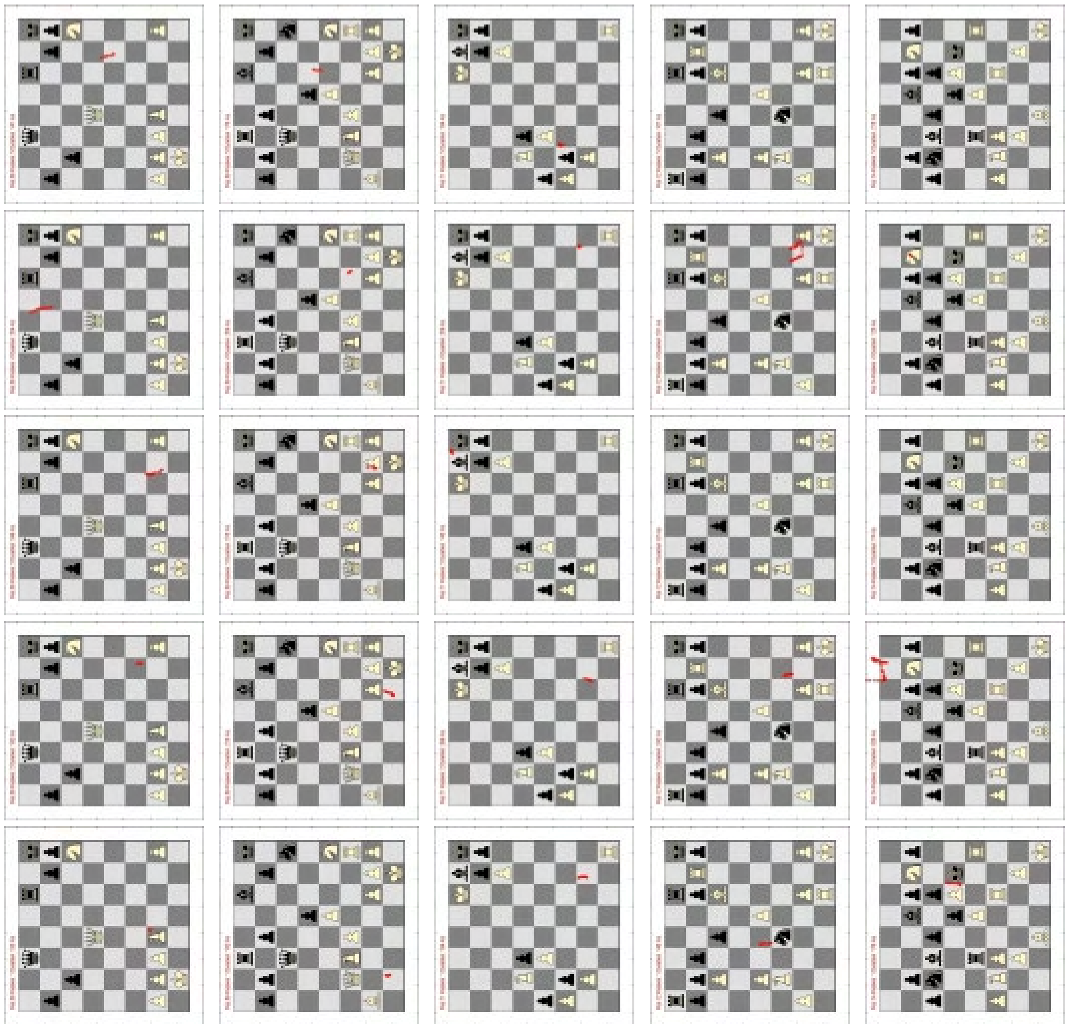


Figure A.40 First five fixations of subject OA on third group of five positions

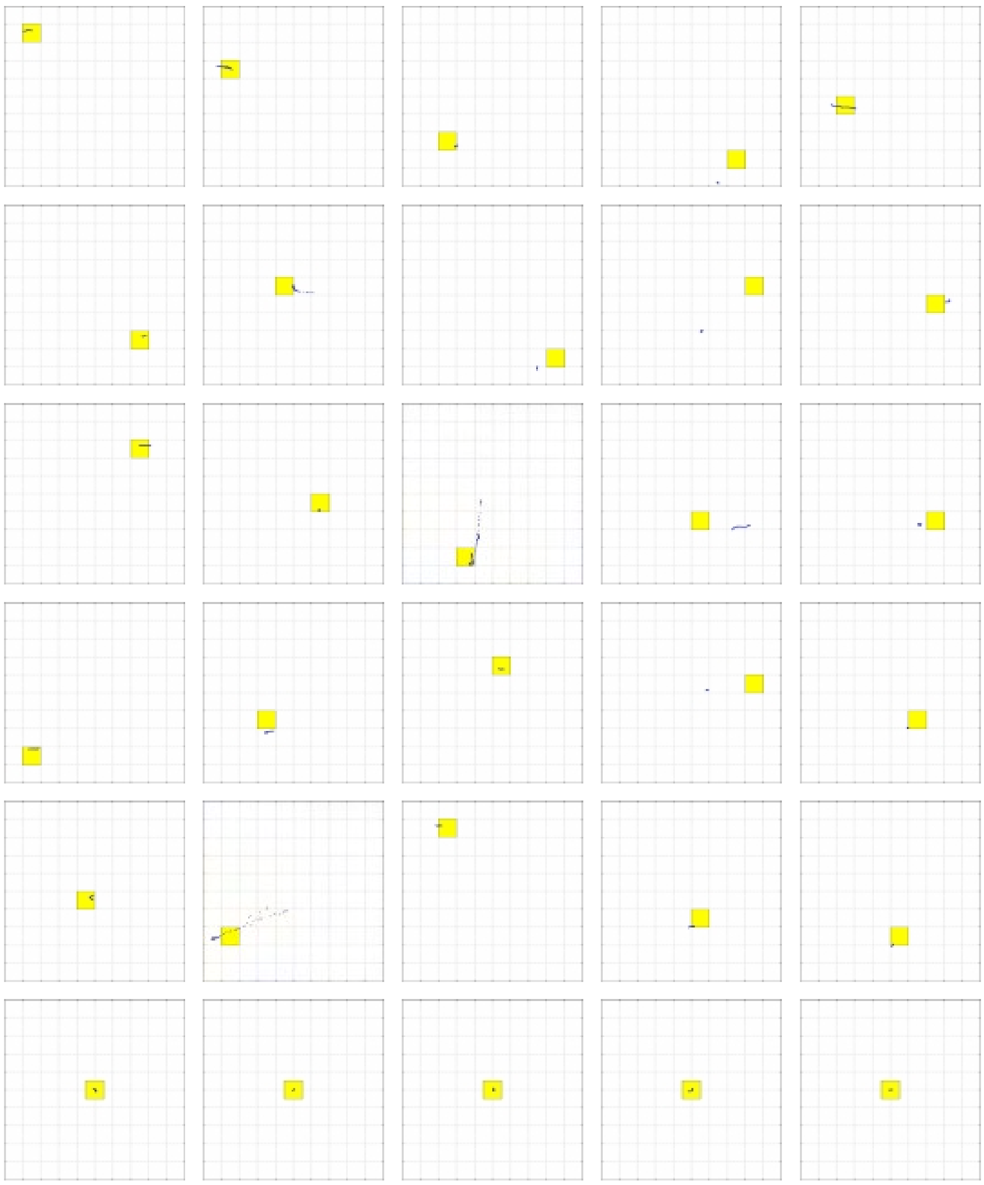


Figure A.41 Test phase of subject EP

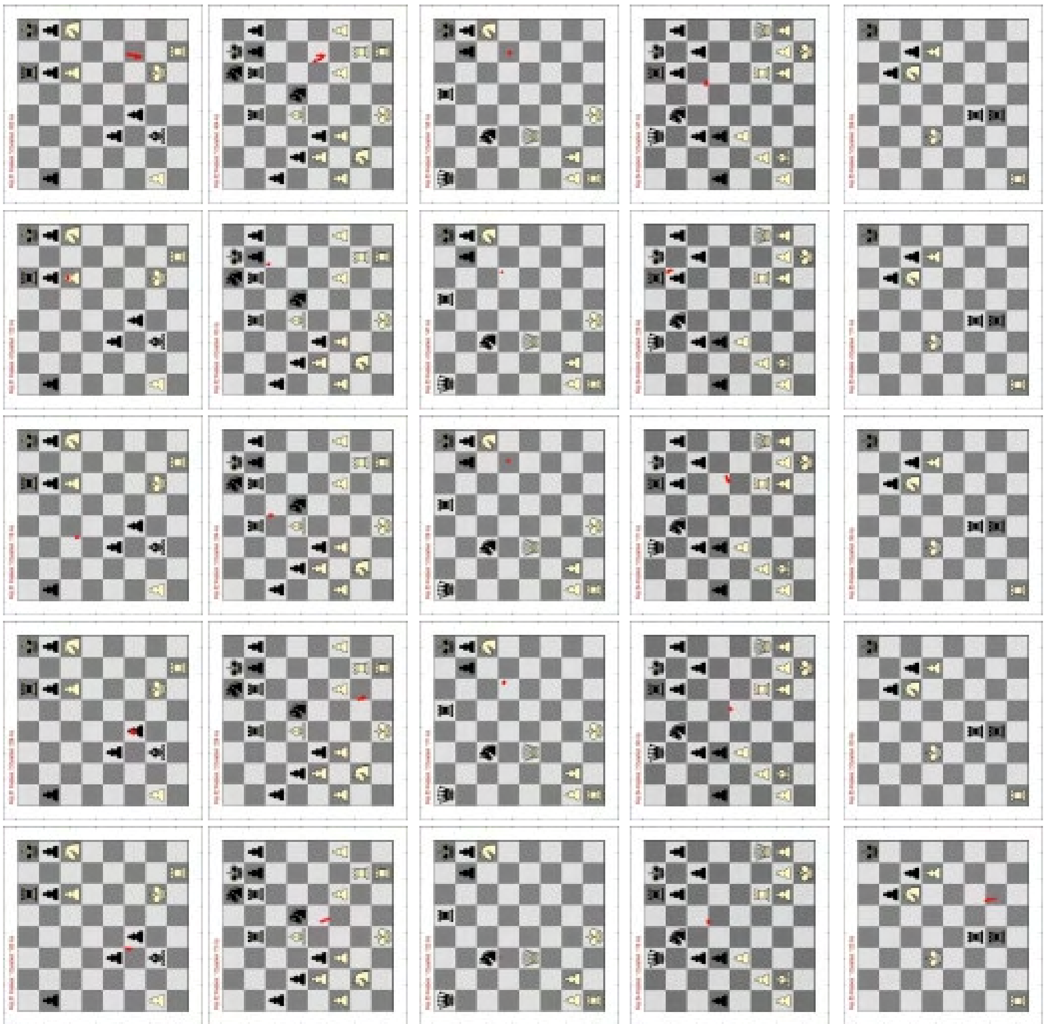


Figure A.42 First five fixations of subject EP on first group of five positions

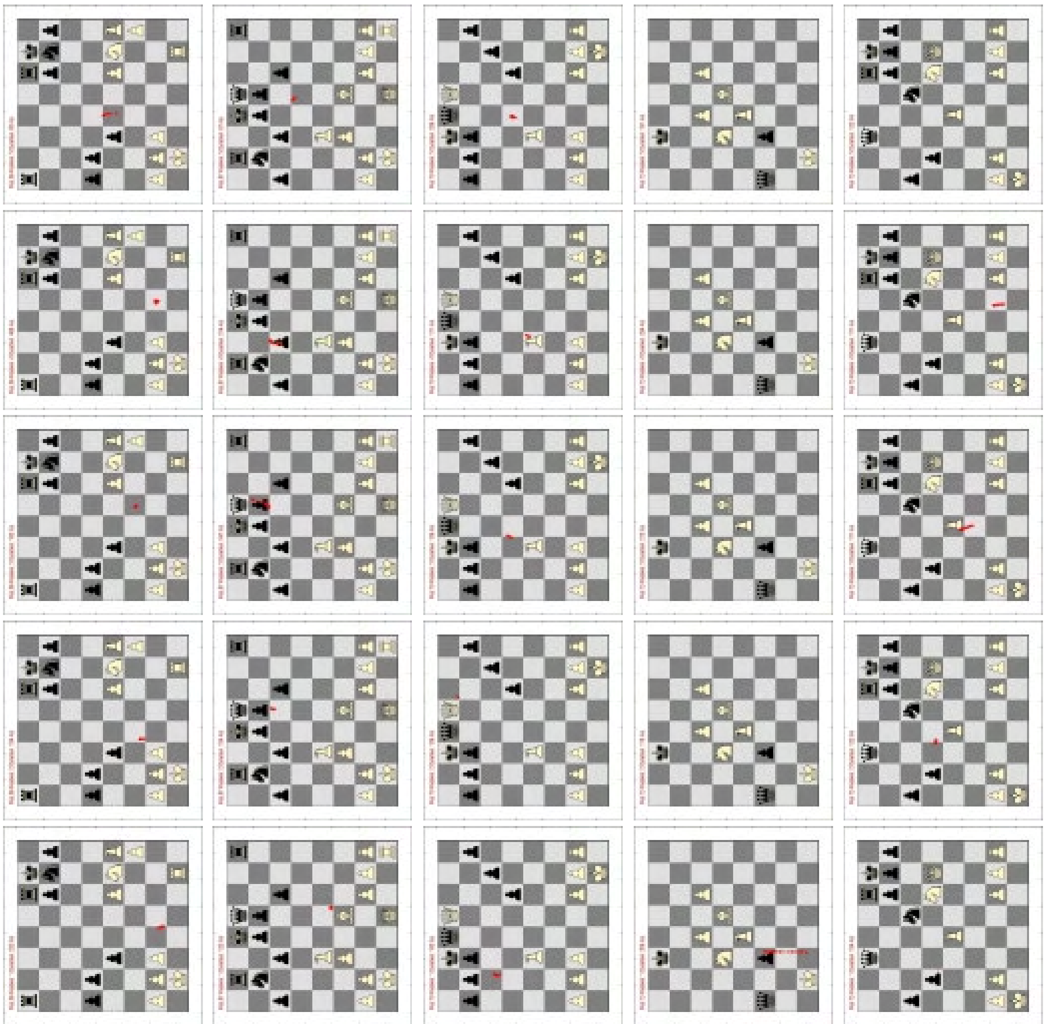


Figure A.43 First five fixations of subject EP on second group of five positions

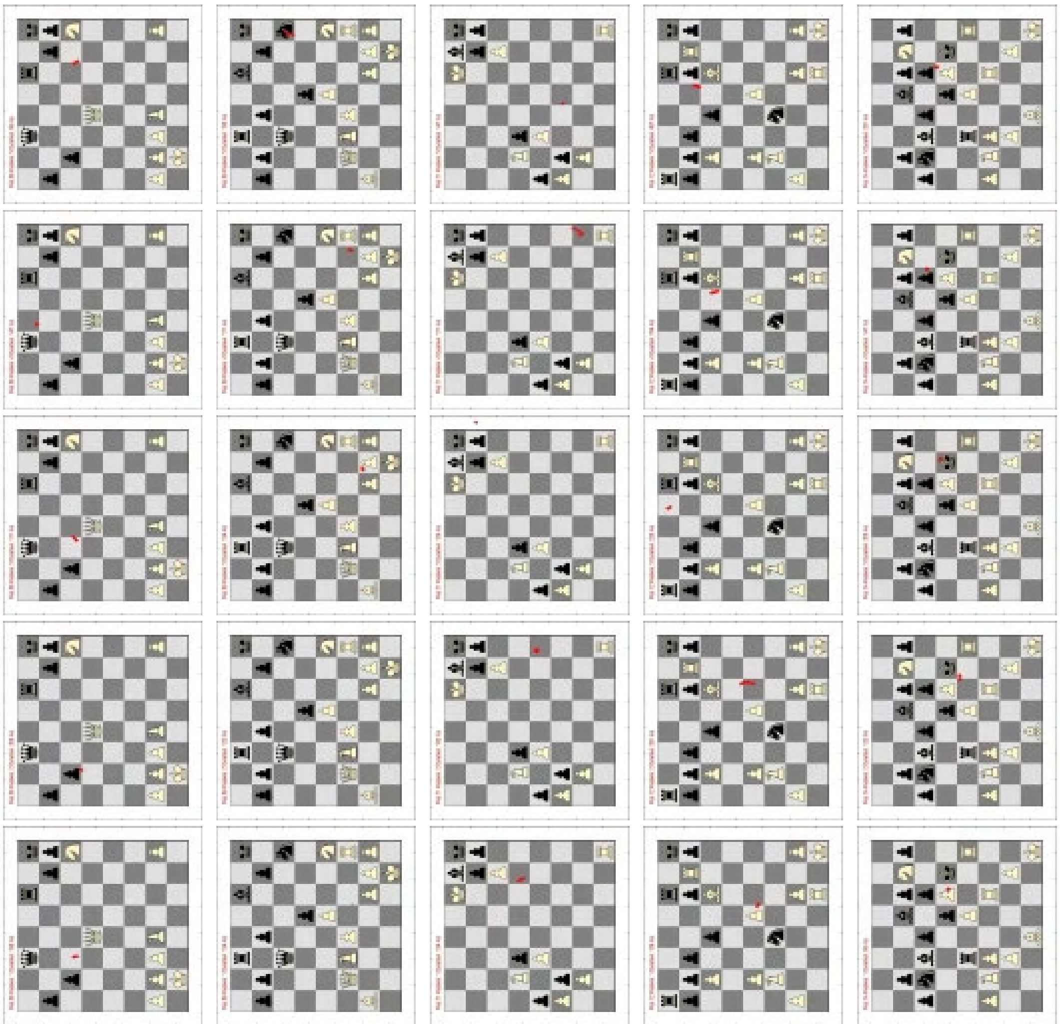


Figure A.44 First five fixations of subject EP on third group of five positions

Figure A.45   Test phase of subject RS

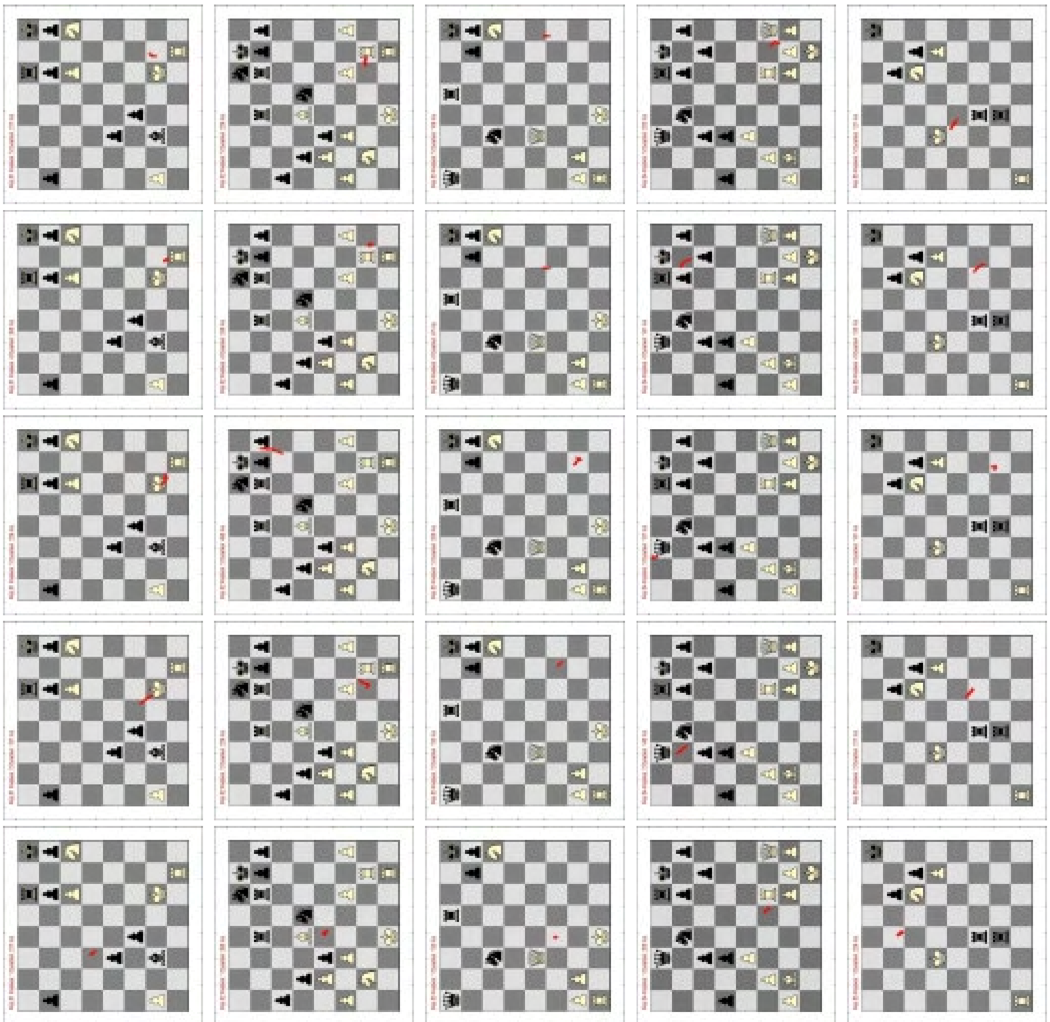


Figure A.46 First five fixations of subject RS on first group of five positions

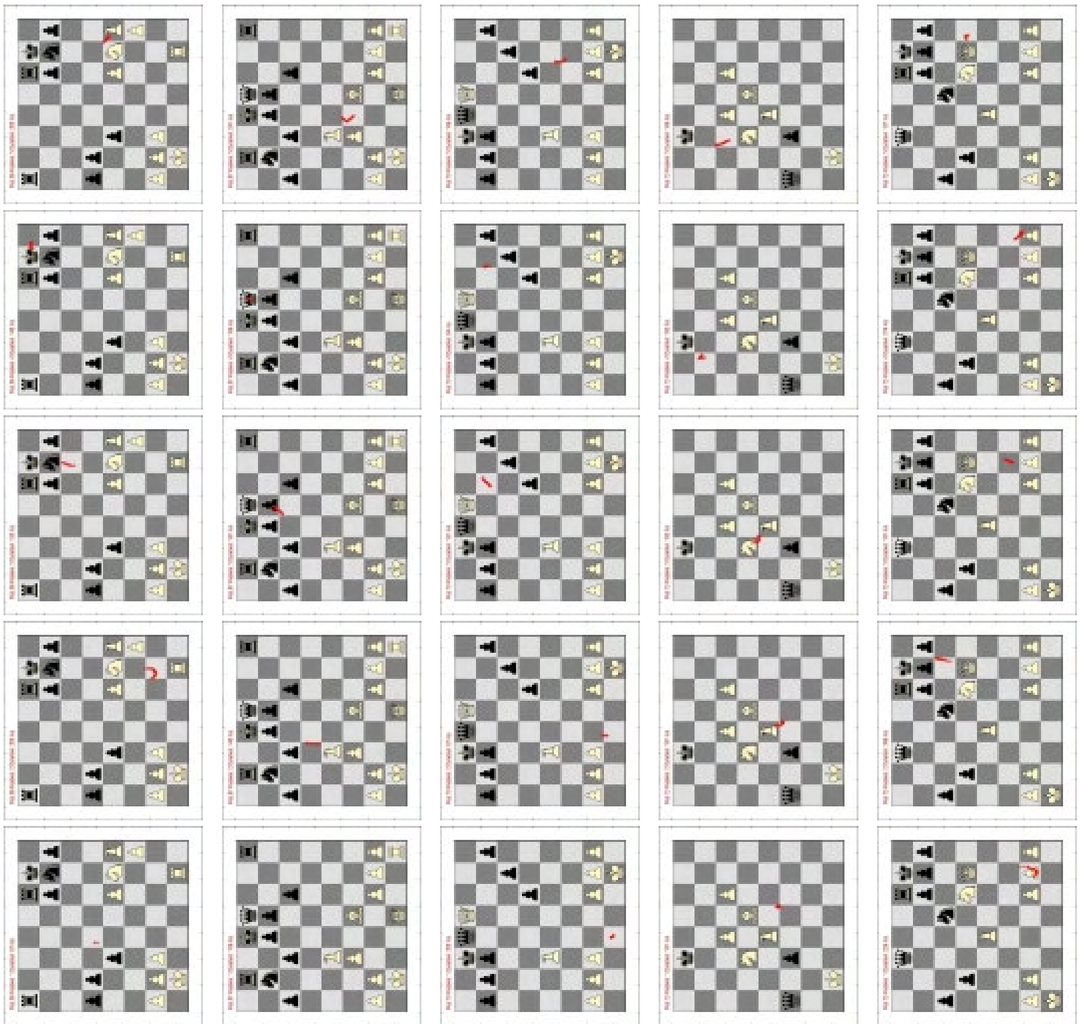


Figure A.47 First five fixations of subject RS on second group of five positions

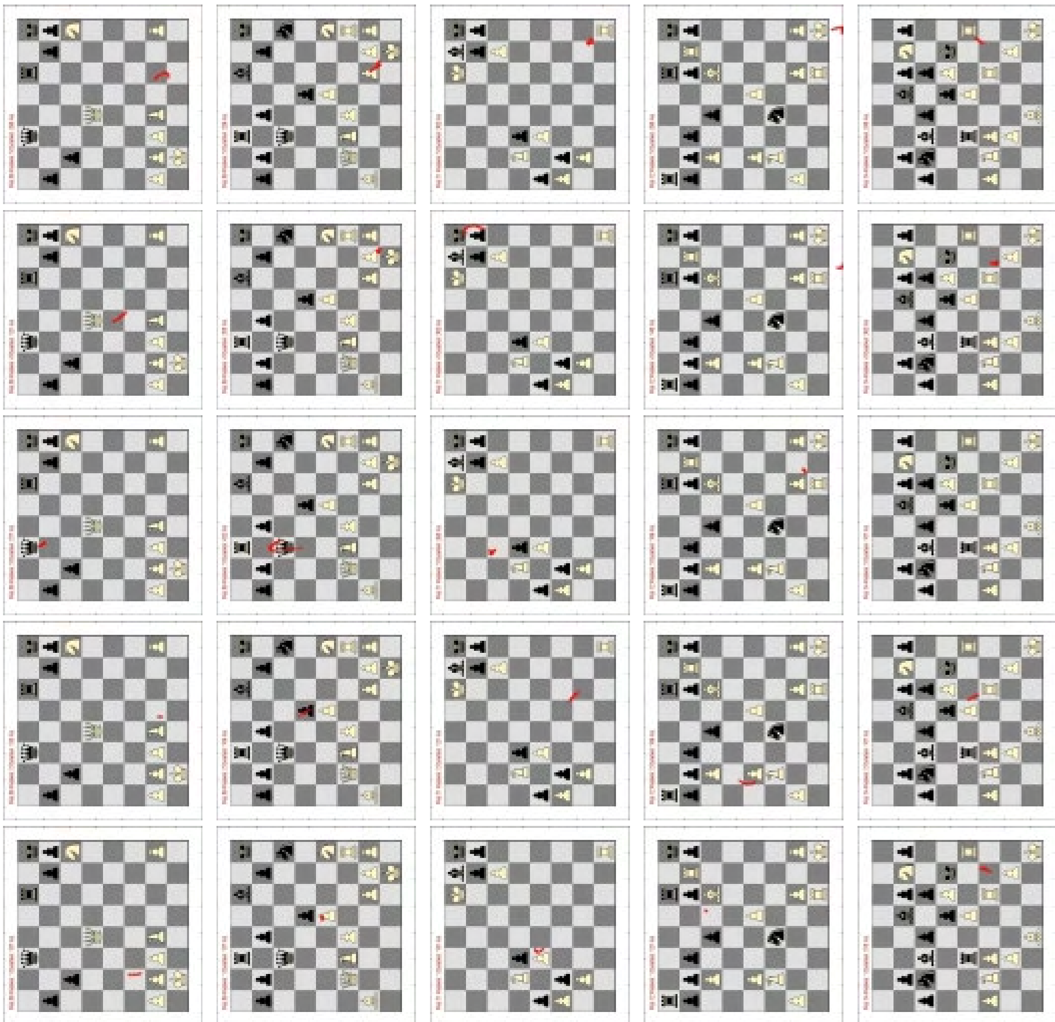


Figure A.48 First five fixations of subject RS on third group of five positions

Figure A.49   Test phase of subject SG

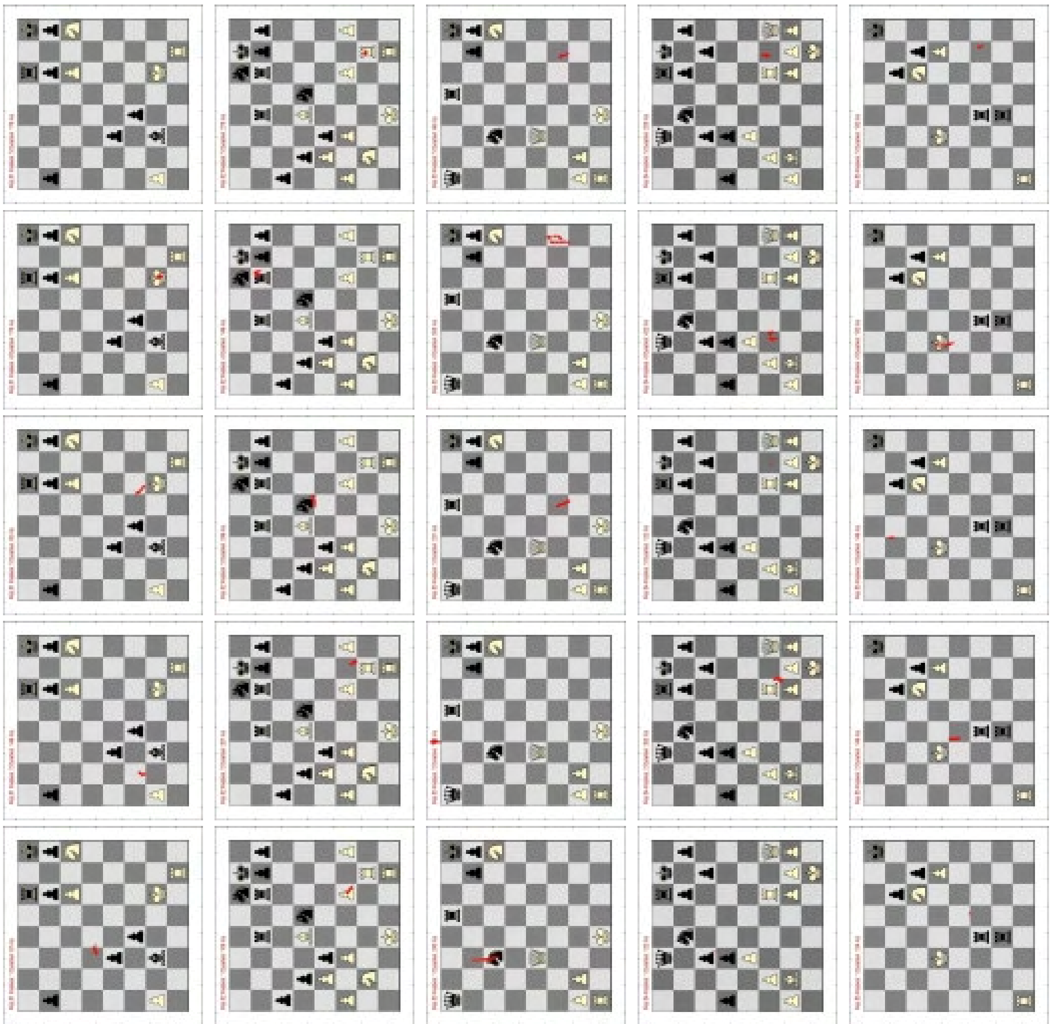


Figure A.50 First five fixations of subject SG on first group of five positions

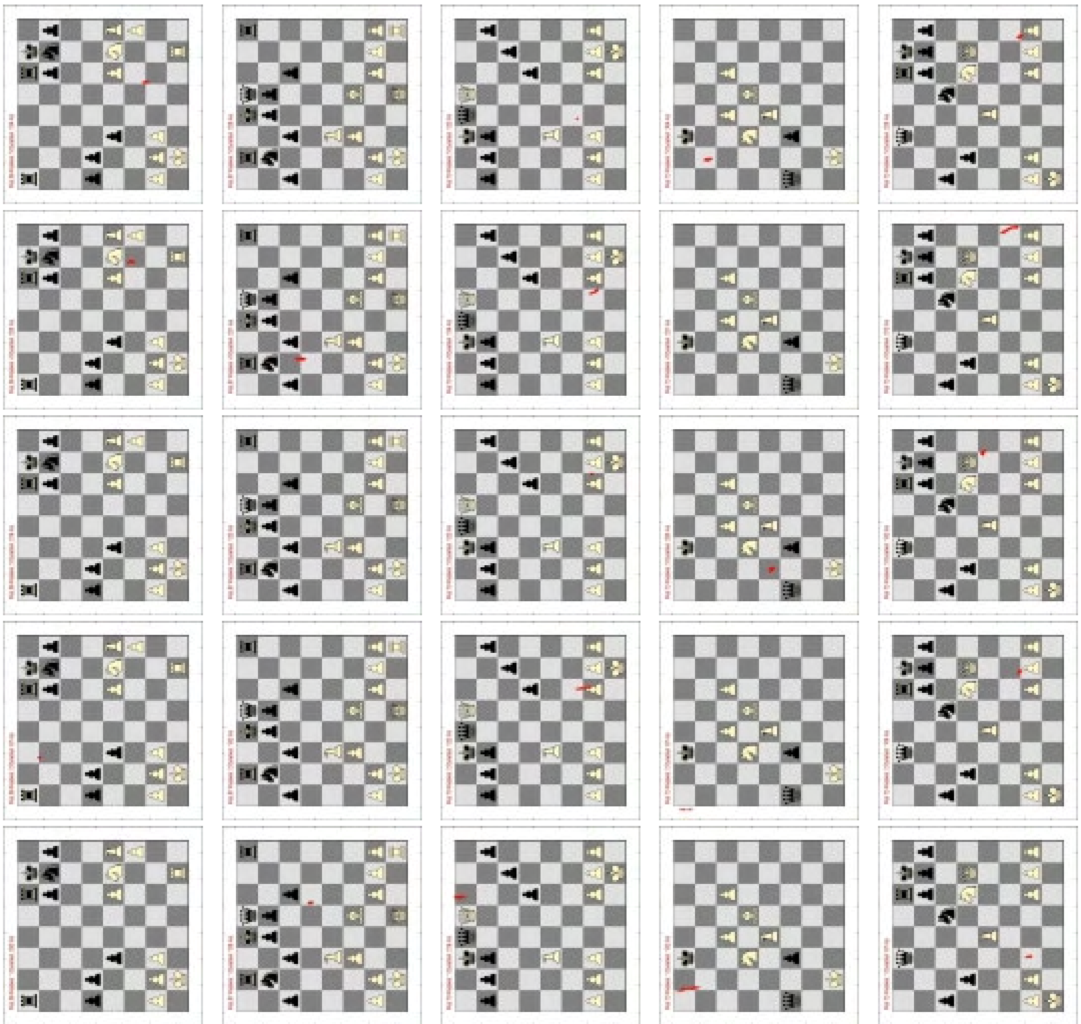


Figure A.51 First five fixations of subject SG on second group of five positions

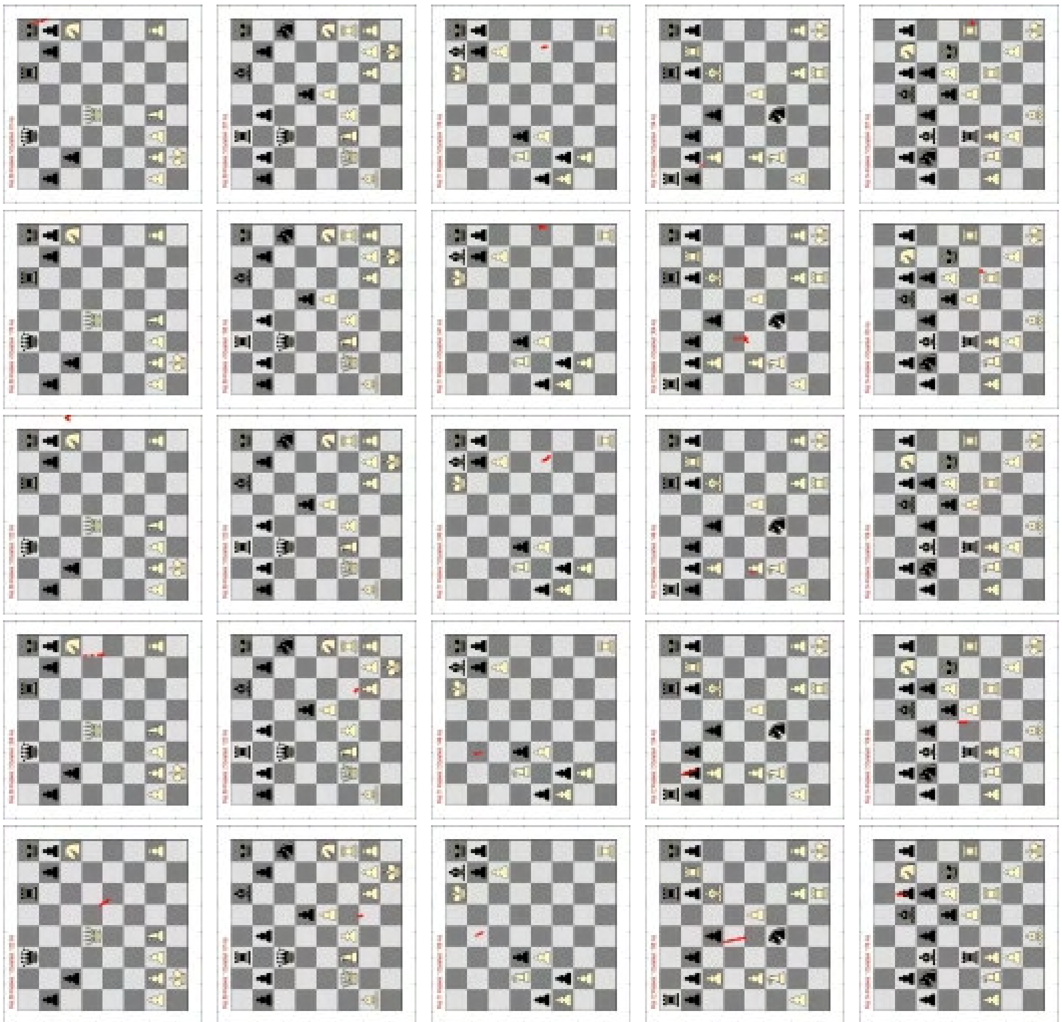


Figure A.52 First five fixations of subject SG on third group of five positions

Figure A.53 Test phase of subject UE

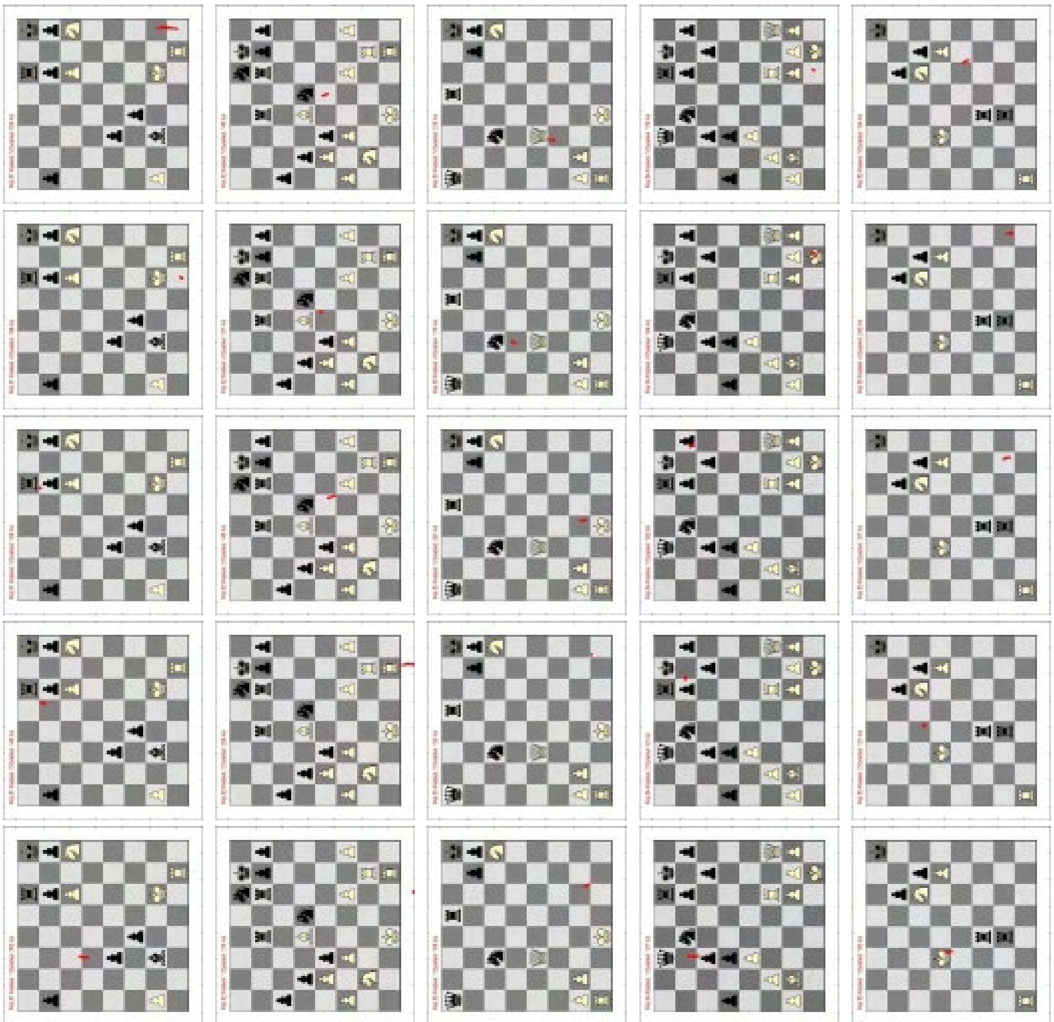


Figure A.54 First five fixations of subject UE on first group of five positions

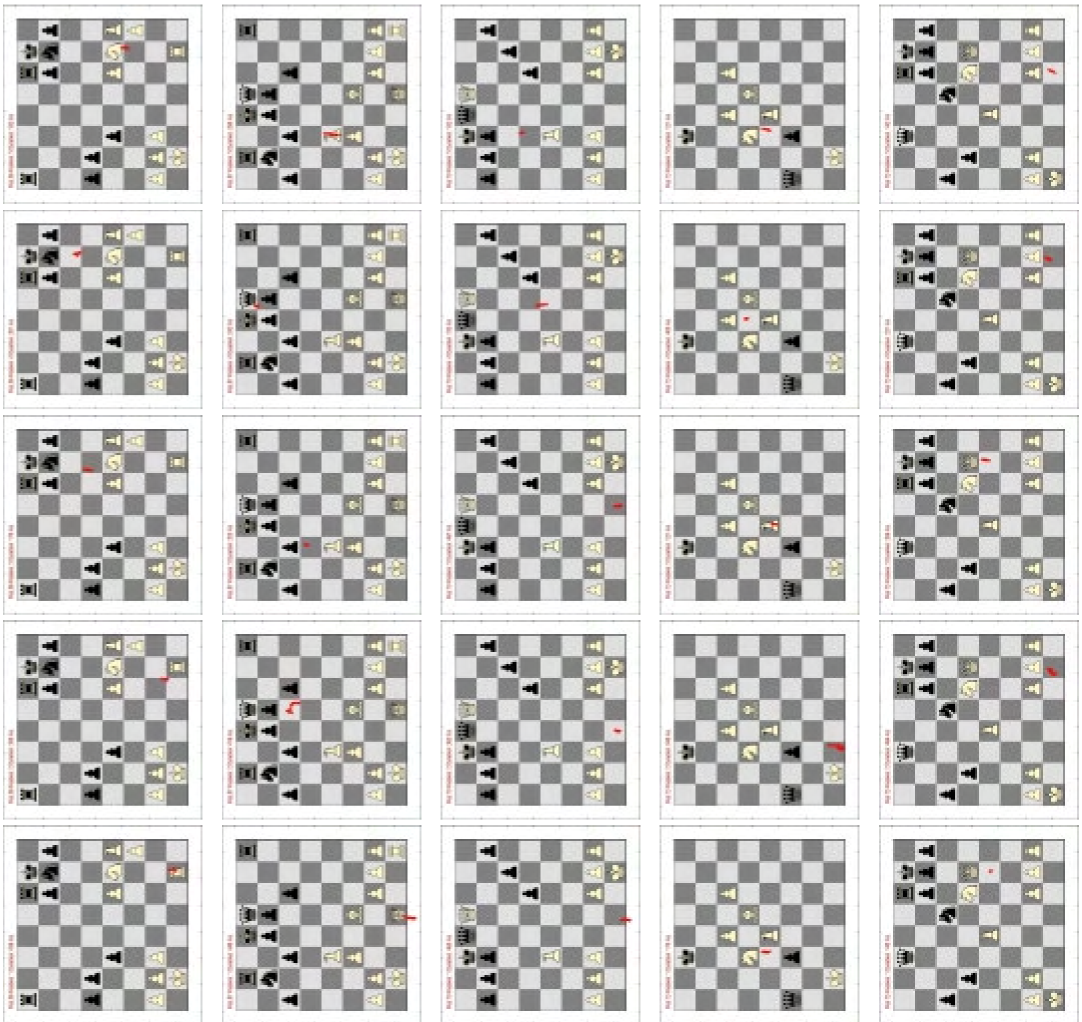


Figure A.55 First five fixations of subject UE on second group of five positions

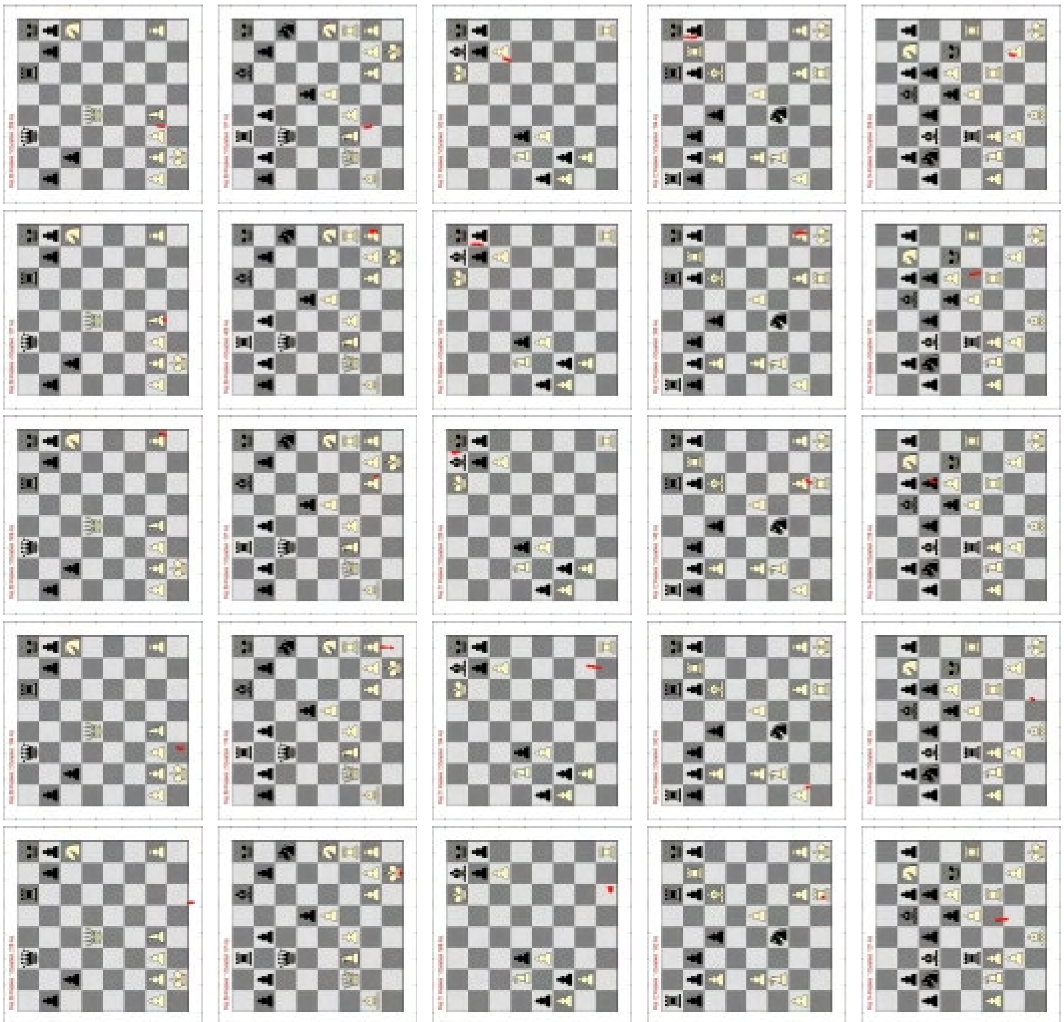


Figure A.56 First five fixations of subject UE on third group of five positions

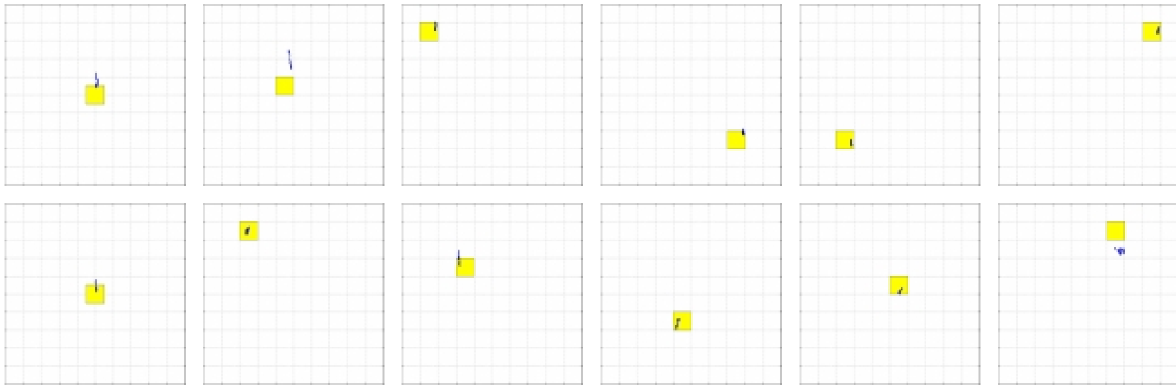


Figure A.57 **Test phase of subject VO. The number of test positions is less than other test phase positions, as the eye movement signals for the positions not shown in the figure in the test phase were not recorded.**

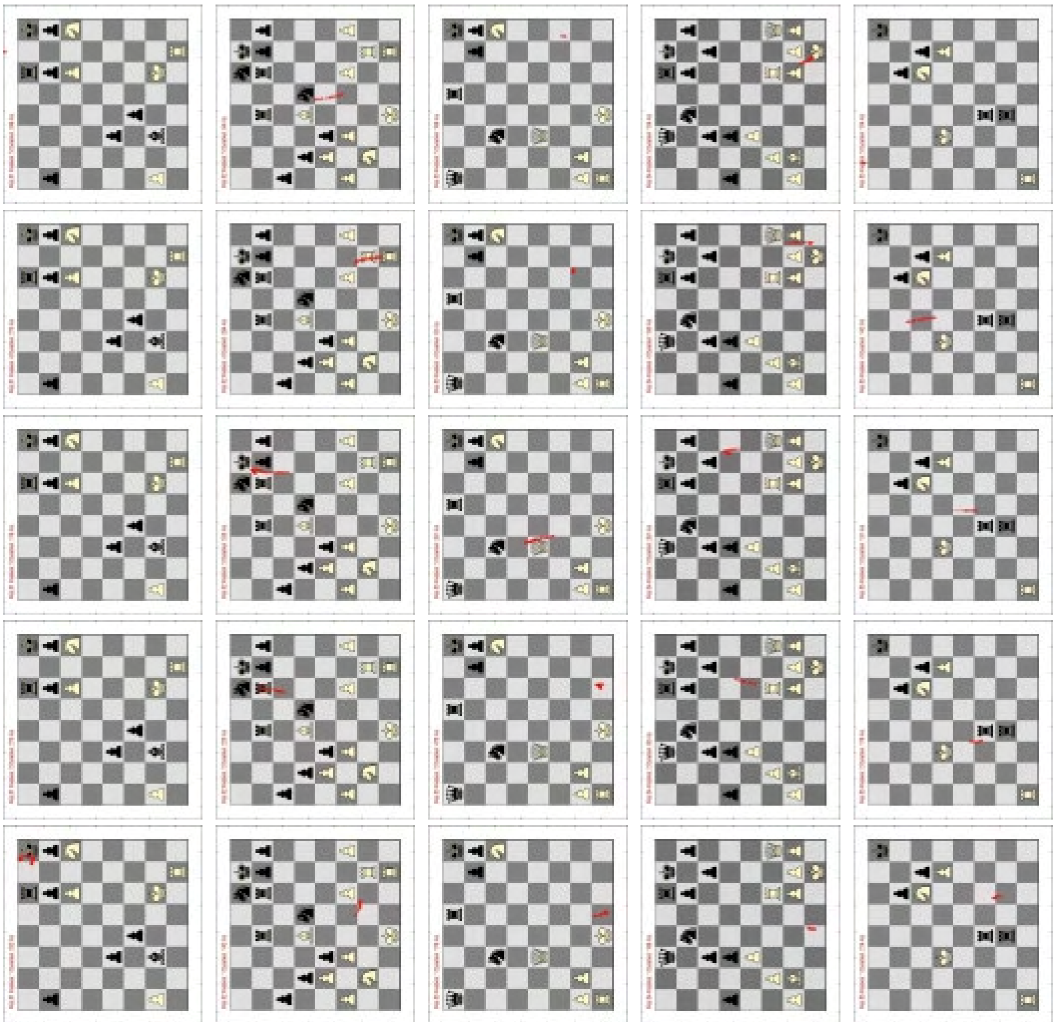


Figure A.58 First five fixations of subject VO on first group of five positions

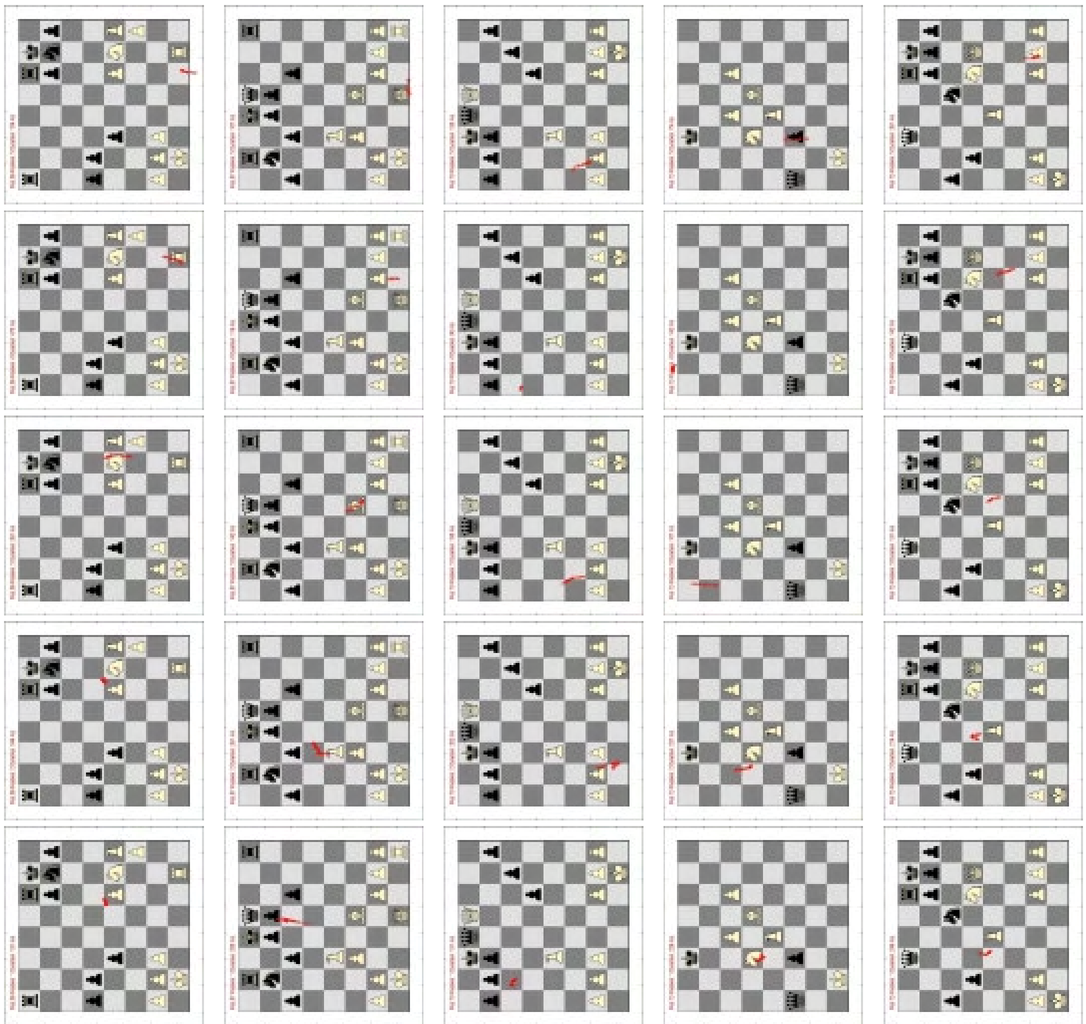


Figure A.59 First five fixations of subject VO on second group of five positions

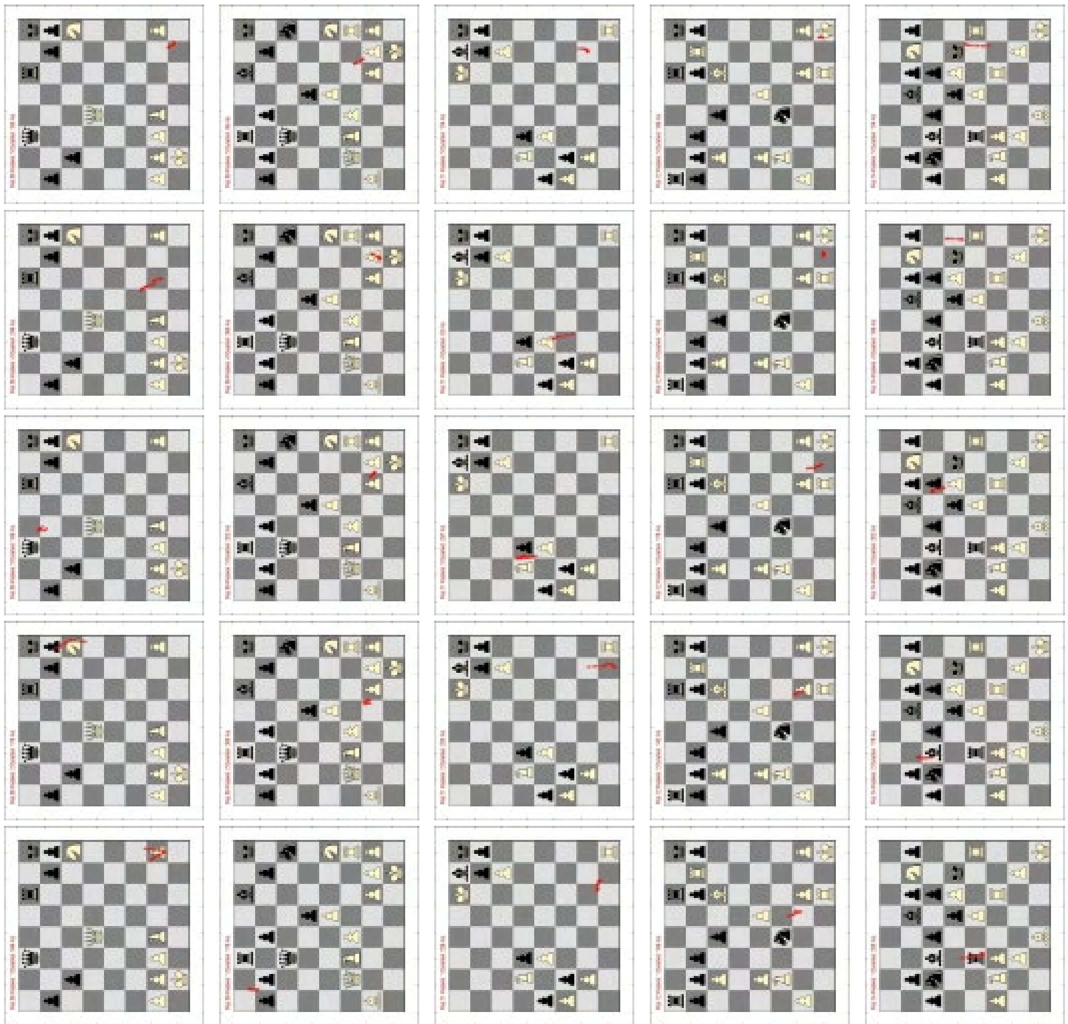


Figure A.60 First five fixations of subject VO on third group of five positions

Figure A.61 Test phase of subject YB

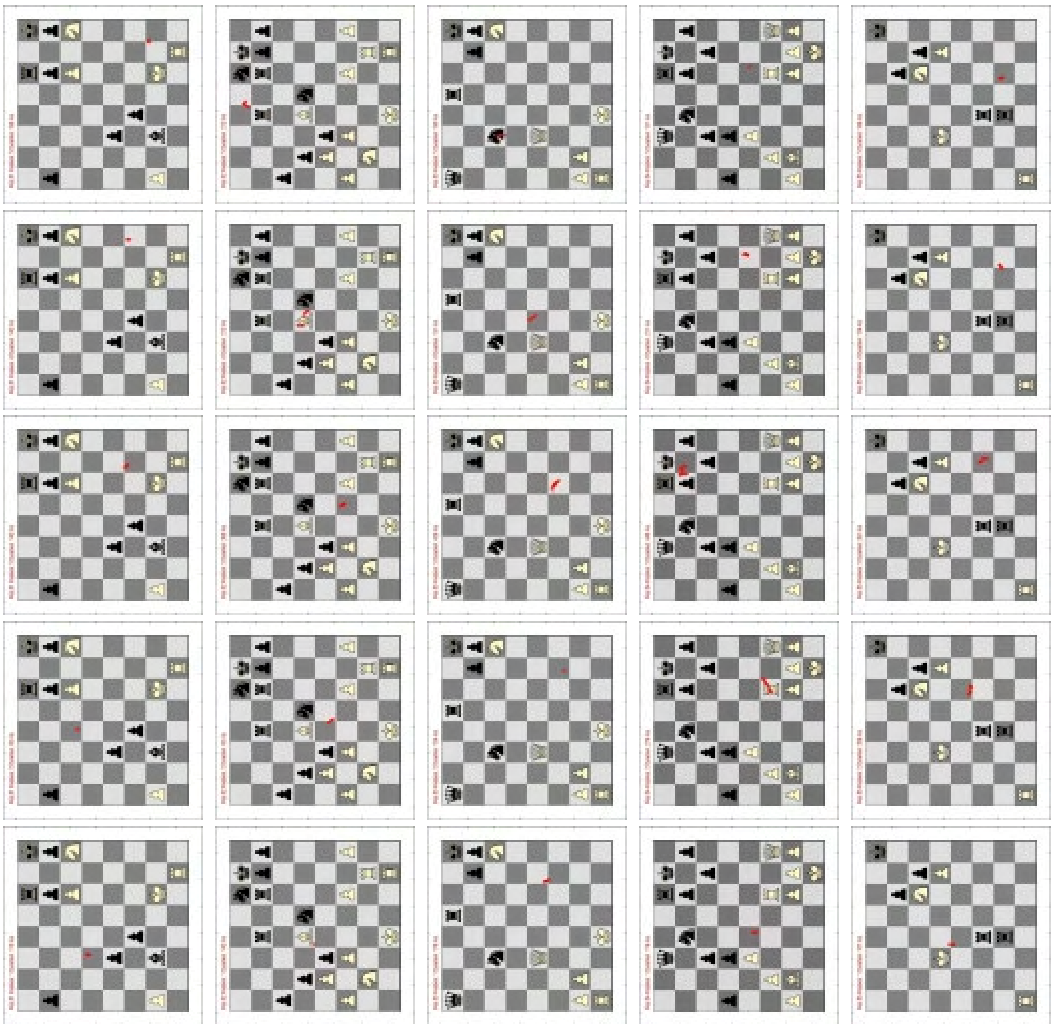


Figure A.62 First five fixations of subject YB on first group of five positions

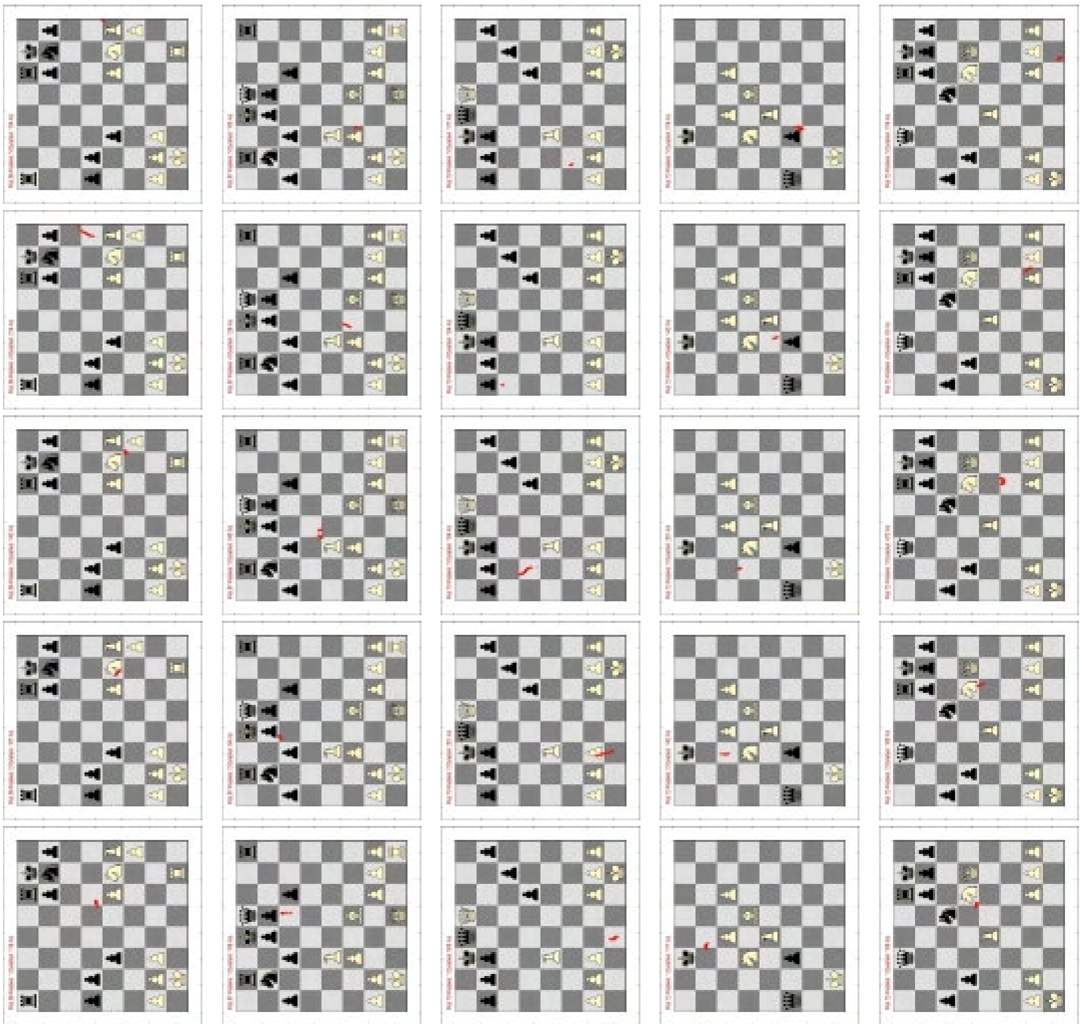


Figure A.63 First five fixations of subject YB on second group of five positions

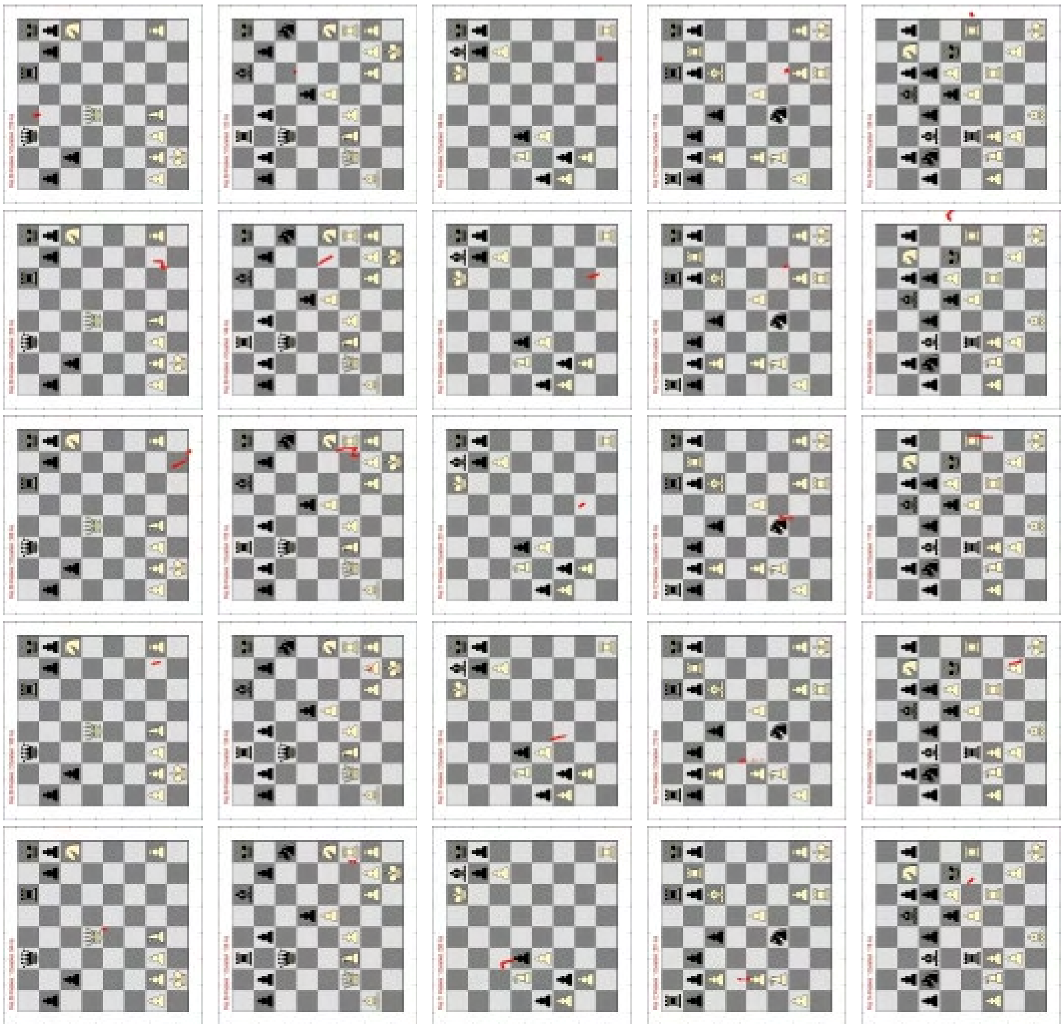


Figure A.64 First five fixations of subject YB on third group of five positions