International Journal of Social Science Research and Review

http://ijssrr.com
editor@ijssrr.com
Volume 9, Issue 7
July, 2026
Pages: 328-339

Strategic Decision-Making and Expertise in Chess: An Engine-Based and Behavioral Analysis Across Skill Levels

Aadya Gupta

Sanskriti School, India

aadyachess2004@gmail.com

http://dx.doi.org/10.47814/ijssrr.v9i7.3511

Abstract

Chess is widely regarded as an effective model for studying human cognition, expertise, and strategic decision-making under conditions of complexity and time pressure. This study examines how decision quality differs across players of varying skill levels by integrating engine-based performance analysis with survey-based behavioral insights. The research compares elite players, titled master-level players, and intermediate or lower-rated players using metrics such as move accuracy, average centipawn loss (ACPL), blunders, mistakes, and inaccuracies. In addition, the study explores behavioral dimensions of decision-making, including reliance on intuition versus calculation, time management strategies, perceived causes of errors, and differences between online and offline play. The study adopts a mixed-methods research design combining quantitative engine evaluations with primary survey data collected from chess players across multiple rating categories. The findings indicate that stronger players consistently demonstrate lower ACPL, fewer severe errors, and more stable decision-making patterns across games. Survey-based insights further reveal that higher-rated players rely more effectively on intuition, pattern recognition, and selective calculation, while lower-rated players experience greater indecision, over-calculation, and time pressure. The results also suggest that expertise influences not only the frequency of errors but also their severity and consistency under complex playing conditions. Overall, the study contributes to the literature on chess expertise and bounded rationality by linking objective performance metrics with underlying cognitive and behavioral processes. The findings highlight that expert performance depends not only on technical knowledge but also on efficient cognitive processing, adaptability, and consistent decision-making under pressure.

Keywords: *Average Centipawn Loss (ACPL); Bounded Rationality; Chess Expertise; Decision-Making; Strategic Thinking*

1. Introduction

The study of human decision-making processes in complex strategic situations has long been an important model system using chess. As opposed to most experiments conducted in the laboratory, chess offers a predetermined environment where people engage in repeated sequential decision-making under uncertain conditions, time constraints, and different degrees of difficulty. Since every action can be objectively assessed with the help of modern chess engines, the game can provide a unique chance to measure the quality of decisions, as well as to investigate the cognitive mechanisms that guide the performance of experts (Chacoma & Billoni, 2025).

One of the key subjects in the study of expertise is the connection between skill and the quality of decisions. Classic research on chess expertise, starting with the research of Adriaan de Groot, indicated that expert players do not search deeper than do beginners but instead depend extensively on pattern recognition and past acquired experience. Subsequently, studies established that chess mastery is closely linked to better position assessment and decision-making techniques (Zegners et al., 2020).

The developments in computer chess and artificial intelligence have greatly improved the possibility of researchers measuring the accuracy of decisions. Chess engines in the modern era like Stockfish are capable of analyzing them with very high accuracy, and researchers are able to measure the quality of human moves using metrics like average centipawn loss (ACPL) and move accuracy. These measures measure the degree to which a move by a player resembles the recommended move given by the engine. Research that has used this metric has shown that the more powerful players always play with the lowest centipawn loss and the highest accuracy, which implies better decision quality (Aggarwal, 2021).

In addition to straightforward accuracy comparisons, chess has also served as a useful empirical setting when it comes to the study of more general theories of human decision-making. The idea of limited rationality is used in economics and cognitive science to imply that people are not able to consider all existing options because of cognitive constraints and time. They instead use heuristics and simplified strategies in decision-making. Computer analyses of chess games have produced substantial evidence of such behavior, demonstrating that the participants tend to strategize by satisfying strategies, instead of maximizing the position when it gets very complex (Connors et al., 2011).

Recently, the interaction of expertise, time pressure, and position complexity has been studied to determine their effect on the quality of decisions made. Empirical studies conducted on chess with online experiments have revealed that player expertise can explain a significant amount of decision accuracy variation with more reliable evaluation and move choice in different time controls (stronger players). In the same way, studies of thousands of chess games show that the strategies that players use to make decisions vary with the complexity of the situation and the available thinking time (Northwestern University, 2023).

Although the literature on chess decision-making is increasing, comparatively few studies have more specifically contrasted the quality of moves across the various categories of players in online tournament settings using finer engine-based metrics (Salant & Spenkuch, 2025). The changes in decision accuracy among elite players, titled masters and standard competitors may give information on how expertise changes strategic thinking and error patterns. These comparisons may also be added to the larger discourse in behavioral economics on learning, expertise, and performance in complex decision making.

Based on this, the current research will examine the quality of moves in online chess games at three levels of level of skills of the players (those who are grandmasters, titled master level and players with 1600 to 2000 level of skills). The study is designed to assess the quality of decisions at various levels of skill by using engine-based measures like move accuracy, average centipawn loss, blunders, mistakes and inaccuracies. Furthermore, the effect of length of time per move, complexity of position, and decision quality is analyzed in the game. The present study would be carried out by a combination of descriptive and comparative data analysis to contribute to the existing literature on studying expertise and decision making in chess as a natural laboratory. Besides the engine analysis, the study also uses survey data to explore the behaviour of players of varying skill levels and understand their decision-making processes in chess. Some of the factors examined are thinking by intuition rather than calculation, time management, the perceived causes of errors and distinctions between online and offline play. The study combines objective measures of performance with cognitive and behavioral measures to gain a more holistic understanding of the role of expertise in strategic decision making with complexity and time pressure.

2. Literature Review

The research on this topic goes beyond the analysis of the specific moves to include cognitive processes, learning, and overall models of strategic decision-making under constraint. The early pioneering studies by Chase and Simon (1973) showed that during the process of mastering chess, the expert chess players form a structured memory representation, which allows them to identify patterns in a much more efficient way than beginners. This study demonstrated that experts store and recall meaningful configurations of pieces, which enables them to evaluate complex positions faster and more accurately through controlled recall tasks. The results have provided the foundation of knowledge of expertise as an integration of memory structures and strategic thinking as opposed to the depth of computation.

Continuing on the cognitive accounts, Holding (1985) examined the connection between memory processes and problem-solving in chess. Using a comparison of recall and reasoning among skill groups, the research determined that stronger players use retrieval strategies and hierarchical knowledge to reduce cognitive load and enhance decision accuracy, especially when faced with time-constrained tasks. The significance of this work is the need to use the limited cognitive resources effectively during expert performance.

Another factor of considerable significance in determining move quality is time pressure. In a study on cognitive search processes under varying levels of time constraint, Saariluoma (1990) points to strategy-based adaptations in search breadth and depth in response to limited time, resulting in different patterns of errors among experienced players. The present results have direct implications for the context of online chess, where time controls are often fast-timed and adaptive decision-making processes might be the mediators of performance disparities across expertise levels.

In addition to cognitive structures and time management, affective and perceptual influences also determine the quality of moves. Eye-tracking was employed by Reingold, Charness, Pomplun, and Stampe (2001) to show that expert players distribute their visual attention more effectively than less skilled players, focusing on the squares and areas of strategic interest more quickly. These attentional differences are associated with the capacity of stronger players to detect high-quality moves under pressure.

Along with the personal cognition, the broader learning processes have been discussed. Burgoyne et al. (2016) have performed a meta-analysis of practice, structured training, and chess skill on a large scale. They found that deliberate practice and instructional feedback were significant predictors of blunder and inaccuracy reductions and that structured learning is important in increasing over time the quality of decisions made. Additionally, Sala, Gobet, Trinchero, and Ventura (2017) showed that systematic training in chess enhanced general reasoning skills and decision-making errors in children, which indicated that training in strategic thinking through chess could be generalized to other areas of cognition.

Other scientists have used computational and machine learning algorithms to differentiate decision-making patterns at different skill levels. Ardiç and Yalçın (2020) used machine-learning classifiers to distinguish between strong and weak players using the move features and evaluation paths, and they determined that different move patterns identify various groups of skills. This helps in the belief that engine-based measures capture cognitive and strategic disparities that run deeper than mere mistakes.

In economic decision-making, Salant and Spenkuch (2025) have presented stringent evidence on satisficing behavior in chess and indicated that players tend to make heuristic decisions in complicated circumstances instead of maximizing expected utility. They determined that the quality of choice is strongly affected by complexity and search resources, that is, in large datasets and using formal models, which is consistent with the theory of limited rationality.

Lastly, Chacoma and Billoni (2025) investigated the emergent complexity of the decision-making process of chess players. Their large data analysis showed that the distribution of moves by players is dependent on the complexity of position and the psychological burden and that the more powerful players are, the more accurate they remain even when position complexity increases. This work supports the perspective according to which expertise is not only a high-quality assessment but also the stability to complexity and strategic ambiguity.

These studies contribute to the knowledge of strategic decision making in chess, exploring the role of cognition, perception, learning, and small rationality in move quality and expert performance, overall. While the literature abounds with evidence of the processes involved in chess expertise, there is relatively little research that has taken a systematic look at move accuracy and error patterns by various classes of players in an online competitive environment. Furthermore, previous research has tended to concentrate on either the computational assessment of move quality, or a more general cognitive theory of expertise, rather than on relations between objective measures of performance and players' actual decision-making strategies for playing moves. The current study fills this gap by combining analysis of engine performance with survey-based behavioral insights to explore how experience influences the quality of moves made and the processes of strategic decision-making in chess. The study compares grandmasters, players at the master level and intermediate players using the following measures: move accuracy, average centipawn loss (ACPL), blunders, mistakes, and inaccuracy. It also explores the nature of the relationship between intuition and calculation, time management strategies, perceived cause of errors, and the difference between online and offline play to gain a deeper understanding of expertise and decision-making in the context of complexity and time pressure.

3. Methodology

This section elaborates on the objectives of the study, research design, survey instrument, data collection, ethical considerations, and analytical framework of the study.

3.1 Objectives of the Study

The study aims to examine decision-making patterns in chess by integrating engine-based performance metrics with survey-based behavioral insights. It seeks to analyze how decision quality varies across different skill levels using indicators such as accuracy, ACPL, and error frequency and to explore how players differ in their reliance on intuition, calculation, and time management strategies. The study also investigates the causes and distribution of errors across expertise levels, along with differences in decision-making behavior between online and offline play.

3.2 Research Design

The study adopts a mixed-methods research design, combining quantitative engine-based analysis with primary survey data to provide a comprehensive understanding of chess decision-making. The quantitative component focuses on evaluating chess performance through engine-generated metrics, which offer objective measures of decision quality. The qualitative component, derived from structured survey responses, captures the cognitive and behavioral dimensions that are not directly observable through game analysis.

A cross-sectional approach is employed, with data collected at a single point in time from players across a wide range of skill levels. Participants are categorized into three groups based on their playing strength, enabling comparative analysis across elite players, intermediate or strong amateurs, and amateur or lower-rated players. This classification allows the study to systematically examine how performance and decision-making patterns evolve with expertise.

3.3 Survey Instrument

Primary data is collected using a structured questionnaire designed to capture key aspects of decision-making behavior in chess. The survey consists of a combination of multiple-choice and Likert-scale questions, allowing for both categorical and scaled responses. The instrument covers several dimensions, including players' reliance on intuition versus calculation, their approach to time management, perceived causes of errors, and preferences for online or offline play.

The questionnaire is designed to ensure clarity, relevance, and alignment with the objectives of the study. Likert-scale questions are used to quantify subjective perceptions and enable meaningful comparison across respondents. The survey structure allows for the systematic analysis of behavioral patterns and their relationship with performance outcomes.

3.4 Data Collection

The study utilizes both secondary and primary data sources. Engine-based performance data is derived from a sample of chess games analyzed using a chess engine, which provides standardized evaluations of move quality. Key metrics extracted include move accuracy, average centipawn loss, and the frequency of blunders, mistakes, and inaccuracies. The selected games represent players across different rating categories to ensure adequate variation in skill levels. Primary data is collected through an online survey administered to chess players. The sample includes participants from diverse age groups, experience levels, and competitive backgrounds, ranging from beginners to titled players such as Candidate Masters, FIDE Masters, International Masters, and Grandmasters. Participation is voluntary, and responses are collected anonymously to encourage honest and unbiased reporting.

3.5 Ethical Considerations

The study adheres to established ethical standards for research involving human participants. Participants are informed about the purpose of the study prior to responding to the survey, ensuring informed consent. Participation is entirely voluntary, and respondents have the option to withdraw at any stage without any consequences. The study does not collect personally identifiable information, thereby maintaining anonymity and confidentiality. All data is used exclusively for academic purposes, and appropriate measures are taken to ensure data security and responsible handling.

3.6 Analytical Framework

The analytical framework of the study consists of two interconnected components. The first involves engine-based performance analysis, where descriptive statistical techniques are used to compare key metrics such as accuracy, ACPL, and error frequency across different player categories. This enables the identification of patterns in decision quality and error structures associated with varying levels of expertise. The second component focuses on survey-based behavioral analysis, where responses are examined using descriptive statistics and interpretative analysis to identify trends in decision-making strategies, time management practices, and perceived causes of errors. The final stage of the analysis integrates findings from both components, allowing for a comprehensive interpretation of how cognitive and behavioral factors relate to observed performance differences. This integrated approach strengthens the explanatory power of the study by linking objective performance metrics with underlying decision-making processes.

4. Results and Findings

This section presents the empirical findings of the study, combining engine-based performance analysis with survey-based insights to examine decision-making patterns in chess across different skill levels.

4.1 Search Engine–Based Analysis

This section presents an analysis of chess performance using engine-evaluated metrics, including move accuracy, average centipawn loss (ACPL), and frequency of blunders, mistakes, and inaccuracies. The analysis compares players across three strength categories to examine differences in decision quality and error structure.

4.1.1 Mean Performance Across Player Categories

Table 1: Mean Engine-Based Performance Metrics Across Player Categories

Category	Player Strength Level	Mean Accuracy (%)	Mean ACPL	Mean Blunders	Mean Mistakes	Mean Inaccuracies
1	Elite players	94.1	16.2	0.5	0.0	0.7
2	Intermediate / strong amateurs	93.8	18.0	0.3	1.1	2.1
3	Amateur / lower-rated players	89.7	30.0	0.9	0.5	2.0

A clear decline in performance is observed as player strength decreases. Category 1 players demonstrate the highest average accuracy and lowest ACPL, indicating strong alignment with engine-optimal decision-making. Category 2 players show only a marginal reduction in accuracy but a noticeable increase in ACPL and error frequency. Category 3 players exhibit a more pronounced decline in accuracy and a significantly higher ACPL, indicating greater deviation from optimal play. While accuracy differences between Category 1 and Category 2 are relatively small, error-related metrics such as ACPL and inaccuracies show clearer separation between skill levels. The relatively small difference in accuracy between elite and intermediate players suggests that accuracy alone may not fully capture performance differences. In contrast, ACPL provides a more sensitive measure of decision quality, as it reflects the magnitude of deviations rather than simply their occurrence.

4.1.2 Error Structure and Decision Quality Patterns

Beyond average performance, the structure of decision errors varies across categories. Category 1 players display minimal error frequency, with very few blunders and almost no mistakes, suggesting high precision in decision-making and strong consistency in move quality. Category 2 players show a mixed error profile, with occasional mistakes and a moderate level of inaccuracies, indicating variability in decision quality despite relatively high accuracy levels. Category 3 players demonstrate the highest concentration of errors, particularly inaccuracies, along with occasional blunders. This reflects both weaker decision quality and less consistent evaluation of positions. Overall, higher expertise is associated not only with fewer errors but also with a shift toward lower-severity deviations from optimal play. This suggests that performance differences across skill levels are driven less by isolated blunders and more by the cumulative effect of smaller inaccuracies over the course of a game.

4.1.3 Performance Variability and Cross-Category Overlap

Performance variability differs across categories. Category 1 players show relatively stable performance, with consistently high accuracy and low ACPL values across games, indicating strong decision-making consistency. Category 3 players exhibit greater variability, with wider fluctuations in both accuracy and ACPL, suggesting higher sensitivity to positional complexity and situational factors. Despite clear average differences, overlap exists between categories. Certain Category 2 and Category 3 games achieve performance levels comparable to Category 1 games, particularly in accuracy. Conversely, a few elite-level games show lower-than-expected performance. This suggests that while player strength strongly influences average performance, individual game outcomes are also affected by contextual and situational factors. This greater variability among lower-rated players may reflect inconsistent evaluation strategies and difficulty adapting to changing positional demands, rather than purely random performance fluctuations.

4.2 Survey-based Analysis

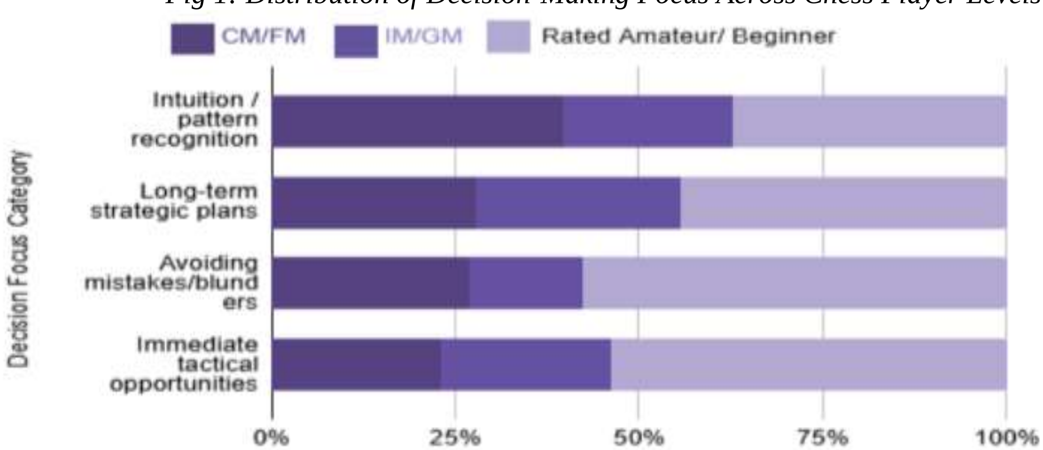
This section presents the findings derived from the survey-based component of the study, focusing on the cognitive and behavioral aspects of chess decision-making across different skill levels. The analysis explores variations in intuition, calculation, time management, perceived causes of errors, and online versus offline playing behavior to better understand how expertise influences strategic thinking and performance.

4.2.1 Sample Profile

The sample includes chess players across varied age groups (under 12 to 25+), with most participants aged 16–25. The sample includes both male and female players, though there is a higher representation of male participants, reflecting typical participation trends in competitive chess. Players range from beginners to titled professionals (CM, FM, IM, GM), with ratings from unrated to 2400+. Most participants have 5–10 years or more of playing experience, with several having over a decade of involvement in chess. This suggests that the sample is largely composed of players with substantial exposure to competitive environments.

4.2.2 Decision-Making Focus and Cognitive Style

Fig 1: Distribution of Decision-Making Focus Across Chess Player Levels



From the data, it is clear that most players rely heavily on intuition and pattern recognition as their primary decision-making approach. Lower-rated players show a greater tendency to either overcalculate or rely inconsistently on intuition. This variation in decision-making style helps explain the differences observed in engine-based performance metrics, particularly the higher ACPL and error rates among lower-rated players.

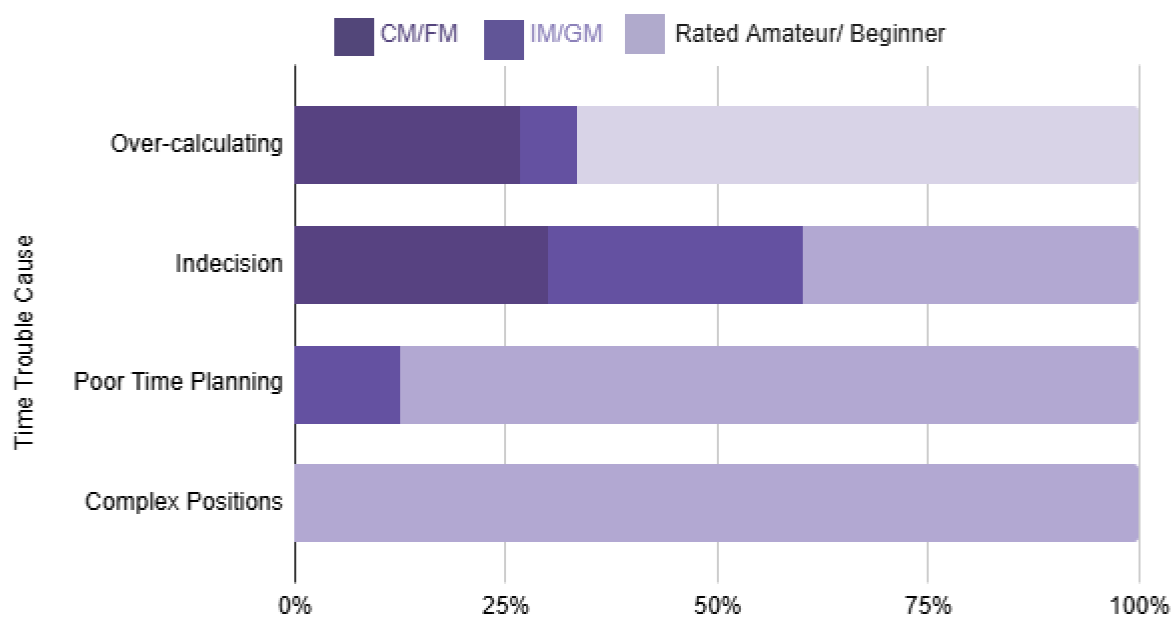
4.2.3 Time Management and Pressure Response

At the higher level, above 2400 ELO, time is used strategically, with better judgment of when to calculate and when to trust intuition. Time trouble still occurs but is more often due to practical complexity rather than poor planning.

FM/CM players show moderate time management skills but frequently face issues due to indecision and unnecessary calculation.

Amateurs experience the most time pressure, mainly due to over-calculation and indecision

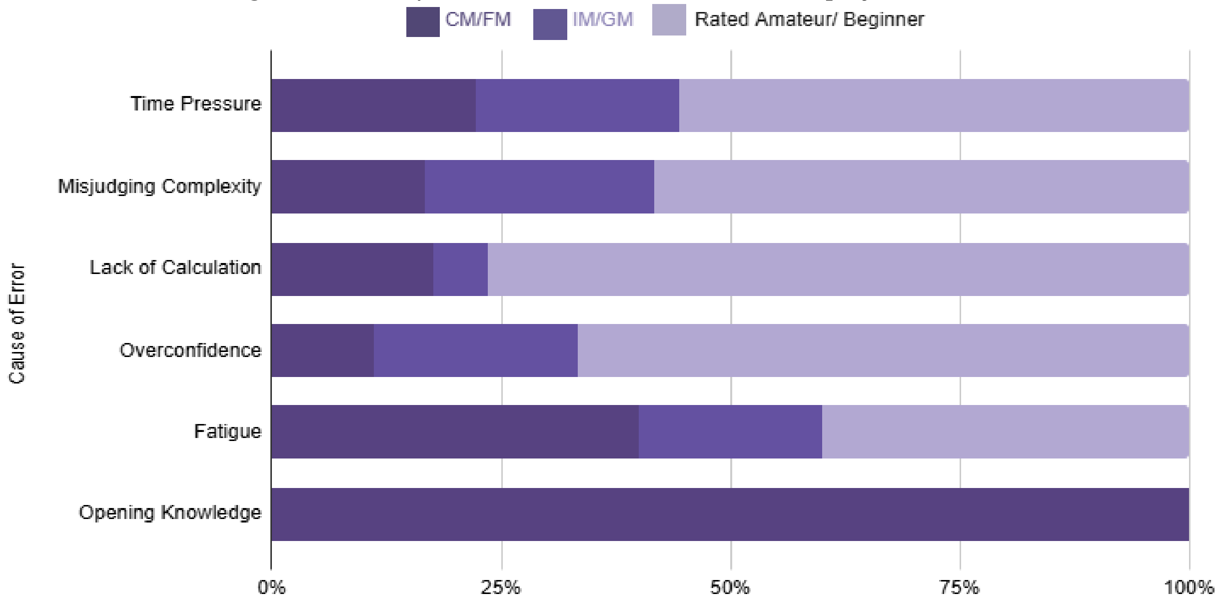
Fig. 2: Time management causes across all three levels of chess players



The chart highlights a clear decline in time-management difficulties as playing strength increases. Stronger players appear better able to regulate their thinking time and identify critical moments for calculation, whereas weaker players are more likely to expend time inefficiently across multiple positions.

4.2.4 Error Patterns and Self-Assessment

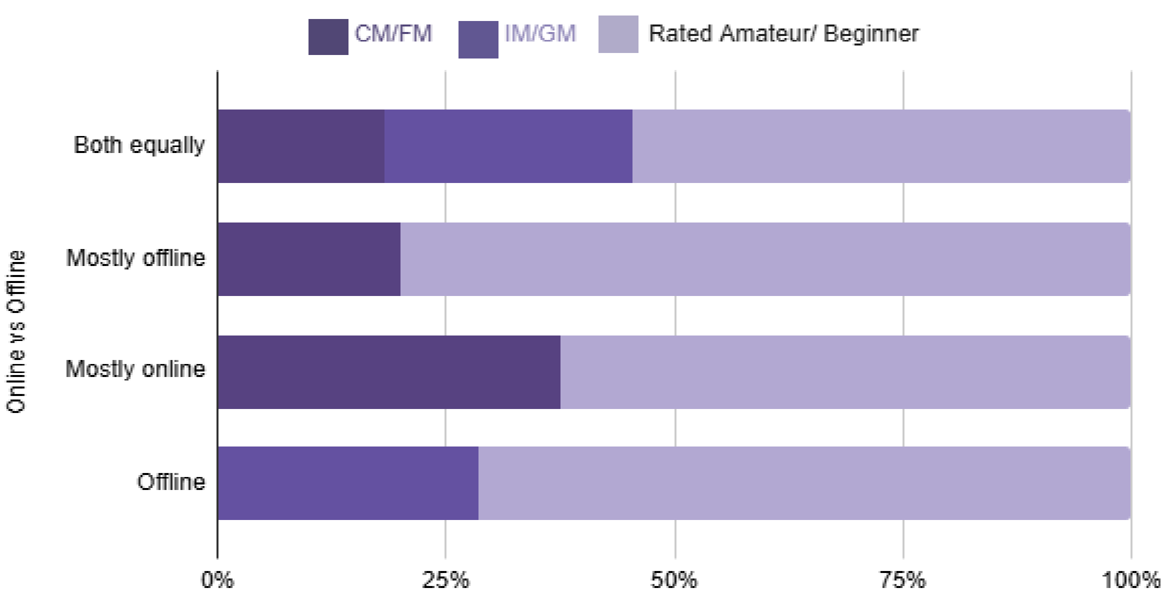
Fig. 3: Causes of errors and mistakes across chess player levels



GMs and IMs commit fewer errors, mainly due to time pressure and misjudging complexity. FM/CM players face occasional calculation and evaluation issues. Amateurs show frequent blunders, especially in the middlegame, largely due to weak calculation, overconfidence, and limited positional understanding. This pattern suggests a shift in the underlying causes of errors with increasing expertise from fundamental cognitive limitations in lower-rated players to situational constraints in stronger players.

4.2.5 Online vs Offline Decision-Making Behavior

Fig. 4: Mode of playing across chess player levels



The graph shows that amateur players prefer online modes of play, playing mostly online or exclusively offline compared to titled players. In contrast, CM/FM and IM/GM players display a more balanced distribution, with many playing both online and offline equally. This suggests that stronger players maintain flexibility across formats, while amateurs tend to favor playing online likely due to accessibility and lower competitive pressure.

GMs and IMs show minimal difference between online and offline play, showing their thinking style does not have a huge difference between the formats. FM/CM players become more intuition-driven online, though some calculation remains. Amateurs display the largest shift, playing faster, taking more risks, and relying heavily on intuition online due to reduced pressure, leading to less consistent decision-making. This behavioral shift in online environments suggests that reduced perceived consequences and lower competitive pressure may lead to increased risk-taking and less disciplined decision-making, particularly among amateur players.

The findings indicate that differences in chess performance are driven not only by technical skill but also by variations in decision-making efficiency, time management, and error structure. Engine-based analysis reveals that stronger players maintain lower ACPL and more consistent performance, suggesting higher-quality decision-making over the course of a game. Survey-based insights further indicate that these differences are associated with more efficient cognitive strategies, including better integration of intuition and calculation, as well as more effective time allocation. In contrast, lower-rated players exhibit greater variability, higher error rates, and less consistent decision-making, particularly under time pressure. Together, these results highlight that performance disparities in chess are shaped not only by knowledge or calculation ability but also by the efficiency and consistency of decision processes across varying game conditions.

5. Discussion

The findings of this study are broadly consistent with earlier research on chess expertise, cognition, and bounded rationality, while also extending the literature by integrating engine-based performance analysis with survey-based behavioral insights. By comparing players across multiple skill categories, the study provides a more comprehensive understanding of how expertise influences strategic decision-making under complexity and time pressure.

The study provides both quantitative and psychological insight as to how different levels of chess players think and make decisions. The analysis of error structure further reinforces this interpretation. Elite players made few mistakes while lower-rated players made more errors, some of which were severe. The results suggest that being an expert changes not how many errors you make but also the kind of errors you make. Stronger players make mistakes whereas amateur players make bigger mistakes that lead to larger losses.

Stronger players tend to develop mental representations and pattern-recognition abilities. This enables them to make more reliable decisions in complex situations. The survey findings help explain how better players think. Rated players reported relying more on intuition and pattern recognition and they use calculation only when it's really needed. Lower-rated players often described overthinking, being indecisive or not relying enough on intuition. This supports the view that expert intuition in chess is not just random or impulsive. It's the result of experience and stored knowledge about positions. Elite players can quickly recognize patterns and use their brain efficiently. Additionally, amateurs may struggle to tell positions from less important ones leading to inefficient thinking and time pressure. Time management is another factor. Stronger players use their time strategically balancing intuition and calculation. Amateurs often run out of time due to overthinking and hesitation.

Moreover, the results also show that context matters. While there are differences between categories there's overlap. Some rated games are as good as elite-level games and some elite games are weaker than expected. This suggests that chess performance can't be explained by rating or technical skill. Things like pressure, fatigue, opponent style and position complexity affect decision quality. The comparison between offline play provides more insight. Amateur players change their behavior online playing faster and taking more risks. Titled players think online and offline. This suggests that stronger players have thinking patterns that work well anywhere. Experienced players are more influenced by reduced pressure and informal environments.

Overall the study supports the idea that chess expertise is shaped not by calculation skill or knowledge but by efficient, adaptable and consistent decision-making. Stronger players integrate intuition, calculation and time management better enabling them to make high-quality decisions throughout a game. The core implications of this study are that since chess is often used to study cognition and expertise, the findings may help us understand decision-making in other high-pressure environments like sports, business, medicine and strategic planning. The relationship between expertise and efficient cognitive processing suggests that expert performance in domains relies not just on knowledge but also on stable and adaptive decision-making systems.

6. Conclusion

The study shows that a player's proficiency in chess includes much more than just their knowledge and computation abilities. Instead, competence is the capacity to make timely, precise, and strategic decisions when necessary. Engine analysis and survey data show differences in decision-making, time management, and responses to complicated positions for each player's level of ability. Stronger players made less mistakes and used their intuition and recognition skills more effectively. On the other hand, players rated lower made more over-thought decisions and mistakes of a larger magnitude. The range in performance suggested that time pressure, fatigue, and the complexity of the chess position also significantly affected decision-making. Through this paper, it is established that chess expertise goes beyond being a mere function of quantitative skills, and includes the development of cognitive skills. Because of the wide use of chess to study human cognitive skills, this research may also be applicable to other professions that involve higher levels of strategic planning and decision making, such as sports and medicine. Moreover, the findings show how experience and repeated exposure to high-pressure situations contribute to expert performance. Players at the international level were able to recognize patterns quickly and depend on intuition efficiently. The findings add credence to the idea that psychological factors like self-assurance and emotional control are crucial. Overall, the findings reinforce the idea that expertise in chess is shaped not only by technical ability but also by efficient cognitive processing, adaptability, and consistency in decision-making under pressure.

Despite these contributions, the study has certain limitations. The sample size for the survey-based analysis was limited, and the engine-based evaluation focused on selected games rather than long-term player databases. In addition, the behavioral responses were self-reported and may have been influenced by personal perception or recall bias. Future research could incorporate larger datasets, longitudinal designs, biometric measures such as eye-tracking, and different time-control formats to further examine the relationship between expertise, cognition, and decision-making in chess.

References

Aggarwal, A. (2021, December 12). *Effects of Chess software on Competitive chess: Accuracy, preparation, and Decision-Making*. https://psvmkendra.com/index.php/journal/article/view/728?

Burgoyne, A. P., Sala, G., Gobet, F., Macnamara, B. N., Campitelli, G., & Hambrick, D. Z. (2016). The relationship between cognitive ability and chess skill: A comprehensive meta-analysis. *Intelligence*, *59*, 72–83. https://doi.org/10.1016/j.intell.2016.08.002

Chacoma, A., & Billoni, O. V. (2025). Emergent complexity in the decision-making process of chess players. *Scientific Reports*, *15*(1), 23234. https://doi.org/10.1038/s41598-025-06335-9

Chassy, P., Lahaye, R., Didierjean, A., & Gobet, F. (2023). Intuition in chess: a study with world-class players. *Psychological Research*, *87*(8), 2380–2389. https://doi.org/10.1007/s00426-023-01823-x

Chess players' thinking. (2020). Google Books. https://books.google.com/books?id=ocgMQapGMu4C&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Chowdhary, S., Iacopini, I., & Battiston, F. (2023). Quantifying human performance in chess. *Scientific Reports*, *13*(1), 2113. https://doi.org/10.1038/s41598-023-27735-9

Connors, M. H., Burns, B. D., & Campitelli, G. (2011). Expertise in Complex Decision Making: The Role of Search in Chess 70 Years After de Groot. *Cognitive Science*, *35*(8), 1567–1579. https://doi.org/10.1111/j.1551-6709.2011.01196.x

Holding, D. H. (2021). *The psychology of chess skill*. https://doi.org/10.4324/9781003170396

Northwestern University. (2023, February 9). *How experts make complex decisions*. Kellogg Insight. https://insight.kellogg.northwestern.edu/article/how-experts-make-complex-decisions?

Reingold, E. M., Charness, N., Pomplun, M., & Stampe, D. M. (2001). Visual span in expert chess players: evidence from eye movements. *Psychological Science*, *12*(1), 48–55. https://doi.org/10.1111/1467-9280.00309

Sala, G., & Gobet, F. (2017). Does chess instruction improve mathematical problem-solving ability? Two experimental studies with an active control group. *Learning & Behavior*, *45*(4), 414–421. https://doi.org/10.3758/s13420-017-0280-3

Salant, Y., & Spenkuch, J. L. (2025). Complexity and Satisficing: Theory with Evidence from Chess. *The Review of Economic Studies*, *93*(2), 1296–1322. https://doi.org/10.1093/restud/rdaf041

Samara, K., Antreassian, A., Klug, M., & Hasan, M. S. (2025). Machine Learning Approaches for Classifying Chess Game Outcomes: A comparative analysis of player ratings and game dynamics. *Electronics*, *15*(1), 1. https://doi.org/10.3390/electronics15010001

Zegners, D., Sunde, U., & Strittmatter, A. (2020, May 26). *Decisions and performance under bounded rationality: a computational benchmarking approach*. arXiv.org. https://arxiv.org/abs/2005.12638?

Copyrights