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Impact of Physiological Stress on Decision Accuracy among Elite Chess Players: A Biometric Analysis

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ABSTRACT: The impact of physiological stress on cognitive performance in high-pressure environments remains a relatively underexplored area of research, particularly in settings such as chess, where decision-making is rapid and cognitively demanding. Although heart rate (HR) and cognitive stress responses have been studied in sports and clinical settings, few studies have examined their impact in elite-level mental competitions. This study aimed to investigate whether elevated HR and time pressure (<30 seconds remaining) negatively affect decision-making accuracy in professional chess players and whether this relationship was influenced by age. We analyzed biometric and performance data from 50 publicly available blitz chess games played by 50 grandmasters. HR data was collected at regular intervals, and move accuracy was calculated using Chess.com's evaluation system. We found that players with higher average HRs (>130 bpm) played with significantly lower accuracy, especially under time pressure. A negative correlation and regression model further confirmed that HR was a significant predictor of accuracy. Additionally, older players had higher HRs under stress. These findings provide novel evidence of how physiological stress can negatively impact mental performance and have important implications for chess players since they highlight the potential of biofeedback-based training to improve decision-making in high-pressure scenarios.

KEYWORDS: Behavioral and Social Sciences, Physiological Psychology, Cognitive Stress, Heart Rate, Chess Performance Analysis.

Introduction

High-pressure environments consistently elicit physiological stress responses that can impact human cognition.[1] In such contexts, decision-making under pressure is closely connected with biological arousal systems.[2,3] Chess, while traditionally focused on cognitive skills and tactical ability, offers a unique platform for studying this relationship. Its demands on memory, attention, and problem-solving make it ideal for analyzing the effects of stress on decision quality.[4]

Among the most widely studied physiological markers of stress are heart rate (HR) and heart rate variability (HRV), which reflect sympathetic and parasympathetic nervous system activation, respectively.[5] Elevated HR is an indicator of sympathetic arousal, often accompanied by mental and acute stress.[6] HRV, particularly the vagally mediated high-frequency component, reflects autonomic flexibility and is inversely related to stress reactivity.[7,8] Research across cognitive, clinical, and occupational settings has shown that lower HRV correlates with impaired decision-making, reduced attentional control, and poorer performance during high-demand tasks. Conversely, individuals with higher resting HRV exhibit better self-regulation, faster recovery from stress, and improved decision-making accuracy under tension.[5,9]

This relationship becomes significant in high-performance environments.[6] For example, first responders with low HRV have been shown to underperform in simulated emergency tasks, while elite athletes with higher HRV scores tend to show greater mental resilience during competition.[10,11] The same relationship has been observed in eSports, where elite gamers have peak HRs exceeding 160 bpm during tournament play, reflecting a sympathetic stress state similar to that of Formula 1 drivers.[12-14] These stress-induced elevations in HR are often accompanied by increased cortisol levels, supporting the association between cognitive demand and physiological stress.[13,15]

Chess is a compelling context for studying psychophysiological performance under stress. Despite its lack of physical exertion, tournament chess has been shown to elicit marked autonomic changes.[4,16] Troubat *et al.* conducted a physiological study on competitive chess, finding that players experienced an average HR increase from 75 to 86 bpm during gameplay, along with a rise in systolic blood pressure and a spike in respiratory exchange ratio (RER), suggesting an acute metabolic stress response. These changes occurred despite players being physically still, emphasizing the role of cognitive demand in activating the sympathetic nervous system.[4]

Subsequent research has expanded on these findings, using HRV and EEG to record real-time psychophysiological responses in chess players during problem-solving.[16-19] Villafaina *et al.* reported that HRV declined significantly as players were exposed to increasingly complex chess problems. Interestingly, higher-rated players were able to maintain higher HRV values than their lower-rated counterparts even under intense conditions, indicating better autonomic regulation.[19] This aligns with more general findings in performance psychology that suggest expert performers are not only more skilled but also better able to manage physiological arousal.[20]

Pereira *et al.* extended this line of research to younger populations, showing that adolescent chess players exhibited both

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decreased HRV and increased EEG theta power during time-constrained decision-making, consistent with heightened cognitive load and stress.[17] These findings suggest that chess performance under pressure involves a coordinated response between central (brain) and peripheral (autonomic) systems and that physiological markers can serve as valid indicators of cognitive strain.[21]

In chess, it has been found that time pressure (operationally defined as the phase of the game when the player's remaining time on the clock is less than 30 seconds) increases stress responses. Blitz chess, which limits players to 3-10 minutes per side, is known to put players under significant HR acceleration and neural activation.[18,22] Amidzic *et al*. showed that rapid chess gameplay elicited increased gamma-band EEG bursts in frontal and temporal regions, reflecting enhanced pattern retrieval and working memory load.[23] More recently, studies have shown that during 1-minute games, players exhibit elevated theta activity in parietal and occipital regions, as well as increased right-hemisphere activation associated with visuospatial processing.[18] These neural changes suggest that extreme time constraints force players to rely more heavily on intuition and pattern recognition, processes that may be vulnerable to stress overload.[24,25]

Although the relationship between stress and performance is well-supported, key topics remain underinvestigated.[26] Specifically, while prior studies have identified general correlations between HR/HRV and chess performance, few have established a quantitative threshold at which HR reliably predicts cognitive decline.[19] Unlike physical sports, where performance is often known to degrade above certain HR levels (e.g., >160 bpm in shooting sports), there is no established physiological "cutoff" in cognitive games like chess.[27] Moreover, existing literature has not adequately addressed whether age moderates the stress–performance relationship. Given that aging is associated with decreased HRV and increased cardiovascular stiffness, older players may be more susceptible to performance degradation at elevated HRs.[6,28]

The present study addresses these gaps by evaluating whether elevated heart rate impairs move-by-move decision accuracy in elite chess players and whether age influences this relationship. We hypothesized that HRs exceeding 130 bpm would be associated with a statistically significant drop in accuracy, particularly under time pressure.[6] We also explored whether older players exhibit heightened HR reactivity and reduced performance compared to younger players.[6,28] Using a dataset of 50 elite-level chess games with publicly available heart rate and move accuracy data, we analyzed how physiological stress correlated with decision-making performance. By combining game accuracy analysis with physiological data, this study contributes novel quantitative evidence on how elevated arousal influences decision quality in cognitively demanding environments like chess.

Methods

Participants:

This study analyzed 50 games played by 50 chess grandmasters, all with FIDE Elo ratings (official rating of the International Chess Federation) above 2500 at the time of competition (mean Elo rating: 2653 ± 37 Elo (SD)).[29] All players held the title of Grandmaster (GM). Games were sourced from publicly available YouTube broadcasts of elite chess tournaments between 2022 and 2024, in which real-time biometric heart rate data was visible on-screen. All games were played under blitz time controls, defined as 3 to 10 minutes per side.[22] For anonymity, no player names or identifying details were recorded. Player ages ranged from 18 to 55 years (mean age: 27.6 ± 6.9 years (SD)) and were grouped into younger (≤25 years) and older (>25 years) categories based on previous research examining age-related variability in chess performance and stress responses.[30] This division also approximately reflected the median of our sample. Of the 50 grandmasters, 22 were aged 25 or younger, while 28 were older than 25.

Data Acquisition and Preprocessing:

While several prior studies have used heart rate variability (HRV) as a marker of cognitive load and stress regulation, the present study focuses exclusively on real-time heart rate (HR) due to the nature of the publicly available data.[6] Heart rate (HR) data was collected every three moves for each game from the visible biometric data displayed during the public YouTube broadcasts. HR data was measured by wrist sensors worn by the players and displayed real-time heart rate values in beats per minute (bpm). HR values were recorded and matched to corresponding moves by cross-referencing player clocks visible on-screen and the move sequence as tracked in real-time using Chess.com's live game interface.[31] HR values were recorded both for the entire game and separately for moves made during time pressure (≤30 seconds remaining on the clock) and during normal play (>30 seconds remaining on the clock).

Game accuracy was calculated using Chess.com's accuracy scoring system, CAPS2 (Computer Accuracy Precision Score), which evaluates every move using the Stockfish engine, one of the strongest chess engines in the world, and compares it to the best available option in the position.[32,33] The official accuracy metric considers how close each move is to the engine's top choice, producing a game-level percentage score ranging from 0 to 100. This methodology has been widely adopted in online chess analysis.[33] Accuracy values were recorded both for the entire game and separately for moves made during time pressure (≤30 seconds remaining on the clock) and during normal play (>30 seconds remaining on the clock).

Time pressure was operationally defined as any phase of the game in which the player's remaining time on the clock dropped below 30 seconds. This was chosen to reflect a widely accepted threshold in competitive chess, under which cognitive performance may be compromised due to rapid decision-making and limited working memory.[34] Both HR and move accuracy were independently measured during these time-constrained periods.

To define heart rate groups, we categorized players into Low-to-Moderate HR (≤130 bpm) and High HR (>130 bpm) categories based on their average game heart rate. This threshold was chosen based on evidence from the psychophysiological literature indicating that heart rates above 130 bpm are associated with a shift toward sympathetic dominance and decreased cognitive efficiency under stress.[2,35] This division also approximately reflected the median of our sample.

Player ages were sourced from FIDE.com and other tournament coverage, allowing players to be categorized as younger (≤25 years) or older (>25 years).[36] All extracted data was compiled into a dataset that included the following variables: mean HR per game, mean HR during time pressure (if applicable), mean HR during normal play (bpm), total game accuracy (%), accuracy during time pressure (if applicable), accuracy during normal play (%), player age group, and HR group.

Statistical Analysis:

All statistical analyses were conducted using Python and associated scientific libraries. A significance threshold of $p < 0.05$ was used for all tests, and 95% confidence intervals (CI) were calculated where applicable. Values are reported as means ± standard error (SE) unless otherwise noted.

To compare decision-making accuracy between players with elevated heart rates and those with lower heart rates, Welch's two-sample t-test was used. This test was selected due to potential unequal variances between groups and was applied to compare mean game accuracy between the High HR group (>130 bpm) and the Low-to-Moderate HR group (≤130 bpm).

2 paired t-tests were conducted to analyze within-player changes in both heart rate and accuracy during time pressure. Specifically, players' mean HR and accuracy values during normal play (>30 seconds remaining) were compared to values recorded during time pressure periods (≤30 seconds remaining) to evaluate physiological and performance changes under stress.

To investigate the relationship between heart rate values and decision-making accuracy across the dataset, a Pearson correlation analysis was performed. In addition, a simple linear regression model was calculated to find whether heart rate could significantly predict accuracy using the equation:

$$\text{Accuracy} = \beta_0 + \beta_1 \cdot HR + \varepsilon$$

Age-based differences in heart rate and accuracy were analyzed using independent two-sample t-tests, comparing outcomes between players aged ≤25 years and those >25 years.

Result and Discussion

Results:

Descriptive Statistics:

The overall mean heart rate across 50 games was 129.6 bpm (SE = 2.1), and the average move accuracy was 91.2% (SE = 1.2). Mean heart rate increased from 123.4 bpm (SE = 2.2) during normal play to 137.6 bpm (SE = 2.1) under time pressure (≤30 seconds). Similarly, move accuracy dropped from 94.1% (SE = 1.1) during normal play to 85.2% (SE = 1.4) under time pressure. Age-based differences were also observed: older players (>25 years) had a higher mean heart rate 132.9 bpm (SE = 2.3), and lower accuracy, 90.6% (SE = 1.6), than younger players (≤25 years), who averaged 123.8 bpm (SE = 2.6) and 91.7% (SE = 1.5), respectively.

Result 1: Accuracy by Heart Rate Group:

A Welch's two-sample t-test was performed to compare mean move accuracy between players with high average heart rates (>130 bpm) and those with lower heart rates (≤130 bpm). The High HR group (n = 26) had a significantly lower accuracy (Mean = 87.9%, SE = 1.5) compared to the Low HR group (n = 24) (Mean = 93.2%, SE = 1.2), t = 2.76, p = 0.0082 (Figure 1), indicating that elevated heart rate is associated with a reduction in decision-making performance.

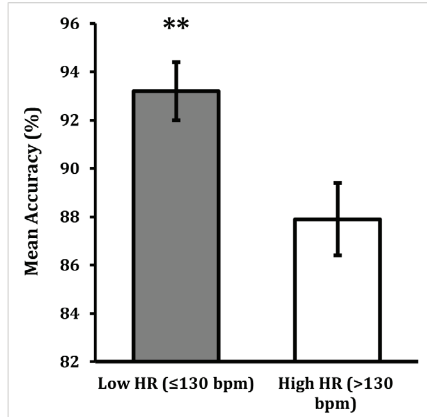

Figure 1: Elevated heart rate is associated with reduced move accuracy in elite chess players. Bar graph showing mean ± SE move accuracy (%) for players with low (≤130 bpm) and high (>130 bpm) average heart rates during tournament games (n = 50 games total). Mean accuracy was significantly lower in the high HR group (87.9 ± 1.5%) compared to the low HR group (93.2 ± 1.2%). Welch's two-sample t-test, **p < 0.01.

Result 2: Accuracy Under Time Pressure vs. Normal Play:

A paired t-test was conducted to compare player accuracy during normal play (>30 seconds on the clock) and time pressure intervals (≤30 seconds on the clock) (n = 50 paired observations). Accuracy was significantly lower during time pressure (Mean = 85.2%, SE = 1.4) compared to normal conditions (Mean = 94.1%, SE = 1.1), t = 4.99, p < 0.001 (Figure 2), indicating that high time pressure significantly impairs move quality.

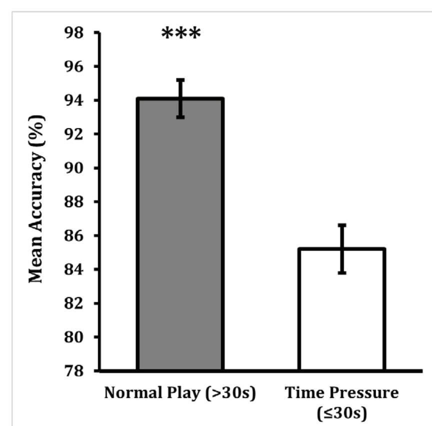

Figure 2: Time pressure significantly impairs move accuracy in chess games. Bar graph showing mean ± SE move accuracy (%) during normal play (>30 seconds) versus time pressure intervals (≤30 seconds remaining) during tournament games (n = 50 paired observations). Accuracy was significantly lower under time pressure (85.2 ± 1.4%) compared to normal conditions (94.1 ± 1.1%). Paired t-test, ***p < 0.001.

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Result 3: Heart Rate Under Time Pressure vs. Normal Play:

A paired t-test comparing heart rate in normal play versus time pressure revealed a significant increase under time pressure conditions (n = 50 paired observations). Mean HR rose from 123.4 bpm (SE = 2.2) during normal play to 137.6 bpm (SE = 2.1) during time pressure, t = 4.67, $p < 0.001$ (Figure 3), confirming that time pressure elicits physiological stress responses in elite players.

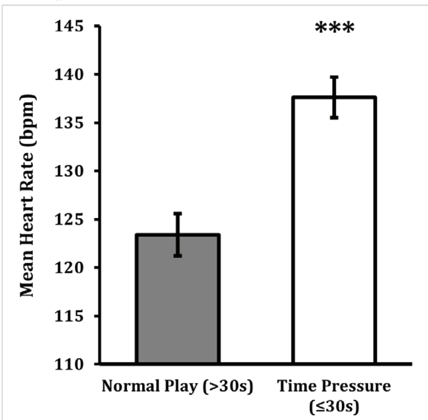

Figure 3: Time pressure significantly increases heart rate in elite chess players. Bar graph showing mean ± SE heart rate (bpm) during normal play (>30 seconds) versus time pressure intervals (≤30 seconds remaining) during tournament games (n = 50 paired observations). Mean heart rate increased significantly from 123.4 ± 2.2 bpm during normal play to 137.6 ± 2.1 bpm during time pressure. Paired t-test, ***$p < 0.001$.

Result 4: Correlation Between Heart Rate and Accuracy:

A Pearson correlation analysis showed a significant negative relationship between heart rate and accuracy across all games (n = 50), r = –0.565, $p < 0.001$. Linear regression further confirmed this association, with heart rate significantly predicting move accuracy (β = –0.3513, $p < 0.001$) (Figure 4). The regression model explained 31.9% of the variance in accuracy (R^2 = 0.319), with the following equation:

$$Accuracy = -0.3513 \times HR + 136.42$$

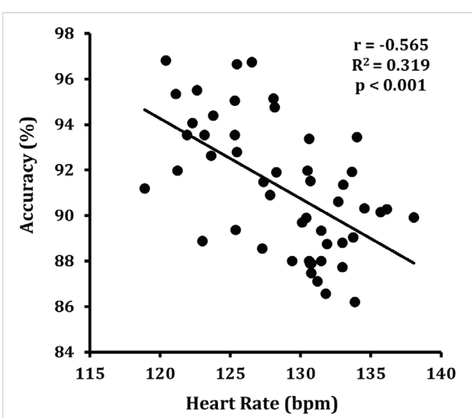

Figure 4: Heart rate is negatively associated with move accuracy across games. Scatter plot with linear regression line showing the relationship between heart rate (bpm) and move accuracy (%) across all tournament games (n = 50). A Pearson correlation analysis revealed a significant negative association between heart rate and accuracy (r = –0.565, $p < 0.001$). Linear regression confirmed that heart rate significantly predicted move accuracy (β = –0.3513, $p < 0.001$), explaining 31.9% of the variance in accuracy (R^2 = 0.319). The regression equation was Accuracy = -0.3513 x HR + 136.42.

Result 5: Age Group Differences in HR and Accuracy:

Independent T-tests were conducted to examine age-related differences in HR and accuracy. Older players (>25 years) (n=28) showed significantly higher mean heart rates (Mean = 132.9 bpm, SE = 2.3) compared to younger players (≤25 years) (n=22) (Mean = 123.8 bpm, SE = 2.6), t = 2.62, p = 0.0119 (Figure 5A). Additionally, while older players had lower accuracy (Mean = 90.6%, SE = 1.6) than younger players (Mean = 91.7%, SE = 1.5), t = 0.5, p = 0.62 (Figure 5B), this difference was not statistically significant.

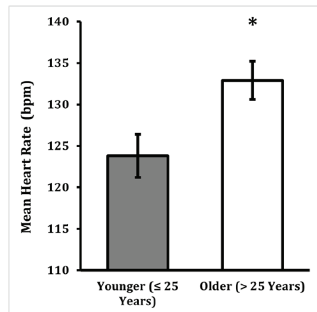

Figure 5A: Heart rate by age group. Bar graph showing mean ± SE heart rate (bpm) for younger (≤25 years) and older (>25 years) chess players (n = 50). Older players exhibited significantly higher heart rates (132.9 ± 2.3 bpm) compared to younger players (123.8 ± 2.6 bpm). Independent t-test, *$p < 0.05$.

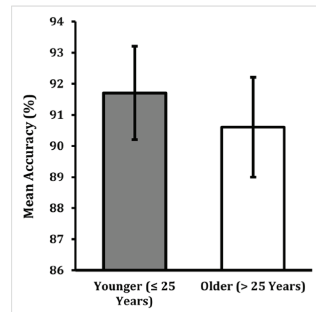

Figure 5B: Move accuracy by age group. Bar graph showing mean ± SE move accuracy (%) for younger (≤25 years) and older (>25 years) chess players (n = 50). Accuracy was slightly lower in older players (90.6 ± 1.6%) than in younger players (91.7 ± 1.5%), but this difference was not statistically significant. Independent t-test, ns.

Discussion:

This study provides quantitative evidence that elevated physiological arousal, measured via heart rate (HR), is significantly associated with reduced decision-making accuracy in elite chess players. The hypothesis that sustained HRs above a threshold of 130 bpm would correspond to lower accuracy was supported across multiple statistical analyses. Players with higher average HRs performed significantly worse than their lower HR counterparts, both in overall game accuracy and under time-pressure conditions. These findings align with established psychophysiological theories suggesting that excessive sympathetic activation impairs cognitive functioning and working memory, particularly under acute stress and cognitive load.[1,37,38]

Time pressure emerged as a particularly important stressor. In blitz-format games, players had limited time to calculate complex positions, and their physiological data confirmed a significant increase in HR during these moments. This autonomic response was accompanied by a significant drop in move accuracy, supporting the idea that stress reduces concentration, encourages faster but less thoughtful decisions, and makes deep analysis harder.[39,40]

The relationship between heart rate and performance was further supported by a significant negative correlation and a significant predictive regression model. Unlike binary threshold models that assume a fixed cutoff, our linear model showed that decision accuracy declines continuously as HR increases. These results mirror the broader literature on cognitive fatigue and physiological dysregulation, and they point toward HR as a real-time biomarker for cognitive strain.[1,41-43] Monitoring HR could thus serve as an indicator of internal cognitive load, especially in fast-paced decision-making contexts.[41,42]

Age-based differences further supported this relationship. Older players (>25 years) exhibited significantly higher HRs and slightly lower move accuracy (not statistically significant) compared to younger counterparts, suggesting they may be more physiologically reactive to stress or experience a sharper decline in performance when under pressure. This aligns with literature linking age to decreased heart rate variability (HRV), reduced prefrontal efficiency, and diminished autonomic recovery.[6,28] The implication is that even among elite competitors, biological age may moderate how well individuals handle cognitive stress.[28] This highlights the potential benefit of individualized stress-monitoring tools in cognitive competition.[44]

The implications of this research extend beyond chess. While the game offers a model for studying cognition under pressure, the relationships researched here are relevant to other high-stakes mental settings. Fields such as eSports, air traffic control, and high-pressure workplaces rely on rapid, accurate judgments under time constraints.[45-47] Training protocols that incorporate biofeedback, stress-regulation techniques, or HR monitoring tools could help individuals maintain cognitive efficiency under stress.[48]

Although the findings are statistically significant, there are some limitations to consider. Firstly, HR data was extracted from publicly available tournament broadcasts and lacked continuous tracking of HR. Secondly, while Chess.com's accuracy metric is widely used, it simplifies decision quality to engine-based comparisons and may not capture psychological or strategic nuances of specific positions, and it does not account for factors such as position difficulty, transparency, or misleading cases. Thirdly, this was a cross-sectional, observational study. While HR and accuracy were correlated, causality cannot be inferred. Finally, the sample consisted exclusively of grandmasters. Hence, the findings may not be generalizable to the broader chess community.

■ Conclusion

In summary, this study provides strong empirical evidence that elevated heart rate, a marker for physiological stress, is significantly associated with reduced decision-making accuracy in elite-level chess. By analyzing biometric and game performance data across 50 games, we confirmed that players with higher heart rates (>130 bpm) consistently played with lower accuracy, particularly under time pressure.

Regression and correlation analyses further established an inverse relationship between HR and cognitive precision, suggesting that even non-physical mental performance is sensitive to autonomic arousal.

Age was also a moderating factor, as older players exhibited significantly higher stress reactivity and slightly lower accuracy, highlighting individual physiological variability in high-pressure decision-making. These findings improve our understanding of performance under cognitive pressure and have broader implications for other domains, where rapid and accurate decisions are critical.[47]

Future research should build upon these findings by integrating continuous heart rate monitoring, heart rate variability (HRV), and neurocognitive markers such as EEG to better understand real-time stress responses.[20,49] Expanding the dataset to include players of varying skill levels, gender, and tournament formats will help increase the generalizability of these results.

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