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Expert Intuition under Time Pressure: Insights from Bullet Chess

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Patrick Finnegan Burns

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Abstract

Existing research on expert decision-making often highlights intuition as a defining feature. Yet there is still no consensus on what the mechanisms of intuition are. Several theories have been proposed to account for this phenomenon, with all of them including chess as a problem space to display their ideas. However, none of these exemplary scenarios have included the use of bullet chess, a time-variant form of classical chess where players have only one minute to complete an entire game. Within this time pressured decision-making space, players must make intuitive decisions to ensure their success as they have on average 1.2 seconds per move. Therefore, it was hypothesized that if intuition is a defining feature of chess expertise, then there should be no significant differences between expert performance in 1-minute games versus 15-minute games. To test this hypothesis, a sample of games was taken from the FIDE World Rapid Chess Championship 2023 (N = 200) and the Bullet Chess Championship 2023 (N= 200). Each game was analyzed using Stockfish 16.1, a state-of-the-art AI chess engine, to obtain an accuracy metric which compared the player's moves to the engine's move. Results showed that there was a significant difference between the groups, with accuracy measures in the longer time variant being higher. The results were discussed in relation to existing theories of intuition. Then a novel approach to exploring the mechanisms of intuition was proposed using ideas from embodied cognition and predictive processing to give a new direction to explore intuition in expertise scenarios.

Abstrakt

In der bestehenden Forschung zur Entscheidungsfindung von Experten wird Intuition oft als entscheidendes Merkmal hervorgehoben. Es besteht jedoch noch immer kein Konsens darüber, was die Mechanismen der Intuition sind. Es wurden mehrere Theorien zur Erklärung dieses Phänomens vorgeschlagen, wobei alle das Schach als Problemraum zur Darstellung ihrer Ideen einschließen. Keines dieser exemplarischen Szenarien beinhaltete jedoch die Verwendung von Bullet Chess, einer zeitvarianten Form des klassischen Schachs, bei der die Spieler nur eine Minute Zeit haben, um ein ganzes Spiel zu beenden. In diesem unter Zeitdruck stehenden Entscheidungsraum müssen die Spieler intuitive Entscheidungen treffen, um ihren Erfolg sicherzustellen, da ihnen im Durchschnitt 1,2 Sekunden pro Zug zur Verfügung stehen. Daher wurde die Hypothese aufgestellt, dass es, wenn Intuition ein entscheidendes Merkmal von Schachkompetenz ist, keine signifikanten Unterschiede zwischen der Leistung von Experten in 1-Minuten-Spielen und 15-Minuten-Spielen geben sollte. Um diese Hypothese zu testen, wurde eine Stichprobe von Spielen aus der FIDE-Schnellschachweltmeisterschaft 2023 (N = 200) und der Bullet Chess Championship 2023 (N = 200) entnommen. Jedes Spiel wurde mit Stockfish 16.1, einer hochmodernen KI-Schach-Engine, analysiert, um eine Genauigkeitsmetrik zu erhalten, die die Züge des Spielers mit denen der Engine verglich. Die Ergebnisse zeigten, dass es einen signifikanten Unterschied zwischen den Gruppen gab, wobei die Genauigkeitsmaße in der längeren Zeitvariante höher waren. Die Ergebnisse wurden im Hinblick auf bestehende Theorien der Intuition diskutiert. Anschließend wurde ein neuartiger Ansatz zur Erforschung der Mechanismen der Intuition vorgeschlagen, der Ideen aus der verkörperten Kognition und der prädiktiven Verarbeitung nutzt, um eine neue Richtung für die Erforschung der Intuition in Expertenszenarien vorzugeben.

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Chapter 1: Introduction

1.1 What is Intuition?

The phenomenon of intuition is a fabled topic within the realm of cognitive science as its mechanisms and uses have been debated amongst researchers from various disciplines. Simply defining what intuition is, calls for investigation as common definitions only obscure the phenomenon more. For example, Epstein (2010) defines intuition as “a sense of knowing without knowing how one knows” (p.296). Although true in experience, it doesn’t tell us much except that intuition involves a sense of unconscious processing. Therefore, the question becomes, what constitutes the unconscious processing that leads to intuition? One way to narrow this down is to first look at the characteristics one would use to describe instances of intuition.

Common characteristics describing instances of intuition are as follows: rapid problem-solving speed; being unaware of how a solution is reached; an emotional element; and a tendency to be correct (Gobet, 2018). Thus, the characteristics of intuition point to the fact that it is a mechanism that aids in decision-making. From here we can note that intuition is unique in its approach to decision-making as it functions without deliberation and instead functions automatically (Plessner et al., 2008). This automatic problem-solving phenomenon is the main attribute of intuition, and it has been studied primarily in the context of expertise.

Experts are defined as those who are able to perform in their discipline at the highest level. This performance is often measured on the speed and ease to which an expert can recognize a given situation and solve a problem (Gobet & Chassy, 2009). Hence, experts are measured on their ability to use intuition. This expert use of intuition has been researched in many areas ranging from firefighting to nursing (Klein, 1988; Benner & Tanner, 1987). However, the greatest amount of research in expert intuition is focused on the domain of chess. Chess offers a great space to observe expert intuition as it is a controlled environment with a complex decision-making space. It also has a quantifiable level of expertise with the Elo ranking system, which makes it easier to find samples containing the best of the best (Elo, 1978). Likewise, there is the ability to manipulate time and therefore observe how experts make decisions under pressure.

Yet, even with the research focus on chess, there is no final consensus on the nature of intuition. Several theories have been proposed to explain intuition in chess and decision-making at large, such as the chunking hypothesis, holistic approach to intuition, and template theory (Chase & Simon, 1973; Dreyfus & Dreyfus, 1986; Gobet & Chassy, 2009). However, there are still many unanswered questions. Therefore, the following paper aims to address these existing theories of intuition as they relate to chess and offer alternative explanations that may be gained from looking at chess strictly under time pressure and through modern theoretical approaches to cognition.

Chapter 2: Theories of Intuition in Chess

2.1 De Groot's Classic Chess Experiments

Intuition's role in chess was first discussed by De Groot (1978) in his work on chess thinking and decision making. In his seminal experiments, players ranging from grandmasters to beginner players were tasked with solving different chess positions.

Within these experiments, several sub-problems were under investigation. One of them looked at the criteria for mastership. In other words, what makes a master player so special? This specific question arose after an analysis of one the experiments which tasked players to analyze a position and report on the depth of their calculations for future possible moves. The results showed that expert players and grandmasters had no significant differences in the depth of their calculations, which was counterintuitive to perceptions at the time that believed a master differentiates themselves primarily on their ability to calculate deeper than lesser ranked players. This led to the idea that there must be a qualitative difference in thinking based on experience which separates masters. De Groot (1978) hypothesizes the following:

"If it is correct that the most important difference between master and non-master lies in the differentiation and scope of the system of experiential linkings and if consequently the master can start thinking from a higher level, then this class difference should come out clearly in the first minutes, nay seconds, of the perceptual and thought process." (De Groot, p.321).

To test this hypothesis, several perceptual studies were conducted. One of the studies involved four participants who ranged in skill level form grandmaster to beginner. Each participant was exposed to 16 different chess positions at various time limits ranging from 2 – 15 seconds. After viewing each position, the players were asked to give a short verbal report describing their initial reactions to the position and their thought processes behind how they would memorize the position. After this introspective verbal report, the participants were instructed to recreate the position from memory. The results from this study showed that the higher-level players were faster and more accurate in recreating the positions than weaker players. Furthermore, the data from the verbal reports showed that recall of past experiences was a major factor in master success. De Groot (1978) found that the master players recalled positions in terms of ‘dynamical complexes’, which he referred to as patterns of pieces that hold game-related meaning. For example, certain pawn structures, such as a castled king, doubled rooks, etc., all relate to previous experiential contexts in which the master players can easily recall. Results from the combined data suggested that master players perceive a single position in 3 – 4 of these ‘dynamical complexes’, making it easier for them to assess and memorize the position. Thus, De Groot was able to confirm his original hypothesis, as it was clear that the master level players were able to outclass the lower rated players through their perceptual and experiential knowledge in the first few seconds of viewing the position.

2.2 Chunking Hypothesis

Inspired by this early work, researchers Chase & Simon (1973) recreated De Groot’s study. The researchers wanted to further investigate the role of ‘dynamical complexes’ or in their words ‘chunks’ on chess skill. Specifically, they wanted to determine the limits of chunks and how chunks were encoded into memory. To investigate this hypothesis, the researchers recruited three chess players: one master, one advanced, and one beginner player to participate in two experimental tasks. The first task, labeled the ‘perception’ task, consisted of two chess boards placed side by side. On one chess board a random position was presented while the other board remained blank with the pieces on the side. The player was instructed to recreate the position on the blank chess board and was able to freely look at the reference board at any time. The goal of this experiment was to record the number of times and length in which the player glanced at the reference board. It was hypothesized that longer glances towards the reference board would indicate the beginning of a new chunk while quicker glances would indicate that pieces were in the same chunk. The researchers found that master players took significantly less time to glance at the reference board compared to their lesser rated peers. This indicated that master players could recognize and encode chunks into memory faster than their peers.

The second task, labeled the ‘memory’ task, was modeled after De Groot’s original memory experiment. In this variation, players were exposed to different positions for 5 seconds then asked to recreate the position from memory. However, unlike De Groot’s methodology, the players were given multiple trials to accurately recreate the position. If the player failed to recreate the position perfectly, the trial would start over with another 5 second view time until it was completed accurately. Although multiple trials were given, the researchers still focused on the accuracy of the first trial to compare it with De Groot’s initial findings. Results from this task showed that the master player had a significant advantage at recreating the positions from memory compared to his lesser ranked peers. These results supported De Groot’s original findings and further confirmed the idea that the accuracy of initial perceptual processing of a chess position differentiates master level players. Therefore, rapid perception is a key component of expertise.

Furthermore, additional analysis of the combined data from the two experiments led the researchers to make several conclusions on the nature of chunks. Firstly, the definition of a chunk was established as two or more pieces grouped together within 2 seconds. Secondly, the factor of chess skill on chunk size was only significant for the first few chunks. Once again, the first initial perceptions accounted for the master advantage. Thirdly, master players were able to recall more chunks overall, within the bounds of short-term memory limitations. Therefore, master players performed better on the tasks due to their ability to produce larger chunks in size and more chunks in quantity. Thus, this would lay the groundwork for the chunking hypothesis to take its place in explaining the mechanisms behind the initial rapid perception of a problem-state.

2.3 Criticisms of Chunking Hypothesis

There are several issues that arise when investigating the chunking hypothesis. Firstly, there is no discussion of a how a single action is linked to a perceived chunk. For any given chunk there can be a multitude of different move possibilities for the position, yet there is no explanation for this action selection. Furthermore, if chunks consist of 3 to 4 pieces of familiar pairs like triangular pawns or double rooks, then this is not enough information to elicit a move. Simply put, the size of the chunks “do not embody the dynamic relationships that would evoke potential chess moves” (Holding, 1992, p. 12). Moves are chosen within the context of previous play and future plans, therefore approaching chess ability from this static perspective cannot fully explain expert ability. Secondly, the role of STM in the chunking hypothesis is questionable. The central claim that chunks are necessary due to the limits of STM has some confounding evidence. Frey & Adesman (1976) designed an experiment in which chess players were tasked with counting backwards while being presented with one or two chess positions. After the presentation they were asked to reconstruct the positions from memory. Results from this experiment showed that there was no significant detrimental effect from the counting condition and recall differences between one position or two positions were also not significant. Therefore, the researchers concluded that STM does not play such a significant role as proposed in the chunking hypothesis. The experimental conditions aimed to disrupt the processing of STM, yet there was no significant decline in performance, therefore Frey & Adesman (1976) proposed that these findings suggest a direct encoding of chess positions to LTM. However, these criticisms do not entirely disregard the existence of chunks, they merely call for a revision to the original idea. In its simplest form the chunking hypothesis does not adequately explain expert skill and intuition, better explanations for action selection and memory encoding are needed to create a stronger theoretical framework.

2.4 Expertise as Intuition

Although there is support for the Chase & Simon's approach to understanding expert intuition, there is an opposing view that states there is no pattern recognition or symbolic representation involved in the matter. This is known as the holistic approach to intuition, a theory that hypothesizes that intuitive decision-making and expertise are developed as one through a series of steps gained through domain specific experience (Dreyfus & Dreyfus, 1986). Expertise in this case is the same as intuition, and a chess grandmaster moves their pieces around the board using the same mechanisms as they would for walking or talking. Meaning their experience in the skill has become so involved that their resulting behaviors display accuracy, fluidity, and automation without the need for deliberation. Dreyfus and Dreyfus (1986) propose a five-step process in which one goes from a novice to an expert. Each stage sees different perceptual and decision-making strategies that differentiate people of various skill levels. At stage one, a person begins as a *Novice* in the acquisition of a particular skill. Here one must learn all the objectively relevant information of a particular skill removed from the context of a real situation. For example, a novice chess player would learn explicitly the difference between pieces and how they move on the board outside the context of a game scenario. After the player understands the basic rules and structure, they would move into the *Advanced Beginner* stage. Here the player begins to get acclimated with situational contexts through exposure to real world experience. The beginner chess player will now be able to recognize positions where their king is in danger based on situational cues combined with their objective knowledge about how the pieces move. With more experience a beginner moves into the *Competence* stage in which the completion of a goal becomes more important than explicitly focusing on executing the rules learned. A player in this stage will look at the situation of their current game and develop a plan to capture the opponent's king. This will require deeper planning, sacrifice, and emotional involvement than the previous stages' approach to decision making. Dreyfus & Dreyfus (1986) state that most scientists studying decision-making are in fact focused on these first three stages, however they state that intuition does not follow these same principles. Intuition is only found in the final two stages: *Proficiency & Expertise*. In the *Proficiency* stage a person can intuitively organize a plan of attack in a chess game, however they will still combine analytical thought in their final decision-making process. They will instantly know their position and plan, but they will consciously think about the best move to achieve this. Only in the last stage, the expert player intuitively knows and acts. The chess master is situated in the game and is not perceptually chunking pieces. Therefore, this perspective sees intuition as the "product of deep situational involvement and recognition of similarity" (Dreyfus & Dreyfus, 1986, pp. 29).

Some evidence for the stages of skill acquisition leading to expertise has been showcased in nursing (Benner, 1982). Data collected from interviews and observations of nurses in acute care settings showed that competent nurses and expert nurses will not approach and solve a problem in the same way. Competent nurses rely on rules and formulas to diagnose and treat, while expert nurses approach problems devoid of standardized procedures. Expert nurses rely on their past experiences to rapidly diagnose and treat patients (Benner, 1982). Similar evidence has been displayed in research that focused on the decision-making processes of firefighters involved in atypical circumstances. Klein et al. (1988) found that firefighters in these situations relied on previous experiences to identify similar visual cues and situational prototypes to base their actions. This allowed firefighters to act intuitively in situations requiring rapid decision-making. When asked to recount their experiences, experts often have a hard time verbalizing their thought processes as they are automatic and intuitive. Dreyfus & Dreyfus (1986) argue that any description of a thought process or mental simulation leading to an intuitive decision would be seen as an attempt to rationalize an indescribable action through the invention of reasons. One thing remains clear is that the holistic approach still emphasizes the role of recognition in explaining expert intuition.

2.5 Criticisms of the Holistic Approach

Unfortunately, the way in which holistic recognition manifests itself is unclear. Under Chase & Simon’s (1973) chunking hypothesis is the assumption that symbolic representation underlies perceptual processing. A chess grandmaster stores around 50,000 of these chunks in memory from past experiences and they are retrieved through pattern recognition. In the holistic approach, experts also rely on recognition using past experiences, however, Dreyfus & Dreyfus (1986) argue that there is no symbolic information exchange or feature detection between perception and memory.

This leaves a large explanatory gap into understanding how a person achieves intuitive expertise from perceiving situations holistically. Likewise, clear evidence for Dreyfus & Dreyfus' (1986) stages of skill acquisition has not been exemplified in many domains. Although, Benner (1982) presents some evidence that expert nurses behave according to the proposed categories. It is not clear that there are actually five distinct stages. The boundaries of these stages are arbitrary and lack empirical support. Therefore, the stages seem to act as mere suggestions rather than concrete sequential milestones, making the proposition of stages somewhat irrelevant to the overarching theory (Gobet & Chassy, 2009).

2.6 Template Theory

In response to these hypotheses of intuition and expertise, a third explanation called the template theory was proposed. The template theory aimed to eliminate the weaknesses of the previous discussed theories and create a more substantial explanation of intuition that encompassed rapid recognition, relationship to action, learning, and memory (Gobet & Chassy, 2009). The theory initially began out of a series of experiments that wanted to challenge some of the conclusions made by Chase & Simon (1973), specifically regarding memory processing. In the chunking hypothesis, it was proposed that a large quantity of chunks had to be held in the long-term memory (LTM) of expert players. This was assumed due to the fact that the expert players were outperforming lesser ranked players in the memory task even thought they were subject to the same short-term memory (STM) limitations.

However, the several studies previously mentioned following Chase & Simon's (1973) work showed evidence that expert chess players could hold more chunks in memory than STM allowed and that interference tasks showed no significant effect on memory performance. Therefore, there was major concern over the role of STM in the grand scheme of the chunking hypothesis. In order to solve this issue, a series of experiments were conducted to sort through the conflicting evidence and create a clearer picture.

The experiments revolved around the concept of reconstructing multiple chess positions. If STM encoding was the sole proponent involved in the task, then the number of reconstructed pieces should remain around the limit of STM. On the contrary, if rapid LTM encoding is possible then more pieces will be remembered over more boards (Gobet & Simon, 1996). Results from these experiments left the researchers to conclude that there was both STM and LTM involved in reconstruction. Expert players were able to reconstruct more pieces over more boards than their lesser ranked peers in short exposure times of 5 seconds. Gobet & Simon (1996) proposed the merging of chunks with the idea of retrieval structures or templates. These templates are slots of information that are held in LTM and can be added to with new information. Therefore, chunks can be rapidly attached to a template that contains positions which have been previously encountered by a player. This would explain why expert players are able to perform better outside the bounds of STM. Information stored in templates and immediately perceived chunks work together to create expert intuition. This theory has been successfully transferred into a computer model called CHREST in which chunks and templates are indexed by a discrimination network that sequentially tests STM inputs for access to LTM (Gobet & Chassy, 2009). Data collected from simulations ran with

CHREST have been used to empirically support the template theory as it performs adequately in chess recall tasks.

The conclusion of template theory is that although aspects of expert intuition are perceived holistically, the mechanisms that lead to them are created locally (Gobet & Chassy, 2009). Therefore, Dreyfus & Dreyfus' (1986) idea of holistic processing is still a very relevant variable in the template theory. Evidence for this holistic processing, as framed in the template theory, has come out of experiments testing positional evaluation. Previous chess intuition experiments often relied on choice-of-move tasks to investigate players' skill levels. Chassy et al. (2023) argues that although choice-of-move tasks are ecologically valid, they are more suitable for measuring analytic thinking. Conversely, positional evaluation tasks are better suited for measuring intuitive holistic comprehension. To test this idea, players ranging from world grandmasters to candidate masters were exposed to different chess positions for a short duration of 5 seconds each. After the time expired, they were instructed to evaluate the position. In order to evaluate the position, players stated an advantage for either the black or white pieces. If there was no advantage, they could deem the position equal. Results from this experiment showed that there was a significant skill difference amongst the different rated players. World grandmasters proved to have the lowest evaluation error and skill ratings accounted for 44% of evaluation scores (Chassy et al., 2023). The results show support for the theory that holistic processing is a fundamental part of intuition, as players were successful in evaluating positions in very short presentation times. The effect of skill difference also further supports the idea that higher skilled players have stronger intuition than lower ranked players even when they are both rated far above the average.

2.7 Remaining Issues

However, issues still remain in the template theory. Although computer simulations have been successfully run under this model, their performance is not up to the standard of grand master players. Similarly, just because a computational model can be created out of a theory, does not mean human intuition acts in the same way. Human cognition is highly flexible, something of which these models lack. If you shift a position on a board down a few squares this requires the model to treat the position as entirely new chunks, however the human player would not reclassify the same way (Linhares & Freitas, 2010). Furthermore, this theory encounters the same criticisms present in the chunking hypothesis, as the template theory is fundamentally based on this research. In the computational template theory models, chunk-to-move associations are learned through scanning previously played games of a masters' database. Still, if presented with a novel position the model will have no reference to make a decision.

On a grander scheme, proponents of the template theory alongside the chunking hypothesis, are highly restricted by the scientific paradigms in which they were framed around. The cognitivist approach to mind was the prominent school of thought in cognitive science at the time. Therefore, the need to fit intuitive thinking in this model appears to be a criterion that many researchers in this domain cannot see past. Treating the mind as a computational device and attempting to model its behavior in code, may be a misguided venture.

Chapter 3: Time Pressure

3.1 Time Pressure on Chess

Tracing back to the defining characteristics of intuition we see that the speed in which a problem is recognized and solved is a quintessential attribute of the phenomenon. All of the theories discussed in the previous section have been formulated with this characteristic in mind. Likewise, the experiments that anecdotally support these theories have all measured success in terms of speed and accuracy. This focus on speed and accuracy assumes that time pressure leads to intuitive decision-making. However, experts might use different decision-making processes under varying time constraints. To explore the boundaries between intuitive and analytical processes in chess, researchers designed an experiment correlating the quality of moves with time pressure. The researchers predicted that the move quality of expert players would be less impacted by time pressure compared to lower-ranked players, as experts rely more on intuitive processes (Calderwood et al., 1988). Players participated in a series of games at two different time levels: 90 minutes and 5 minutes. Each move from each game was coded using a standardized score sheet on a scale from 1-5. Results from this study showed that there was no significant difference in move quality between the two time classes. Therefore, this research further supported the idea that experts rely on intuitive thinking more than analytical thinking (Calderwood et al., 1988).

Similar research was conducted comparing chess ratings amongst players who played in both blitz (5 minute) and classical (90 minute) tournaments. The skill level of players in these tournaments ranged from beginner to master. Burns (2004) found that 81% of performance variance was shared between blitz and non-blitz chess, which infers that intuitive processing accounts for most of the differences between chess skill levels. Furthermore, under the blitz time control skill differences were equalized for lesser ranked players. However, at the master level there was no equalization factor. This is because master players significantly rely on intuitive decision making over search-based decision-making (Burns, 2004).

Although these studies claim to show evidence that experts rely on intuitive processes over analytical ones. There are some potential problems in the theoretical assumptions made by the researchers. In a 5-minute blitz game, a player has on average 6 seconds per move, as a standard chess game consists of around 40 moves. Hence, the question arises as to how much time is necessary for analytical search-based decision-making? Similarly, is 6 seconds sufficient for strictly intuitive processing? If 6 seconds is enough time to conduct an accurate search, then the conclusions made by the previous research are misleading.

When these studies were conducted blitz chess was just gaining more popularity. The first official FIDE (World Chess Federation) world blitz championship was officially organized in 2006. Previously there were only two unofficial world tournaments which took place in 1970 and 1988 (Harding, 2016). At the time of these studies, expert players did not have the same exposure to speed chess as they do today. Likewise, traditional views on blitz chess have seen this variation as "poor quality that is considered to be of little or no value to analyze" (Henebry, 2010, p. 478). Given the lack of exposure and stigmatism behind blitz chess, it can be inferred that the players exemplified in these studies were not playing at a level on par with modern experts. Today, blitz chess is a common occurrence with world championship tournaments being held every year. However, it is still unclear as to how much this variant is being played as opposed to more classical versions.

3.2 Online Database Insights

To gain some insights into the playing habits of expert players, data was queried from the largest online chess website, Chess.com. Online chess provides a great opportunity to gather data as it hosts players from a wide variety of skill levels. Users of Chess.com can select the time variant they want to play in and are matched with players of a similar caliber. The major time categories are as follows; Rapid chess refers to any time control that is longer than 10 minutes per player. The Blitz category consists of games between 3 and 10 minutes, with the most popular choice being 3 or 5 minutes. Finally, Bullet chess consists of any game under 3 minutes. In this ultra-fast paced category the most common games are played at 1 minute (*Time Controls in Chess - Chess Terms*, n.d.).

Since the time pressure experiments explained in the previous section, exposure to fast chess has grown drastically. The goal of this data analysis is to determine to what extent are the best players in the world participating in these games. If expert players are indeed playing these games significantly more than longer variants, there is reason to believe that the results from the time pressure studies conducted decades prior might see different results in today's chess world.

3.3 Data Collection from Chess.com

All analyses were performed using R Statistical Software (v4.2.3; R Core Team 2023). Data for this analysis was collected from Chess.com using the chessR package in R (v.1.5.3, Zivkovic, 2024). The chessR package provides functions to interact with the Chess.com API, allowing for the extraction of various game and player statistics. The data was collected on games played by a selection of the top 5 FIDE ranked chess players in the world as of July 17, 2024. The data query extracted every game the players have played on Chess.com in the last five years. Games that were not of the standard chess rules were removed. The period of games extends from 2019 to 2024, with a total count of 55,887 observations.

3.4 Results of Database Analysis

As shown in Figure 1, the majority of games played were of the blitz time control, with total games numbering 36,520 (65% of total games). Second, was the bullet time control, in which players have an even shorter amount of time to play. This variant registered 17,690 games (32% of total games). Lastly, the rapid category made up the remaining 3% of total games played, with a low number of 1,677 games. The most popular clock time was the 3-minute game which accounted for 51% of all games played. The next most popular clock time was the 1-minute bullet game, which accounted for 16% of all games.

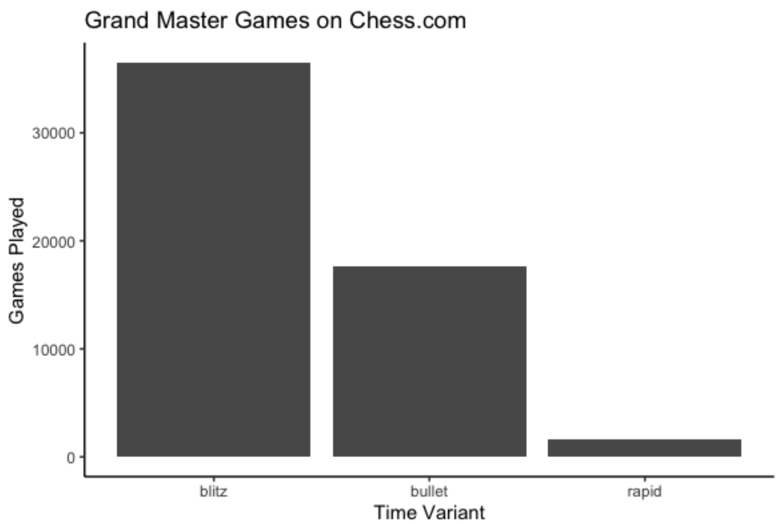


Figure 1

3.5 Discussion of Database Analysis

According to the online game data collected, the top players in the world are spending most of their time playing different variations of speed chess. In the most popular game type, the 3-minute blitz game, players have on average 4.5 seconds per move. This is 1.5 seconds less per move than the 5-minute game trials employed in the previously mentioned time pressure experiments. Even more extreme is the prevalence of 1-minute bullet games, in which players have on average 1.5 seconds per move. Why are the top 5 players in the world playing these games over longer time controls in which deeper analysis can be utilized?

There are several possible answers to this question. Firstly, games with shorter time limits take less time to play. This is the simple practical answer to the data. Why spend 1 hour on a game when you can do it in 3 minutes? Expert players might have less time in the day to play longer matches and reserve most of these games for in person training or tournament play. This may be a better explanation for the average player, as most people play chess as a hobby and may have only have a limited time to play. However, these are the top 5 players in the world. Their job is to play chess and therefore time shouldn't be a serious issue. Therefore, there must be some value in playing fast paced chess.

One potential way that this may be of value is the increased exposure to different positions. In line with the chunking hypothesis, greater exposure to patterns would lead to a greater repertoire of accessible chunks. After playing five 1-minute bullet games, a player has experienced a significantly larger number of positions as opposed to one a 60-minute classical game. According to the chunking hypothesis, the boundaries of a chunk are recognized within 2 seconds (Gobet & Simon, 2000). In a 3-minute blitz game, this means that each chunk must be recognized and an action must be chosen within 4.5 seconds. Here the time pressure becomes tricky for the chunking hypothesis explanation as there is no understanding to how many chunks are necessary to make a move. Surely, only recognizing one chunk out of an entire board position does not give enough information to make a promising move.

After recognizing two chunks at 2 seconds each, there is 0.5 seconds left to select a move. This may be possible but seems unlikely, as both chunks need to point to a single move within the allotted time frame. Furthermore, 4.5 seconds per move is the average time. This means that there are plenty of times in which players are making faster decisions. How does the chunking hypothesis account for this speed? What is happening when players are making moves in 2 second time intervals? What is happening when players are playing bullet chess at the 1-minute time control?

To account for this speed, the chunks would have to be recognized faster than proposed in the original hypothesis. Likewise, an explanation for action selection would have to formulated in which little time is necessary. Then there needs to be an explanation to why mere access to more chunks leads to better play. Any player can play the blitz or bullet chess time control for thousands of games and therefore gain access to an enormous number of possible chunks. However, this will not make them a grandmaster. Recognizing patterns is only a piece of the puzzle, but knowing what move to make is what separates amateurs from experts. This is learned through experience and training in dynamic games and scenarios. Thus, considering these criticisms, the potential benefit of increasing one’s chunk inventory seems less likely for the expert player.

Viewing the appeal of speed chess from the perspective of holistic processing might offer a better explanation. Instead of focusing on individual chunks and moves, experiencing a speed chess game as a dynamic embodied interaction relinquishes some of the challenges the chunking hypothesis faces. In line with Dreyfus & Dreyfus' (1986) claims that expertise is intuition, expert performance in speed chess heavily relies on intuitive decision-making as the demands of time pressure leave little time for deep search. Therefore, the top chess players in the world may prefer to play speed chess as it hones intuitive thinking. Differences in skill at the highest level comes down to the strength of intuition, which is only available through experience. Playing thousands of blitz and bullet games would only strengthen this experience.

However, the holistic approach still runs into its original shortcomings. There is no explanation to how this experience-based recognition works at the base level. If expertise is also based on experience and intuitive processes precede any analytical thought, then why are the highest ranked players in the world not the same highest ranked players in the categories for speed chess. For example, Magnus Carlsen is ranked number one in the world according to the FIDE rankings and he is also ranked number one in blitz chess according to Chess.com. But, as of July 2024, he is ranked seventh in the bullet category. Shouldn't the best player in the world be the best player in every time category? If expertise is intuition, then according to the holistic theory, performance under different time pressure should not vary as the same intuitive decision-making will be at use if there is 1-minute to make a move or 1.5 seconds. Similarly, if we look at the third ranked FIDE player, Fabiano Caruana, we see he is ranked #13 in blitz chess and #29 in bullet chess. How can the simplistic view of holistic processing account for this discrepancy?

3.6 Call to Investigate Bullet Chess

Evidently, the best players in the world are playing variations of speed chess over longer form games at significant rates. Both 3-minute and 1-minute games dominate the overall game play and the reasons behind this are only speculative. However, further investigating and observing the appeal and mechanisms behind speed chess can shed light on intuition under time pressure in general. Although previous research has considered these games, there has not been a revised investigation into the modern era of chess under time pressure. There is reason to believe that with the increased exposure to these games and overall preference for speed chess, that the level at which experts perform under time pressure may be significantly different to the results gathered decades prior. Similarly, previous research has only investigated expert performance under the blitz time control, specifically at 5 minutes. As shown in the results gathered here, even in the blitz time control players are playing at 3 minutes the most. But, more importantly experts are playing at the 1-minute time control in massive numbers. Here the time pressure is at an extreme that is untested amongst any of the previous research. Therefore, insights gained from bullet chess have the greatest potential to shed light on the mechanisms behind expert intuition.

3.7 Relevance of Bullet Chess

According to the data provided in the previous section, in the past five years the top 5 chess players in the world have played 32% of their online chess games in the bullet category. From these games, the 1-minute category accounted for 51% of all bullet games, while the 30-second category accounted for 31%. Like the blitz category, it is unclear as to why expert players are playing at these speeds over longer form games. To put this into perspective, in the 30-second time control, players have on average 0.75 seconds per move! Although this may seem nonsensical, expert players are taking this extreme play seriously. There are yearly world championships for bullet chess hosted by Chess.com, in which the top players in the world compete for a cash prize. The current 2024 bullet chess champion is Alireza Firouzja, who is ranked #15 in the world according to FIDE. To win the tournament he beat Hikaru Nakamura, who is ranked #2 in the world according to FIDE (McGourty, 2024).

3.8 Attributes of Bullet Chess

Before going further, bullet chess must be explained in more depth. Bullet chess differs from other versions of chess primarily in time pressure, as already mentioned. However, there are some other key differences in this variation. Firstly, bullet chess is primarily played on a computer. Although it is possible to play in a physical setting, the time it takes to move around pieces and set the clock creates too much of a time issue for players. The digital setting of bullet chess also allows for the act of pre-moving. Pre-moving allows a player to pre-select a move while it is their opponents turn. This allows for the move to be automatically made once the opponent has played their turn. If the move is illegal then the pre-move is automatically cancelled by the program, if it is legal then the move is made. Pre-moves may also be cancelled by the player if they do it before their opponent moves (Nakamura & Harper, 2009). This feature allows players to significantly save time, however these moves are not always the safest. One miscalculated pre-move can lead to a certain defeat. Therefore, the pre-move does not give a certain advantage to a player in bullet chess. Likewise, it does not significantly differentiate it from longer variations of chess, as it is plausible to pre-select a move mentally in longer form games. The digital board just allows pre-moves to be physically manifested and the time-pressure encourages its prevalence.

Bullet chess also inflates another mental aspect to chess, as time-pressure increases the ability to “psych-out” your opponent. As Nakamura & Harper (2009) write “the best mistakes are the ones you get your opponent to make” (p. 215). This psychological aspect of understanding your opponent’s behaviors and emotions plays a large role in bullet chess. It can often be the advantage that decides a game. Playing moves that your opponent does not expect can throw off their intuitions and pre-moves, leaving them to spend more time in recuperating their strategy. This is detrimental to players as running out of time means you lose the game, regardless of how many pieces you captured.

Additionally, the nature of bullet chess often leads to a more aggressive playing style. Players should attempt to take the initiative and set the pace of the game by putting constant pressure on their opponent (Nakamura & Harper, 2009). Since the fast-paced play limits the opportunity for careful deliberation, opponents can struggle combating this tactic. This dynamic lends itself to the “psych-out” phenomenon where aggressive play can interrupt the opponents’ thought processes. Therefore, there is an intense pressure to keep focus and maintain this initiative.

Thus, when examining bullet chess, the obvious difference of time-pressure may produce some non-obvious changes in the way the game is played. Of course, players will play faster, but they will also look to save time in any way they can. Since time holds a much larger value, players’ approach to the game incorporates more predictions and understanding of social and emotional dynamics. Knowing when to pre-move or knowing when to make moves that surprise your opponent can be beneficial in this way. Bullet chess is then less based on traditional approaches to calculation and theory that would be present in longer form variants. Therefore, it can rely more on intuitive based play which replaces the time-consuming process of methodological calculation. In this manner bullet chess is an ideal candidate to gain insight into the nature of intuition.

Chapter 4: Methods

4.1 Introduction to Experiment 1

Now that the essence of bullet chess has been explained, we can explore how expert players perform in this category. If intuition is a driving factor in expert decision-making, then performance in this extreme time pressure variant should be closely related to other time controls. Previous studies have shown how expert chess players are able to perceptually recognize chess positions accurately under time pressure. However, most of the experiments are static, as they only incorporate single fixed positions into the experiment. In order to explore the performance of expert players in chess, it can be beneficial to explore the game as a whole dynamic phenomenon.

Therefore, one way to investigate the performance of chess players is to utilize the evaluations of a chess engine. Since the chess engine Deep Blue beat the world champion Gary Kasparov in 1996, computer chess programs have been proven to outperform human capacities and have only gotten stronger in the present day. Thus, the chess engine can used as a benchmark for expert performance in this domain, therefore, comparing a human player’s moves to what the engine would play in the same situation can give us a metric to rely on.

In a sense this analysis is a modern update to the Calderwood et al. (1988) experiment. Instead of human evaluation scores, chess engine scores will be used. Likewise, instead of 90 minutes versus 5 minutes, the comparison will be 15 minutes versus 1 minute. Calderwood et al. (1988) found that there was no significant difference between the time-classes in his study, thus using it as evidence for the prominence of intuitive thinking in expertise. Yet 5 minutes is arguably enough time for analytical thinking to be present, making the conclusions proposed by the authors a bit underwhelming. Moreover, bullet chess was not popular when this study was conducted, whereas today it is commonly played amongst the best players in the world. Hence, the 1-minute bullet game is a much stronger benchmark for representing intuitive thinking as the average time per move is significantly lower than a 5-minute game.

In the following data analysis, experts' performance in bullet chess (1-minute) versus rapid chess (15-minutes) are compared using the evaluation metric provided by the chess engine Stockfish 16.1. The goal of the comparison is to see to what extent intuition plays a role in chess expertise. If intuition is the driving factor of chess expertise, then it is hypothesized that the average evaluation scores between the two time controls will not have any significant differences. Furthermore, the evaluation scores will support a general exploration of the processes involved in bullet chess as there has not been much research focused on this phenomenon. The evaluation scores can provide some insight into the way time-pressure may affect normal chess thinking and give ideas on the limits of intuitive thinking.

4.2 Data Collection for Experiment 1

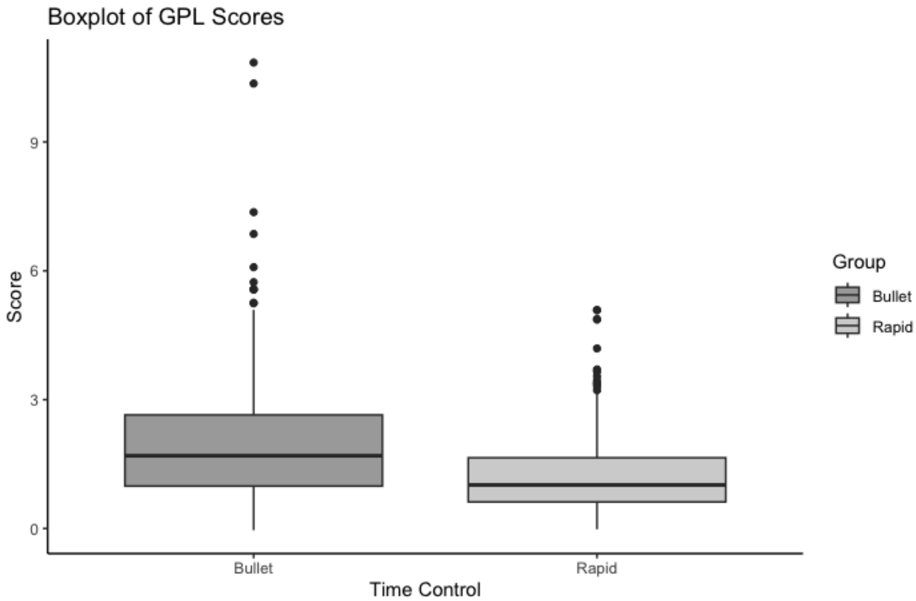
The dataset for this analysis was collected from two world championship chess tournaments conducted in 2023. The dataset was made up of a total of 400 games, with 200 games randomly sampled from the FIDE World Rapid Chess Championship 2023 and 200 games randomly sampled from the Bullet Chess Championship 2023. The FIDE World Rapid Chess Championship 2023 played under the official time control of 15 + 10. This means that each game is 15 minutes long and 10 seconds are added to the clock after each move is played. While the Bullet Chess Championship has an official time control of 1-minute per game, with no increment added after each move. PGN (Portable Game Notation) files were downloaded from Chess.com for each of the respective tournaments. PGN files are plain text files which represent chess game information and are used in modern chess programs. A python script was then utilized to randomly select 200 game PGNs from each tournament. The resulting PGN files were used to obtain the evaluation data via Stockfish 16.1, a state-of-the-art chess engine.

4.3 Evaluation Data

Every position in the PGN files were evaluated and annotated by Stockfish at a depth setting of 20. The evaluation scores in which Stockfish annotates the positions are in centipawn loss values. Centipawns represent (1/100) of a pawn value and evaluation scores at each position therefore show different advantages for black or white. A (+50 evaluation) means that the white player has the advantage at a value of half a pawn (Linville, 2023). These annotated PGNs were then used to calculate the GPL score, which is the main performance metric used to compare the two samples. GPL measures the difference between the perfect moves determined by Stockfish and the actual moves played in the game. Therefore, a value closer to zero means that the moves were closer to the engine's recommendations (Ismail, 2024). GPL scores for each player of each game was recorded, leaving 400 GPL scores for each tournament. See Table 1 and Figures 2 & 3 for an overview of the two groups scores.

Figure 2

Figure 3



4.4 Results

A Mann-Whitney U test was conducted to compare the GPL scores between the bullet tournament (*N* = 400, *M* = 1.98, *SD* = 1.42) and rapid tournament (*N* = 400, *M* = 1.21, *SD* = 0.91). The results indicated a significant difference between the two groups, *U* = 51,150, $p < 0.001$, with the rapid tournament (*Mdn* = 1.015) having significantly lower GPL scores than the bullet tournament (*Mdn* = 1.694). The extremely low p-value indicates a powerful difference between the two groups, thus indicating players playing under the rapid time control played much more accurately (according to the engine) than players in the bullet time control. Furthermore, the variability in GPL scores was higher in the bullet tournament (*SD* = 1.42) compared to the rapid tournament (*SD* = 0.91), suggesting that the faster pace of bullet chess led to more diverse player performance. The interquartile range for the bullet tournament was (*IQR* = 1.66), while for the rapid tournament it was (*IQR* = 1.03) further indicating that players under the rapid time control were more consistently accurate in their gameplay.

4.5 Interpreting the Results

Thus, the results from this data analysis show that expert players under the time pressure of bullet chess are performing less accurately than expert players playing with more time. It can be inferred by the significant difference between the two groups that relying on intuitive thinking alone is not as powerful as incorporating deeper search and planning. Therefore, analytic thinking may be more important to expertise, which is contrary to what was concluded by Calderwood et al. (1988). Since, this experiment utilized 1-minute games, the measure of intuitive thinking is much more accurate compared to the 5-minute games used in previous research. The findings of Calderwood et al. (1988) may then be attributed to a false comparison, as the researchers were not able to truly evoke intuitive thinking. Instead, they seemed to measure analytical thinking at two-time limits. This was also the method of comparison in the tournament research by Burns (2004) which found that skill difference was attributed to stronger intuition amongst master players. Therefore, it can be recommended to reexamine both of these studies under the guide of 1-minute games as the marker for intuitive play.

Likewise, this interpretation directly questions the statements on the nature of intuition made by Dreyfus & Dreyfus' (1986). If expertise and intuition are interchangeable, as described in the holistic processing theory, then the results seen here should have been different. There should have been no difference between the bullet and rapid time controls, as experts' intuition should be the determining skill factor. It can be inferred from these results that experts are indeed engaging in deep analytical thought alongside intuitive decision-making and that there is a distinction between the two. The question arises for Dreyfus & Dreyfus (1986) as to what is more important. In the holistic theory, calculation or "deliberative rationality" can still be utilized by the expert, however, they only serve the purpose to "improve whole intuitions" (Dreyfus & Dreyfus, 1986, p. 40). Hence, these calculations should only be a guiding factor when there are many areas to deliberate on. Chess is a game of constant deliberation, yet Dreyfus & Dreyfus (1986) would still see this process of "deliberative rationality" as a secondary cognitive mechanism to intuitive decision-making. Yet, the results of this analysis point to the conclusion that the primary mechanism is not intuitive decision-making, which falsifies the proposed hypothesis.

4.6 Possible Objections

The present analysis gives some insight into the role intuition plays in chess expertise, but it is important to explore some possible objections to this method. Firstly, the evaluation metric of this experiment measured the accuracy based off how the engine would play. Therefore, the question arises to how important is it to play like the engine? As mentioned in the previous section, the time pressure of bullet chess causes players to adapt their normal chess playing style. The prevalence of aggressive play and "psych outs" do not lend themselves well to the deep calculations performed by stockfish. The chess engine lacks the psychological human element of the game, which seems to be more prevalent in lower time controls. In this sense, it is not surprising that GPL scores would be worse in the bullet time control because often times players are making moves that they know are not expected. They do this intentionally to throw off their opponent as the irrational moves can be the strongest. On the other hand, stockfish is searching for the move with the greatest probability to win, it is making moves that are based on concrete calculations not on emotional or psychological strategy. These approaches to the game are very different, although the end goal is the same. Here is where there could be major deviances in scores, at the point where seemingly illogical yet strategic moves are made. However, there is no way to determine what moves are "psych outs", if there are any at all in this kind of data set.

Still the metric of comparison is informative and there is reason to believe that playing with more time will lead to better play.

Specifically focusing on bullet chess there is a lot more to the game that this metric cannot measure. Mainly the psychological strategies human players often employ. As for comparing average bullet versus rapid GPL scores, there seems to be a definitive difference that on average more time leads to more accurate play. Nevertheless, there are times when intuitive thinking is more than enough to also play accurately in line with the engine. In this sense, these times in which players are playing incredibly accurately at extreme time pressures are the data points that may also hold valuable information regarding intuition.

4.7 Outliers

To look at these instances in which bullet chess players are playing incredibly accurately, we can turn to the outliers of the data set. Since a GPL score of zero means that there is no difference between the chess engine recommendations and the player's moves, the lower scores that are below the 2.5^{th} percentile will be considered for this portion of discussion as they are the most accurate GPL scores of the data set. The lower bound of the 2.5th percentile was found to be a GPL score of 0.17. Therefore, all bullet scores with a GPL score less than 0.17 were collected. This leaves a total of 9 games out of 200 that met the outlier requirements. Thus, these are games in which expert players are playing almost identically to how the chess engine would play under the same circumstances. Surprisingly, in one instance the human player is rated to be better! This is possible as Stockfish was set to a depth setting of 20, depth being the depth of calculation in half-moves (*Depth - Chessprogramming Wiki*, n.d.). Therefore, the player outperformed Stockfish at this setting, which has been determined by computing power and general use. Given a higher depth setting, Stockfish could perform better, but it does not discredit the impressive GPL scores seen in this outlier game as a depth setting of 20 is already highly regarded.

The game was between Magnus Carlsen and Daniel Naroditsky, where Carlsen won the game and received a GPL score of -0.04. This means that Carlsen outperformed Stockfish 16.1 at a depth setting of 20. Carlsen made 57 moves during this game, leaving him with an average of 950 milliseconds per move to achieve such an impressive evaluation. Out of the 9 outlier games, Carlsen's scores accounted for 4 of them. As for his opponent Naroditsky, he accounts for 3. This makes the result even more intriguing as Carlsen is playing against a player who also makes up a significant portion of these extremely accurate games. Therefore, the score of this game cannot be written off as a product of disproportional skill levels.

Although these are only 2.5% of the bullet games, they provide evidence that intuitive thinking has the capacity to perform in line with longer paced games. These results are intriguing as they evoke the question as to what causes players to play certain games so well? One practical answer could be luck. Players were simply lucky to play as accurately as in longer games. Yet, another answer to this question could be that in these specific games players are both making moves that do not deviate from opening theory. Chess opening theories in the modern era are different sequences of moves or plans which have been developed by grandmaster and computer collaboration (De Firmian, 2008). They allow for moves at the beginning of a game to be quickly played out of memorization and have the potential to last quite a while keeping the game at an even level. Yet opening theories only account for a portion of the game. Therefore, all of the moves that come after will determine the winner of the game and in this case the resulting GPL score. The chunking hypothesis might say that these types of games are filled with patterns that have been extensively encountered. Therefore, recognition is operating at a greater level than usual, leading to more accurate play. Unfortunately, recognition alone cannot explain how players make the moves as there is no procedure for detailing how a certain move can be selected in a given scenario. Likewise, if the players were relying on chunks shouldn't there have been more than 2.5% of games in which performance was operating at this level?

The holistic theory might suggest that experts are simply acting on their intuition which is the determining skill factor. However, if this is true then it is clear from the analysis that intuition alone is not as strong as deliberative thought. This would be counter-effective in supporting Dreyfus & Dreyfus (1986) view of expertise, which sees deliberation as an attribute of lower skilled players. Yet, in the present analysis the players being investigated are of the expert class and therefore deliberation should not show the effect that it has. Or if it has an effect at all. Since there is no phenomenological investigation tied to this study there is no way to be certain that players are actually deliberating in longer paced games. Critics of Dreyfus have claimed that expert players do deliberate in games and that intuitions are rational and conceptual even in bullet games (Montero, 2016). Therefore, the nature of intuition is still debated.

4.8 What to make of this?

On one hand performance in bullet chess is significantly degraded compared to rapid chess when the metric of measurement is GPL scores. Although there a few outliers in which players score highly in bullet games, these instances do not give significant support to existing theories of intuition and its role in chess. Likewise, recognition-based theories do not give a comprehensive explanation of the findings recorded in the present analysis. Therefore, there are still many open questions regarding intuition's role in expert decision-making as well as its role in general cognition. Focusing on the validity of the GPL metric, its ability to measure bullet chess can be debated as the nature of play in bullet chess is different than longer form time controls. Thus, this nature may in turn give rise to the skill differences seen in the analysis.

Yet, this opens the door to exploring alternative theories of intuition and their relation to bullet chess. Due to the increased psychological and social phenomenon found in bullet chess, it can be argued that the game is more complex than classical time controls. Players' intuitions must reflect not only tactical solutions but also social problem solving that may be more present than in classical variations. Therefore, intuitions cannot only rely on recognition of chunks on a board, they must take into account their opponents perceived intentions and strategy. In other words, a chess player's intuition must be able to predict how the game will play both on the board and in the mind of their opponent. The speed chess player is dynamically intertwined with the game much like a tennis player is on the court.

Chapter 5: Embodied Cognition

5.1 Introduction to Embodied Cognition

One way to explore this problem is from the viewpoint of embodied cognition, which states that the mind "must be understood in the context of its relationship to a physical body that interacts with the world" (Wilson, 2002, p. 625). This view challenges the traditional cognitivist paradigm in which the mind works akin to a computer. Also known as the computational view of the mind, it is a belief that the mind is a symbol manipulating device where neurons and their configurations represent different objects or concepts in the world (Shapiro, 2019). Appropriately, this is the very idea that exists at the basis of Herbert Simon's chunking hypothesis. According to Simon, chunks are symbols or patterns that are stored as representations in memory and are accessed when perceived by a player. This then triggers a process of symbol manipulation which leads to some action (move). The chunk is the input, and the move is the output in its simplest form. Therefore, this standard cognitivist view sees the brain as the sole perpetrator of cognition, as the computational analogy "begins with inputs to the brain and ends with outputs from the brain" (Shapiro, 2019, p. 29). Yet on the other hand, the embodied perspective extends the mind outside the bounds of the brain and into an individual's relationship with their body and surrounding environment. Instead of passively taking in information as an input from a perceiver-independent world, embodied cognition sees the processes of the mind as perceiver-dependent operating through sensorimotor knowledge (Varela et al., 2016). Here the chess player is actively engaging in the sense-making process of the game and their playmaking decisions are a result of this embodied cognition. Therefore, to understand the way a chess master intuitively makes decisions under time pressure, it is necessary to consider the way the perceptual and motor systems contribute to cognition.

5.2 Phenomenological Ideas of Embodied Cognition

Before diving into the applications of embodied cognition on bullet chess and intuition, it is important to give some background on the discipline's underpinnings. Since, embodied cognition is concerned with an individual's interaction with the world, it is crucial to understand their subjective experience. Here phenomenology, what one experiences, is an important building block of embodied cognition. The embodied view of phenomenology sees the individual akin to Heidegger's idea of "being in the world". We experience the world because we interact with it and are intertwined with it, we cannot be separated from our environment or our body. Therefore, our perceptions rely on these interactions and shape new ones. There exists a coupling between our experience and body within the environment. As Merlau-Ponty (2012) writes "the theory of the body is already a theory of perception" (p. 245). This is why phenomenology is a key tool in the investigation of embodied cognition, as we are able to tune our attention to conscious experience of the body. Yet, we can also utilize phenomenology in a scientific way to inform us about things that can go beyond our own conscious perceptions. Gallagher (2024) explores two important ways phenomenology aids in scientific exploration of the embodied mind. Firstly, when analyzing an action, one can discover in a negative way things they “cannot” experience. For example, I may not experience the way my hand shape changes when I reach for certain pieces on the chess board. My hand shape may be different depending on the shape of the piece or my intentions for the move I will make, however, this happens often unconsciously and only through reflective phenomenological analysis can I see this difference. Through this reflective analysis one can scientifically explore how “elements of body-schematic motor control integrate with and modulate conscious and intentional aspects of perception, attention, and action.” (Gallagher, 2024, p.16). Secondly, phenomenology is a necessary factor in understanding the bodily cognition at a sub-personal or neuronal level. Knowing that certain neurons are firing without any knowledge of how it affects the first-person experience does not give a proper understanding of the phenomenon being investigated. Therefore, pairing phenomenological investigation with neuroscience practices is important to understand how cognitive processes are actually functioning (Gallagher, 2024). Bottom line is that phenomenology is a foundation for approaching the role of the body in cognition and consciousness, it is the contextual basis for the discipline of embodied cognition to grow out of. Without a phenomenological element incorporated into future studies surrounding intuition, there is as knowledge gap between what is observed in quantitative data as expressed in this paper and what is the first-person experience of the player. We can infer that intuition is apparent based on outside observation, but with phenomenological data we can cross reference these observations and gain more meaningful experiential evidence for the phenomenon.

5.3 Enactivism as Insight

Embodied cognition can be interpreted as a call for the investigation of the mind from a lens explicitly tied to action because action is our body's ability to operate within the world. Hence, our perceptions and our actions are fundamentally linked together (Varela et al., 2016). This is the claim of enactivism, which states that perception is dependent on and partially constituted by an individual's sensorimotor knowledge (Noë, 2004). Perception, action, and thought cannot be separated in this view, as they are part of one whole system. Thus, the subjective quality of consciousness, being the experience of a particular situation e.g. experiencing the checkered squares of a chess board, rests in the specific patterns of sensorimotor engagement (Degenaar & O'Regan, 2017). This is contrary to the standard practices of cognitive science in which perception is the input and action is the output. Thought is then the middle calculation between the two. A chess player sees a position, thinks about the possibilities of an action and then makes his move. Each step in this process is categorized separately and can be analyzed on its own. However, the enactivist would approach this problem from a different angle. The action and perception processes of a chess player's move selection are coupled together. This is possible due to a person's attunement to sensorimotor dependencies. A person is able to use their perceptual capacities, e.g. identify and move a black rook, because of their implicit knowledge regarding sensorimotor dependencies of the object (Degenaar & O'Regan, 2017). In the case of moving the black rook, a player has knowledge of these dependencies through previous interaction with the piece. Furthermore, with time and increased experience, one's knowledge of sensorimotor contingencies can change and become more adept.

This idea can be tied back to Dreyfus & Dreyfus' (1986) ideas on expertise in skill acquisition, where through experience one becomes more attuned to a particular skill and therefore requires less mental deliberation to complete the tasks. This is further supported by evidence that shows experience gained in youth is a strong determiner of expert level performance as the amount of deliberate practice is significantly increased. It has been found that the average starting age of grandmasters born in the 20th century to have been 9 years old when they started playing chess, with the oldest being 14 (Ericsson et al., 1993). Developmentally, children are constantly involved in action-based sense-making. This is an idea found in early ideas proposed by Piaget (1952) with the first stage of cognitive development being characterized by sensorimotor exploration. Likewise, research has shown that there are immense psychological changes that happen together with the onset of movement in early child development (Kontra et al., 2012). Thus, the development of a skill is greatly enhanced when exposed early in childhood as there are large portions of neural resources being directed towards learning at a young age. This learning is facilitated through an embodied interaction with the world in which knowledge of sensorimotor contingencies are cultivated. Some of which are richer and more developed than others.

Therefore, the enactivist would say that the expert chess player has acquired certain biases pertaining to specific sensorimotor dependencies. The expert chess player has attuned themselves to patterns of play through biases in experience, which are likely to have begun at an early age. These biased attunements are also domain specific, as superior knowledge of sensorimotor dependencies is focused on specific experiences. A chess player may excel in pattern recognition of chess positions, yet their performance in pattern recognition of neutral scenarios might be generic. This is important because it can be used as an argument against the representational view of the mind. In the representational view, chess positions or patterns of dots on a screen should not have strong differences in performance. Both are just patterns with no extra inherent meaning assigned to them, therefore a chess master with increased pattern recognition skills should perform at least above average in a generic scenario. Yet this is not what we see in practice. Research has found that expertise is domain specific with no significant transfer to other skills. For example, the games go and gomoku are played on the same board with the same pieces yet recall by go players of gomoku configurations are unsatisfactory (Bédard & Chi, 1992). Hence, players are attuned to memorizing configurations through their interaction with the game itself. Dynamic play is necessary for the improved perceptual capabilities of an expert.

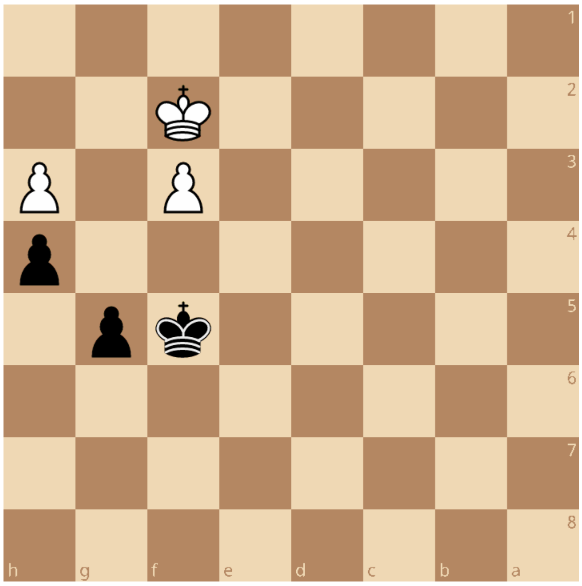
This is why the enactivist approach is attractive to understanding bullet play because players are just “doing”. There is a constant flow of intuitive actions that are hard to explain from the standard cognitivist framework in which mental representations rule. Since mental representations require semantics and deliberation, they are often tied to ideas about classical chess because it is widely accepted that classical chess relies on this form of slow thinking. Yet when applying this same methodology to bullet chess it causes immense problems, as the flow of the game should not be interrupted by thinking. Moreover, the reliance on mental representation requires more processing power and therefore requires more neural resources. When one is able to bypass these mental representations, they are in turn reducing their processing time to perform higher level activities. High level activities like surfing, martial arts, soccer, and in our case bullet chess, a reduction in processing time and increase in mental clarity are positive attributes of performance

(Krein & Ilundáin-Agurruza, 2017). This is the very idea behind enactivism's role in bullet chess, as enactivist approaches to cognition do not require mental representations in the sense classical approaches do.

5.4 Embodied Decision-Making in Chess

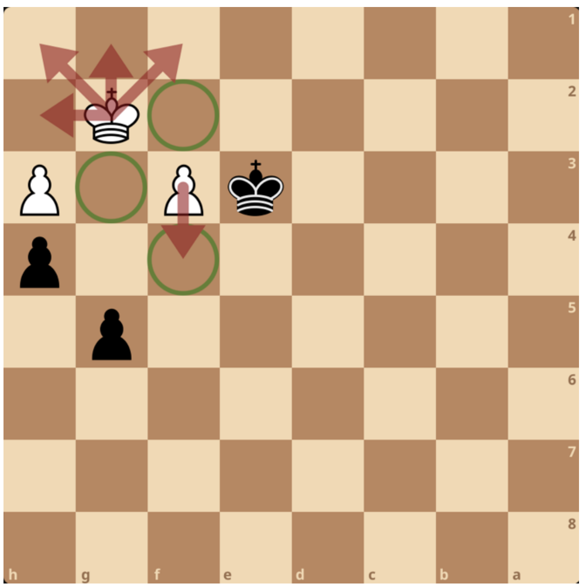
Embodied decision-making takes into account how action choice influences the decision-making process. In the *Embodied Choice Framework*, problem states are approached as dynamic processes that are constantly changing (Lepora & Pezzulo, 2015). Therefore, the brain examines both the decision and action simultaneously. The decision needs to be beneficial, and the action needs to minimize movement costs. Thus, the action and its constraints influence the decision that will be made (Lepora & Pezzulo, 2015). For example, a chess player needs to make the right call to advance their pieces in a chess endgame (see Figure 4). From the black position, the king sits at f5 with a pawn sitting next to it at g5. These are the two pieces that are available to move. The goal of black is to advance the pawns to the other end of the board and makes sure the opponent's pawns do not slip by. Here the decision comes down to which piece to move and to which square to move to. The action is the movement of the selected piece to the desired square. Since, bullet chess is played digitally, the action is fulfilled by the mouse and the movement cost in this scenario would be clock time. The action needs to minimize the clock time wasted as time pressure is the dominant factor in bullet chess. Specifically, the examined scenario represents an end game sequence, where these moves will be certainly under extreme time constraints as running out of time counts as a game lost. In this position black can either move their pawn on the g5 square to g4 or move there king from f5 to f4, f6, g6, e5, or e6. With six possible moves available the expert player must choose the best one based on intuition, as there is not sufficient time on the clock to deliberate over the consequences of each move.

Figure 4



According to Stockfish 16.1 the best move for black in this position is to move the king to f4. Then white moves to g2 and black to e3. Now white is in trouble as black has taken control of the area (see Figure 5). In this position white's pawn on f3 is going to be captured regardless of the next move being taken by white. This leaves the game at a certain advantage for black as they are up a pawn and must now make the right moves to advance their pieces to the opposite end of the board while keeping the white king at a distance. From an outside perspective this example might seem like a strange one as there are only six pieces on the board. Yet in this position one wrong can lead to certain defeat as there are not enough pieces for recovery. Likewise, endgames follow some guiding principles that are engrained into a player through experience. However, traditional approaches to endgames will not always play out the same way in bullet chess due to the time variable. For example, white is in a losing position as displayed in Figure 5, however if black has less time than white there is a leveling of the advantage as black can run out of time and lose the game. Now let us assume that this is the case and black is at a time disadvantage in the current position. In these scenarios players need to rely on automatic processes or intuitions to minimize their action costs. For the expert player this example is quite straight forward and as long as they can move the pieces fast enough their knowledge of similar scenarios should guide them to victory. At the position of Figure 5, white must retreat their king leaving the pawn on the f file open for capture. Once this has been done, black must maintain control of the space and march one of their pawns to the other side of the board. The expert player has played these kinds of scenarios many times and has the knowledge of what moves will limit time costs and maximize win success based on their experiences with the dynamic sensorimotor contingencies the position presents.

Figure 5



Now let's look at a different example taken from Nakamura & Harper (2009), where knowledge about past experiences can lead to mental errors. In the presented scenario (Figure 6) there are many more pieces on the board and many more options for move selection. Here the position is quite even and both players still have all of their pieces. From this point both players begin to play outside of the normal variation one might see in a classical match with the moves (*9. h4 b5, 10. Kg5 b4 11. Kxd5?)*. Now at move 11, white sacrifices a knight in an unexpected way. Black captures the piece and then white makes a threatening move to the h5 square. The new position can be seen in Figure 7, with white attempting to checkmate black. Here black makes the fatal mistake of moving their pawn to g6 to attack the queen which makes an easy win for white with queen moves to h7. In this scenario it's as if black was not even paying attention, the threat is obvious to even beginner players, yet they still missed it. Thus, it can be concluded from this game that black was perceiving something else going on. They were predicting that white was threatening some other moves. In their automatic play they failed to see beyond their past experiences, which is even more apparent as Nakamura & Harper (2009) describe that in the game prior the same player fell for the same checkmate. Approaching this scenario from the embodied perspective, previous experiences in these positions were leaving biased attunements to specific sensorimotor dependencies.

When white plays the knight sacrifice they are intentionally disrupting the expectations of their opponent and thus leaving them with the task to recalibrate their perceived intentions. In this way, white's sacrifice maximized move cost even though it technically lost material advantage. This is because it mentally strained the opponent and made a threat to their clock time. As a result, black began to question white's attacking plans and missed the direct threats on the h file which ultimately led to defeat. The sensorimotor knowledge that black possessed was disrupted and therefore this created a blind spot, an error in perception that lost them the game.

Figure 6

Figure 7

Here black fell victim to their predictions about how white would act. However, prediction is not always a negative attribute of bullet play. In fact, predictions about how an opponent will move is what drives the best players to succeed at such high levels. This fact can be seen in the phenomenon of pre-moving as described in an earlier section of this paper. Pre-moving can save significant amounts of time and prove to be effective when they are accurate. This accuracy is of course determined by a player's ability to accurately predict their opponent's moves given the circumstances of how the game is developing. As for its role in cognition, prediction in the mind is the subject of predictive processing, a theory that has the potential to merge the roles of action, perception, and cognition into a unified framework within the bounds of embodied philosophy (Clark, 2016). Therefore, bullet games can be an interesting example into how the predictive mind works together with the embodied cognition ideas presented. Likewise, these insights can give evidence towards a definition of intuition from a predictive processing viewpoint.

Chapter 6: Predictive Processing

6.1 Introduction to PP

The base idea underlying predictive processing (PP) is that our mind functions as a prediction machine. Meaning the reality we experience is actually a prediction made by our brain which is guided by past experiences and updated through active sensory engagement (Clark, 2023). Thus, PP emphasizes the role of top-down processing where prior knowledge is always involved in perception. This prior knowledge informs hierarchical statistical estimations which serve as representations that help the brain predict current and future sensory inputs. Furthermore, when actual sensory inputs do not match the predictions made by the brain, there is an active update to the internal representations. The goal of these updates is to minimize prediction errors (Wiese & Metzinger, 2017). As for integrating this idea into embodied cognition, one way to approach the problem is to see how minimizing prediction errors is approached. Venter (2024) proposes the process of sensorimotor inference, an idea that states that inferences are made on the basis of embodied action and any future states the body might play a role in. Therefore, perception and action are again viewed as part of the same phenomenon. This idea integrates itself well with the enactivist claims made by Noë (2004), in which sensorimotor knowledge partially constitutes perception. Through active engagement with the world a person is able to minimize prediction errors and update internal models aka models related to embodied action. This works as humans are often seen offloading certain mental stress into the environment through a process of dynamic exchange. For example, the outfielder problem is often referenced in the sphere of embodied cognition. The problem aims to look at how a baseball outfielder is able to catch a fly ball while on the move. The classic answer to this problem is that the player is relying on internal mental representations and models to calculate where the ball will land. However, the embodied view would state that the player is running at a pace to keep the ball stable on the retina and maintain a dynamic relationship with the ball which minimizes sensory processing (Kersten, 2024). Here the first answer is a passive and a high energy consuming solution, while the second answer is an active and energy minimizing solution. Thus, minimizing energy costs lends itself to minimizing prediction errors. The resulting system utilizes action-perception loops that are actively looking to minimize error through a complex circular causal flow. Within this flow "actions select sensory stimulations that both test and respond to the bodily and environmental causes identified by the multilevel cascade" (Clark, 2016, p. 296).

6.2 Integrating PP with Embodied Decision-Making

With this view in mind, we can now look back into the decision-making processes of a chess player under time pressure. As stated in section 5.4, the role of embodiment in decision-making determines the best action for minimizing movement cost. Integrating this idea with PP, we can say that within the decision-making process a person is minimizing movement costs using the same mechanism that minimizes prediction errors. Under the lens of PP, choices can be seen as competing hierarchical predictions about future sensory states. Therefore, during decision-making, choices are selected based on their ability to minimize error between attainable and desirable outcomes (Burr, 2017).

The chess player is then making their choices based on what predicted action sequences will lead to checkmate or a desirable position. There is a decision-making process happening at both micro and macro level within the game space. At the macro level, there is the goal state of capturing the opponents. Underneath this lies decisions based in strategy and basic principles. Things like controlling the center, development of pieces, and protecting the king are all microstates which impact the result of the game. For example, in the opening section of a game, high level players will play an opening line that is rooted in theory. This means that players have memorized sequences of moves that have been tested throughout time and studied based on their advantages and potential outcomes for the game. Usually, this portion of the game is automatic as both players act in accordance with one another. However, when one breaks away from opening theory this causes the decision-making process to begin. Now predictions have larger room for error leading to more costly decisions. Thus, the generative model of the predictive brain must be accurate to perform at a high level. For expert players, experience has created a highly accurate internal model and therefore they are able to accurately play under time pressure.

6.3 PP and Time Pressure in Chess

Time pressure is always apparent in cognition, as limited time creates a "representational bottleneck". Wilson (2002) writes "when situations demand fast and continuously evolving responses, there may simply not be time to build up a full-blown mental model of the environment, from which to derive a plan of action" (p.628). Wilson's view represents a traditional view of embodied cognition previous to the era in PP. Therefore, the notion she is addressing is representational view of the mind in line with the cognitivist paradigm. Yet, the PP idea of a mental model generates itself before situations arise, as they are models based on prediction and updated through active engagement with the environment. Therefore, the PP framework operates well in the context of time pressure. Activities in which time pressure is an essential variable to cognition is apparent in any form of perceptuomotor activity. Specifically, in activities that involve reactions to rapidly changing conditions (Wilson, 2002). Bullet chess fits this category nicely as rapid hand eye coordination is needed to move the mouse or pieces on a physical board and the fast-paced flow of the game introduces constantly changing conditions in which the player must accurately adapt to. In this sense it is a perfect scenario to explore PP and embodied cognition in a future empirical setting. Although this paper does not address this idea from an empirical view, we can look further into scenarios in bullet chess from a theoretical side.

Before moving to chess, we can first take a look at a few examples of PP's role in other interactive time pressure scenarios. In a classic study by Land and

McLeod (2000) it was found that during batting, cricket players make predictive saccades to the place where they think the ball will bounce on the ground and furthermore to the location it will end up after bouncing. Within these findings, the researchers also noticed that the players with a higher skill level were also making earlier and more accurate predictive saccades. This evidence is interesting to consider amongst previously discussed research in the realm of expertise in which more skilled people have shown greater reliance on intuition and score better in exercises of pattern recognition (Chase & Simon 1973; Gobet & Chassy, 2009; Gobet & Simon, 1996). When revisiting these conclusions, it can be inferred that the mechanisms behind the success in these tasks is not due to pattern recognition but due to accurate prediction models that are being incorrectly observed as something else. More evidence from Diaz et al. (2013) showcased predictive saccades using a virtual racquetball game. Results from this study showed that participants were making predictive saccades to locations where the ball would be slightly after the bounce at a consistent time of 170 milliseconds. Irrespective of ball speed, participants were reproducing this prediction of where the ball would be consistently. The study also showed that even the novice players were able to accurately produce predictive saccades after only a few trials. The researchers concluded that participants must have been relying on an internal mental model which relied on both real-time and prior information as it could be inferred that the novice players were using sensory information from early trials to update their models. The updated models would then lead to consistent predictions. Both of these studies are examples of interceptive activities. Meaning an activity in which a person is trying to make contact (hit, kick, catch, etc.) with something moving at high speeds. Thus, it is a time pressured scenario where the person has one goal state to achieve, and the activity is relatively simple from a cognitive load standpoint. Yes, one needs to "decide" where to swing, how fast, how high, but these variables can be solved by a novice.

However, bullet chess lives in a slightly different universe compared to cricket or racquetball. Time pressure is still crucial, but as previously mentioned there are many more goals to consider within a game. It is a mental exercise more than a physical one and the layers of complexity can give more of a challenge to the reality of hierarchical prediction models. The chess player does not just need to decide when to move a piece, they need to decide what piece to move and to where and for what purpose. Each move a player makes will have consequences down the line. Therefore, the decision-making space of a chess player under time pressure is incredibly difficult. Certain scenarios like the opening make it easy to select moves, while other situations offer multitudes of options where the position is ambiguous.

Here making a move represents the action of the scenario, the same action that is used to verify or update internal models. Turning back to the attributes of bullet chess, we see that actions are often aggressive, and intentions should be based on putting pressure on the opponent (Nakamura & Harper 2009). From a PP lens, aggressive play can be beneficial in these scenarios of ambiguity as forcing the pace of the game and trying to impose your intentions of how the game will play out can make it more likely that the internal models will be making less errors. Since prediction errors cause computational time to resolve, there is a large incentive to make moves that minimize this cost, as time is a significant variable in the game. This may be a reason as to why there is a discrepancy in accuracy observed in the data presented in section 4.4 between rapid and bullet games. Often times players make moves in bullet chess that would otherwise be devasting in a longer time format. These moves can stem from this aggression and drive to impose their intentions on their opponent. Or in a similar vain to purposefully throw off their opponents' own predictions about how the game is playing out. We must remember that chess is an interactive game in which both players have individual styles, experiences, and intentions. Thus, in-line with PP, in order to read another player's action intentions, one has to have an extensive sensorimotor driven experience with those actions themselves (Ridderinkhof et al., 2022). Referring to the scenario illustrated in Figure 6, white makes a knight sacrifice that sets up the coming checkmate a few moves later. Although we do not have access to the actual experience or intentions white was utilizing in this game, we can infer based on the play that they were making the sacrifice as a deliberate disruption. Likewise, this move is inherently aggressive as it threatens to take space in the center of the board. As for black's perspective, this move comes as a surprise since in a typical game this move is not played. Therefore, black's internal prediction model failed based on white's aggressive actions. This failure in prediction was the commencement of the sequence that led to an easy missed threat in which white was able to mate on h7. Black had perceived that white's intentions were focused on a different side of the board and they acted as if they were blind. Likewise, black could have been trying to impose their own intentions onto white, with a similar result in being blinded by the incoming attack. The major point is that there is a misstep in prediction that causes errors that would otherwise be avoided in longer time games.

Looking back at the GPL scores of the experiment, it makes more sense that bullet games produce less accurate play according to the engine. The nature of bullet games is much more dependent on alternate strategies that would be disadvantageous in classical matches. The chess engine performs in a way that is statistically based in probabilities and often makes moves that are not intuitive to the human mind. It is not able to reconcile with psychological strategies that may come to use. Things like illogical sacrifices, obscure openings, and deviations from major theory do not win games in the eyes of a logic-based program. However, if we turn to the predictive processing of the human player, it is bound to a world that is perceived through knowledge of sensorimotor dependencies, it is confined to the human experience which operates through in sphere of possibilities determined by our embodied mind.

6.4 PP and Intuition in Chess

"Intuitions are always anticipatory" (De Groot & Gobet, 1996, p.18)

These are words by the famous chess master and psychologist Adriaan de Groot, whose early chess studies have been discussed in section 2.1. Although not exposed to the ideas of PP, his ideas about intuition seem to fit within the same thought process. If intuitions are anticipatory then they should be tied to previous experiences which serve as predictors for future situations. These predictors make up the internal mental model to which the predictive brain operates under. Furthermore, the sense of "knowing" and fluid action that defines expert intuition is then a natural product of this prediction machine that is accurate and quick to error correct based on sensory information. Given this interpretation of intuition, it fits well alongside the evidence observed in expert decision-making. Yes, experts utilize intuitive thinking more often and accurately than their lesser skilled counterparts because of experience. But this experience is tied to active sensorimotor engagement with the world and not to representational memory "chunks" as proposed by Chase & Simon (1973).

In a way it falls closer to Dreyfus & Dreyfus' (1986) ideas about holistic processing where intuition relies on situational involvement and recognition of similar scenarios. A PP view of intuition would still emphasize deep situational involvement; however, recognition of similar scenarios could be replaced by utilizing predictions which are trained upon past experiences in similar scenarios. The differences are subtle yet intriguing as they give an explanation to one of the major criticisms Dreyfus' ideas face which is that the idea of holistic recognition is not thoroughly explained. Dreyfus claims that recognition takes place, but it is somehow different than pattern recognition. This of course leaves a large gap to be filled. Yet, with PP replacing this idea of pattern recognition, it may easier for researchers in this field to find underlying mechanisms and fight the opposition party still pushing cognitivist-based theories. Looking to Dreyfus' theory of skill acquisition, the PP view would see that each stage in the development of expertise coincides with different levels of sensorimotor involvement and evolution of internal models. Therefore, the expertise stage would constitute a person with an exceedingly accurate and flexible internal model of the skill space and intuition would then be this model operating with minimal error and high adaptability. When faced with unpredictable circumstances the expert is still able to act successfully as flexibility in error correction allows internal models to adapt rapidly. This becomes the fluid and fast-paced decision-making which experts express in their field.

However, intuition still categorizes a certain experience. There is a subjective nature to intuition that separates it from just effortless action. For example, walking can be considered a process in which our predictive minds work exceptionally well and therefore there are not many times in which the internal prediction models involved with walking need updating. I walk effortlessly without deliberation or error and therefore I could classify myself as an expert walker. But I may not be quick to classify myself as an intuitive walker. Then what are the conditions for intuition? Kahneman & Klein (2009) answer this question with two necessary conditions: firstly, the environment must provide adequate cues and secondly a person must be able to learn these cues. They conclude that skilled intuitions develop in areas of sufficient regularity. This maybe true if one is interpreting through the lens of recognition-based theories of intuition, which these researchers were. However, they leave out some key attributes that make intuitive skill different than repeated behaviors. There has to be choices, solutions are ambiguous, and there is a final goal state. Thus, intuitions do develop under increased exposure, but there is another component that pulls one to act or choose in a specific manner. There is a 'gut' feeling.

Humans are built for walking; it is an innate process that leaves little ambiguity. On the other hand, humans are not built for chess. It is an abstract decision-making space where intuition often holds an emotional dimension. Players are drawn to choices that have specific meanings to them. Given an ambiguous situation, two expert players might make two very different choices. These choices are determined in part by their style and intentions. Their sensorimotor interactions with game are deeply personalized, thus making the phenomenon of intuition also personalized. An expert player will act on this personalized 'gut' feeling which can be seen as emotion tied to action. According to PP, these emotions are predicted based on past experiences. These experiences are driven by sensorimotor exploration and therefore, emotion also arises from this exploration and cannot be separated from the context to which it is tied (Del Popolo Cristaldi et al., 2024). In the case of intuition, the feeling that arises with a certain instinctual decision is explicitly linked to predictions about the situation at hand. When a chess player predicts that their opponent will begin an attack on the kingside there are predictive emotions that also cause the player to defend in that area and through this action of defense, they are actively confirming these sensory predictions. When this is successful it can be deemed intuition, as the internal predictive model of the chess player was accurate. This idea lends itself well to explaining why players have different styles of play. Emotional pulls tied to intuition can create the stylistic preferences amongst players, like risk taking versus defensive positional play. Feedback from previous experiences strengthen these preferences and give players their unique approach to the game. This individualistic angle gives predictive processing the edge over theories like the chunking hypothesis or holistic recognition, as these theories do not account for an emotional dimension. Since every person’s experiences are individualized, so are their internal prediction models. Thus, intuition cannot be boiled down to pattern recognition stored in memory, otherwise we would see the same automated play at the top level of chess. Instead, we see player’s with unique styles that reflect their emotional and sensori-motor experience with the game.

Chapter 7: Final Thoughts

7.1 Limitations & Future Research

This paper lacks a phenomenological dimension in the empirical portion of investigating bullet chess accuracy. A future methodology could incorporate some descriptive experience sampling (DES) or some other phenomenological based analysis to pair alongside accuracy scores from Stockfish. This would be important in understanding the decision-making process in time-pressured scenarios from a micro level and hopefully further categorize the phenomenological experience of intuition. It would also shed light on any attributes that might support an embodied account of the phenomenon and narrow down scenarios in which this is measurable. One way to achieve this would be to select a small group of grandmaster chess players and incorporate DES into moments of a bullet chess match. At some point in the middle of the game, an alarm can go off which stops the game and requires players to report on their experience in the prior moment. Ideally, this alarm can be set off in moments of exchange or ambiguous positions in which players are expected to make tactical moves. If the players describe noticing patterns in piece positions this could be evidence for the chunking hypothesis. Likewise, if they describe noticing possible intentions of their opponent, this could be evidence for a predictive processing approach to intuition. Combining this with Stockfish evaluations could show the accuracy in quantitative terms while getting a qualitative reasoning the score. For example, Stockfish might score a move less accurately, but the DES report would show that the player was trying to surprise their opponent by doing something out of the ordinary. Therefore, the move could be classified as beneficial in the context of the game.

From this analysis, researchers might be able to narrow down certain scenarios in which moments of intuitive play are present. Moments where decision-making cannot be fully verbalized by the player, but thoughts leading up to the move could shed insight into possible mechanisms.

Another limitation of this research is that it only takes a total sample of 400 games. Although this is a significant amount of data, there is potential to analyze thousands of games instead. This would require more computing power and time, but the results from an analysis on a larger data set could give more clear results. It could be possible that a larger dataset would show that there was not as much of a significant difference between bullet and rapid time controls. Likewise, different comparison groups could be used. One possible way to re-evaluate this idea is to compare the top ten chess players' game performances at different time controls. A sample of games at the bullet level and classical level could be compared against each other for each player separately to see if there are individual differences in accuracy. There might be some players that do not differ in accuracy at different time controls. If this were the case, then they could be selected for further research utilizing the phenomenological method described above. The point being that this methodology can be further incorporated with other techniques within cognitive science to gain insight into topics of intuition, expertise, and decision-making through lenses associated with 4E cognition and predictive processing.

7.2 Conclusion

This paper is not a comprehensive account of the nature of intuition, but an exploration of its role in real world applications. This paper calls to attention the medium of bullet chess as a ground for investigating intuition in context. Time pressure, decision-making, and expertise come together in the controlled environment of the chess board where there is lots of data to take inspiration from. The analysis in this paper demonstrates the ability to use interdisciplinary tools to approach problems from unconventional angles. In this case large online databases were used to collect sample conditions, and an artificially intelligent agent was used to serve as a benchmark for accuracy measurements. The methodology is novel in the space of chess and intuition research; however, it takes inspiration from foundational studies that compare performance in two different time scenarios. Furthermore, this research improves upon the previous time comparisons as the time scenario measuring intuitive play is set at 1-minute, where previous iterations only looked at 5-minute games. Another advantage this methodology possesses is that it takes into account games from a holistic view. Contrary to positional based studies, this research looks at the accuracy sum of every single move over 200 games for each condition. Moreover, the scale at which the analysis is performed is much larger than previous research with a sample total of 400 games. Likewise, the advantage of database driven research is the potential to scale the sample sizes to hundreds of thousands of games. Future research can utilize this potential advantage and advancements in chess AI.

Although the hypothesis presented in chapter 4 turned out to be false, as there was significant difference in GPL scores between the two time controls. The analysis provided proof of concept for the methodology used. Data from the experiment still showed that chess players in the bullet category still performed exceptionally well given the time pressure added and there were even instances where they performed in line with the Stockfish evaluation. On another note, it also opened the discussion surrounding comparisons between human and artificial problem solving as it can be argued that humans do not approach problems in the same way that Stockfish would. When solving problems in a game setting, humans are taking into account their opponents play style, strategy, and perceived emotions. While Stockfish is taking into account probabilities and raw data. There is no psychological element to its performance and thus it is not a perfect comparison for human problem solving. That is why it is important to understand these differences and acknowledge them, as it can allow research involved with artificial agents to be more fruitful and honest. Therefore, alternative ideas were presented to further understand and explore the role of bullet chess in gaining insights into expert intuition. From a theoretical standpoint, this paper introduces an embodied approach to decision-making and intuition within chess. It also explores these embodied ideas in relation to predictive processing as an integrative theory. Chess as a subject matter has been used successfully in the cognitivist realm of psychology and decision-making, therefore, it should be used to further examine 4E approaches and predictive accounts of the mind in modern methodologies.

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