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Cognitive Abilities in the Game of Go during the Opening, Middle, and Endgame Phases: When Experimental Psychology Meets Artificial Intelligence

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The game of Go, also called Weiqi or Baduk, is one of the most sophisticated board games in the world. The players compete with each other by surrounding more territory using their stones. There are three phases in a game of Go, including the opening, middle, and endgame. Only a very few psychological studies have investigated the underlying processes or neural mechanisms used while playing Go. It has been suggested that some cognitive abilities may be important during the game, but the recruitment of different kinds of cognitive abilities in three phases is still unknown. The present study addressed this issue by combining experimental psychology approaches and artificial intelligence (AI) algorithms. Twenty-four Go players tried their best to quickly answer 48 Go questions in each of three phases, with different cognitive interference tasks appearing simultaneously. Their accuracy and reaction time on these questions were recorded as their performance. The Go questions were designed and organized by a professional Go player, and some basic requirements for psychological experiments were met. In addition to a control task, there were three types of interference tasks: a visual spatial search, logical reasoning, and calculation. The results showed that the spatial interference task decreased the accuracy in the opening phase, suggesting that spatial ability is the most important cognitive ability used in the opening of a Go game. The logical reasoning interference task decreased the accuracy in the middle and endgame phases, implying that reasoning ability is very critical in these phases. The calculation task had a less significant interference effect. In addition, we used three AI-related algorithms to classify the subjects' performance in the three phases of Go questions under different degrees of cognitive interference. The results showed that these algorithms had much better than chance accuracy to correctly classify the performance in three different phases of Go questions or under different degrees of cognitive interference. Cross validation procedures ensured the generalizability, and permutation tests also indicated that the predictive accuracy of these models was statistically significant. We thus argue that there are indeed different cognitive representations in these three phases under different levels of interference. In summary, in the present study, an experimental approach was adopted to reveal the involvement of cognitive abilities in three phases of Go. In addition, we provide a new perspective for experimental psychology by introducing an AI-related analysis of multivariate data, which infers that artificial intelligence can have a greater influence and make a greater contribution to the understanding of psychology and human intelligence.

Keywords: *artificial intelligence, calculation ability, game of Go, logical reasoning, spatial ability.*

Introduction

Chinese Go is the most sophisticated board game in the world. Go includes three stages that the players must complete: the "opening," the "midgame," and the "endgame." After thoughtful consideration of each move, the player with more territory is finally declared the winner.

Artificial intelligence (AI) is the most popular and well-studied area in the literature on Go. A well-known example is AlphaGo, which in recent years has defeated two top professional Go players. As the best application of AI in the domain of Go, AlphaGo has focused the research on Go on the design of a better algorithm, which has led to significant developments in AI for Go. In addition, some psychological studies have also been done to investigate the underlying processes and the neural mechanisms of Go players. Although existing studies are very rare and have yet to provide useful implications for the psychological processes that underlie a Go game, they still provide some preliminary information and have consistently suggested that various cognitive abilities, such as spatial ability and mental inference, are required for Go.

Although a few psychological studies have provided snapshots of how players compete in Go, little is known about the underlying cognitive processes during the three distinct stages of the game. It is still unknown whether these three stages recruit different cognitive abilities. Furthermore, even if the implications of AI have infiltrated fields from neuroscience to clinical psychiatry, AI-related algorithms have not yet been widely applied in experimental psychology. It may be possible that AI-related algorithms could help us understand the psychological mechanisms in a process in terms of the abilities of AI-related algorithms to handle data with high dimensionalities. There is no doubt that those AI-related algorithms will be useful to probe the cognitive processing of Chinese Go.

To fulfill these research gaps, this study combined experimental psychology approaches and AI-related machine learning algorithms to determine whether these three stages recruit different cognitive abilities and which kinds of cognitive abilities were involved in a game of Chinese Go. We hypothesized that the opening stage would require more spatial ability to obtain a whole picture of the game, that the midgame would require greater involvement of inference ability to select the best option for the next move, and that the endgame would require greater calculation ability because players must carefully calculate the detail of both territories in order to increase their own one near the end of the game. Furthermore, we expected that these three stages might have differences in cognitive representation, so we hypothesized that these three stages could be correctly classified by the AI algorithm using players' behavioral data.

Methods

The participants included 24 Chinese Go players (age, 10 to 20 years; mean, 13.12 years; SD, 2.93 years) with advanced knowledge of Chinese Go. They were required to perform a dual task that involved the simultaneous appearance of Go questions and cognitive interference tasks (Figure 1). The Go questions were manipulated to obtain three kinds of questions corresponding to the three stages (i.e., the opening, the midgame, and the endgame). To ensure the correctness of each question, the Go questions were designed and organized by a Taiwanese professional Go player and confirmed by two other professional players. These questions were used to examine the abilities of the players in these three stages. An open-source Go AI, Leela, was used to verify the given correct answers to further ensure the correctness of the questions. Likewise, three kinds of cognitive interference tasks were manipulated, including a spatial interference task, an inference interference task, and a calculation interference task. In this dual task, the Go questions and cognitive interference tasks appeared simultaneously. Also, Go questions without interference were used to assess the players' original ability. The players were asked to answer the questions as correctly as possible within a limited time. Figure 1 demonstrates the dual task used in this study. The accuracy of all of the trials and the reaction time of trials with correct answers in both questions (i.e., Chinese Go questions and cognitive interference questions) were recorded as the major dependent variables. Using this dual task, we examined the impact of the interference tasks on the three Go stages to reveal which cognitive abilities are required in each stage.

Two series of analysis were performed; first, we used a 3×4 analysis of variance to examine the effect of the Go

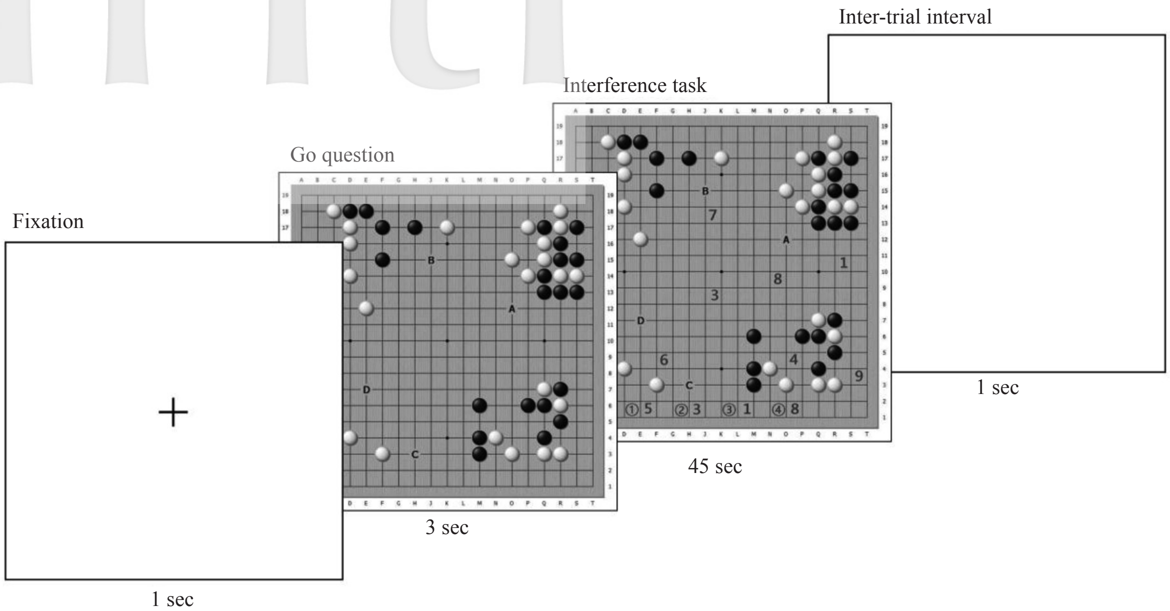

Figure 1. **Procedure of the dual task. Interference tasks were superimposed on the Go questions**

stages (i.e., three Go stages: the opening, the midgame, and the endgame) and the effect of the interference type (i.e., four interference types: none, spatial, inference, and calculation interference). Second, we further analyzed these data by adopting three machine learning algorithms, random forest (RF), support vector machine (SVM) and deep neural network (DNN), to examine whether the classifier trained by these algorithms could correctly classify three different stages in the Go question of the dual task. An eight-fold cross-validation procedure and permutation tests with 10000 resampling were used to ensure the generalizability of the results of these algorithms.

Results

As summarized in Figure 2, the results for response accuracy showed a significant main effect of the Go stage ($F(2, 46) = 13.69$, $MSE = 225.42$, $p < 0.001$), a significant main effect of the interference type ($F(3, 69) = 20.32$, $MSE = 349.15$, $p < 0.001$), and a significant interaction effect ($F(6, 138) = 6.00$, $MSE = 197.27$, $p < 0.001$). Simple main effect analyses showed that the spatial interference task significantly decreased the accuracy of the Go questions during the opening stage but had no impact on the accuracy during the midgame and endgame stages. The inference interference task significantly decreased the accuracy of Go questions during the midgame and endgame stages and did not affect the accuracy during the opening stage. The calculation interference task had no significant effect on accuracy during any of the three stages.

In the analysis of the machine learning algorithms, players' behavioral responses (accuracy and reaction time) were used as input variables for training to classify the three stages of Chinese Go questions. These results were demonstrated and verified using an eight-fold cross-validation procedure. The cross-validation classification accuracies for RF, SVM, and DNN were 73.61%, 63.89%, and 76.39% respectively. To ensure that these accuracies were significantly higher than the level of chance (i.e., 1/3), we adopted the permutation test that empirically generated null distribution of the cross-validation classification accuracy, which were assumed to be distributed with a mean around 33.33%. The results of real data showing the aforementioned cross-validation classification accuracies were located outside the 99.95^{th} percentile of the null distribution (45.83% for RF, 54.17%

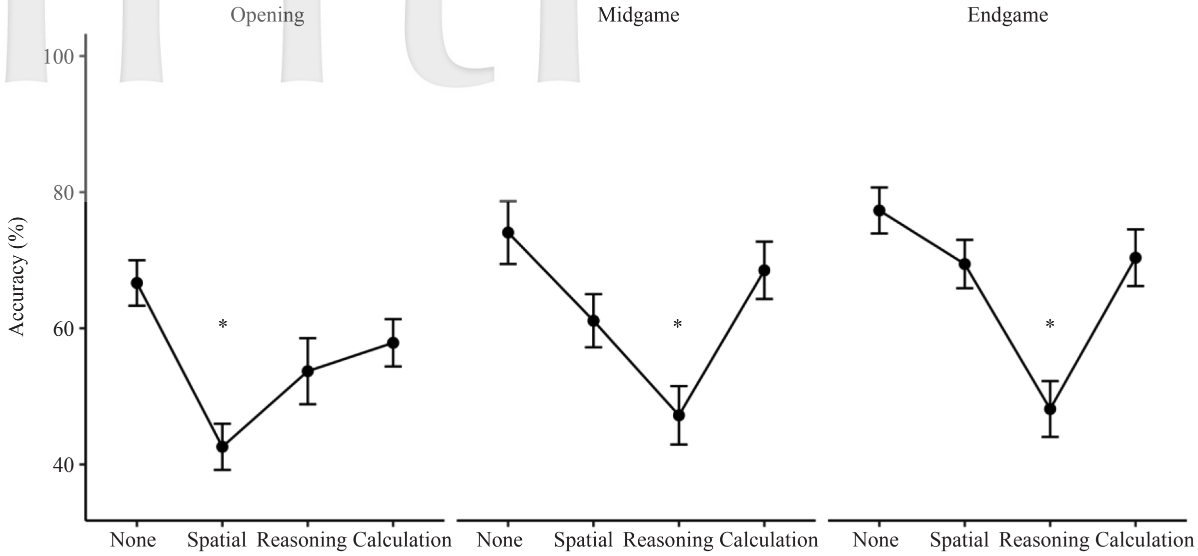

Figure 2. **Response accuracy for different interference tasks and Go stages. Asterisks indicate a significant difference between the interference task and the control condition (None). Circles and error bars represent averaged accuracies and standard errors, respectively**

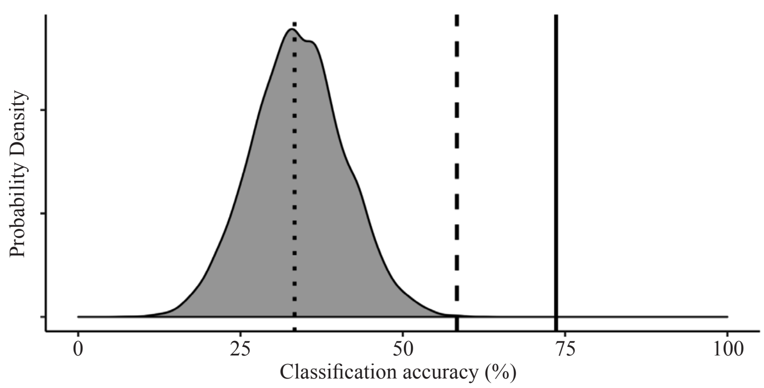

Figure 3. **Results of cross-validation classification accuracies in discriminating three Go stages predicted by the random forest algorithm. Null distribution was generated by the permutation test. Dotted line indicates the mean probability of chance level (33.33%), and long-dotted line indicates the criterion of alpha = .001. Solid line indicates cross-validation classification accuracies produced by the real data (73.61%), suggesting a significant difference between the real data and the null distribution**

for SVM, and 63.89% for DNN), which indicated that it was significantly better than chance level ($p < .001$, two-tailed). The results of RF are shown in Figure 3 as an example.

Discussion

This study aimed to investigate the underlying cognitive processes in the three stages of Go: the opening, the midgame, and the endgame. We adopted a dual task with the manipulation of Go questions in the three stages to evaluate Go ability, and four kinds of interference tasks were used to assess their influence on cognitive abilities. In addition, AI-related machine learning algorithms were implemented to further validate the results.

The results revealed that the spatial ability was the most important cognitive ability used during the opening stage, which supports our hypothesis. We speculated that players must obtain a whole picture of the game during the opening stage, which requires greater involvement of spatial ability. These results were supported by previous studies that used neuroimaging approaches. These studies found that the occipitotemporal cortex, which is associated with the integration of visual information, and the parietal cortex, which supports spatial attention, were more activated when Go players watched Go-related stimuli than when they watched control stimuli. According to previous evidence and our present findings, we extend the formulations by directly identifying the requirement for spatial ability during the opening stage.

In addition, we found that the inference ability to reason the next move or the best place was required during both the midgame and the endgame. During these stages, the two players fight to gain more territory. During the fierce battles, players must consider several previous moves and many potential future moves to determine the best move in the current situation. Subtle differences between several potential places should also be discriminated and determined. Thus, the inference ability that allows players to consider several possible moves plays an important role during these stages.

Psychological experiments have often used a single dependent variable to identify a significant difference between two psychological processes. However, if the responses of two conditions are similar, the researcher cannot easily infer whether a significant difference exists between two psychological processes. Therefore, our study adopted machine learning algorithms that could consider multivariate data (both accuracy and reaction time) to reveal the differences among the three stages of a Chinese Go game by using the response pattern from those variables. Our findings of machine learning algorithms supported our hypothesis by showing that the different stages of a Chinese Go game could indeed be correctly discriminated with our models. These results further suggest that the cognitive representations of these three stages indeed differ. Also, our findings provide a future direction to include machine learning algorithms for further identification of potential differences not been found with traditional methods.

Furthermore, we adopted a Go AI, Leela, to verify the answers to the Go questions. The results show that the win rates provided by Leela were highly consistent with the correct answers provided by the professional players. This finding not only verified the appropriateness of the Go questions but also suggested that some shared representations may exist between AI and human intelligence, which implies that we could learn from AI to improve human intelligence. Although the ability that AI developed was based on millions of simulations, which could never be performed and could not be directly adopted by humans, we could still improve ourselves from the moves suggested by AI to revise our thoughts. Therefore, it might provide the potential to produce new ideas that differ surprisingly from traditional Go rules and knowledge, thereby allowing us to improve human intelligence and refine the theoretical framework of Chinese Go.

In conclusion, our study combined traditional methods in experimental psychology and AI-related machine learning algorithms to explore whether different kinds of cognitive abilities are recruited during a Chinese Go game. Our results show that the different Go stages, the opening, the midgame, and the endgame, recruit different cognitive abilities and have different cognitive representations. The findings are not only helpful to understand the cognitive abilities involved in a Chinese Go game but also inspire the future development of AI. From the perspective of applied science, our empirical evidence will be helpful for the education of Chinese Go. Finally, we demonstrate that AI-related algorithms can have a significant impact on experimental psychology and further facilitate the collaboration of human intelligence and the AI domain.