実時間認知処理における没入の機能的な側面：
二重課題における認知資源の増加

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Chapter 1. Introduction

When people are deeply focused on activities such as sports or video games, they sometimes enter a state called "flow"—a feeling of being fully absorbed with both concentration and enjoyment (Csikszentmihalyi, 1990). Flow experience has been linked to better performance, with meta-analyses showing a moderate positive correlation between flow and game performance (Harris et al., 2023). Performance in cognitive tasks is usually judged by speed and accuracy, which typically trade off against each other (Speed-Accuracy Trade-off; Wickelgren, 1977; Heitz, 2014). However, athletes in flow states report unusual experiences. Taylor (2020; 2024) found that athletes in deep focus reported being able to "think faster than usual" and "respond accurately to brief events," suggesting that flow may help overcome this trade-off.　Previous studies had methodological limitations: most manipulated task difficulty beforehand rather than tracking immersion changes during performance, relied on post-task questionnaires, and did not examine physiological indicators and performance simultaneously.

In this study, I developed an experimental framework using Tetris to examine whether flow-related mental states co-occur with better performance under time pressure, after statistically controlling for time pressure and skill. I measured performance by whether players created "pits"—empty cells surrounded by blocks that cannot be filled by any Tetris piece. I tested three hypotheses.
Hypothesis 1: Flow increases cognitive resources, improving secondary task performance.
Hypothesis 2: Flow-related states improve performance, especially under high time pressure.
Hypothesis 3: The relationship between immersion and performance depends on skill level.

Chapter 2. Method

Twenty-four graduate students from Japan Advanced Institute of Science and Technology participated (20 males, 4 females, mean age = 24.54, *SD* = 2.53).　Participants played standard Tetris using the Meta-T platform (Lindstedt & Gray, 2015), which records all key presses and board states in milliseconds. Participants were instructed to play as fast as possible while aiming for high scores.

As a secondary task, participants performed a simple reaction task. A red circle appeared randomly at one of four screen corners for 400 ms, and participants pressed a key as quickly as possible. The inter-stimulus interval followed a power-law distribution ($\alpha = 2.0$, 3 to 40 seconds) to prevent prediction. Pupil diameter was recorded using a Tobii Pro Spectrum eye tracker.　After practice games, participants completed 8 main games. After each game, they answered a 10-item Japanese flow questionnaire (Ishimura, 2014).

Chapters 3–5. Time Pressure Index

To measure time pressure at each Tetris episode (from block appearance to completion in one move), I used principal component analysis on 9 board state variables plus game level. PC1 explained 81.0% of total variance. Board state variables showed high loadings, while game level showed relatively low loading, indicating that time pressure in Tetris is mainly determined by board state rather than piece falling speed.　Time pressure had a significant main effect on pit creation ($\beta = -0.609$, $p < .001$, OR = 0.54), confirming index validity.

Chapter 6. Immersion Index

To measure immersion during task performance, I used canonical correlation analysis (CCA) to find relationships between three measures (pupil diameter, reaction time, response rate) and 10 flow questionnaire items. The first canonical correlation was $r = .523$. The loadings based on CCA were: reaction time (reversed) = .393, response rate = .447, and pupil diameter (reversed and squared) = .159. Games with higher flow tendency had better secondary task performance, supporting Hypothesis 1: cognitive resources increase during flow states.

Chapter 7. Performance Prediction

Logistic regression predicted episode-level performance from time pressure, immersion, and skill (all standardized). Skill had a significant main effect ($\beta = +0.306$, $p < .001$, OR = 1.36). Immersion also had a significant main effect ($\beta = +0.150$, $p = .007$, OR = 1.16), meaning episodes with 1 SD higher immersion had approximately 16% higher odds of not creating pits. The time pressure × immersion interaction was marginally significant ($p = .055$). The three-way interaction was significant ($\beta = -0.116$, $p = .003$). In the low skill group, the effect of immersion was small under low time pressure (+.015) but large under high time pressure (+.059). In the high skill group, the effect was similar across conditions (+.007 and +.039). The difference was about 1.5 times larger in the low skill group (+.044) than in the high skill group (+.032), supporting the prediction that beginners benefit more from flow states.

Chapter 8. Discussion

The three-way interaction can be explained by automatic versus controlled processing (Schneider & Shiffrin, 1977). Experts have automatized basic processing and use few cognitive resources, maintaining performance regardless of immersion. Beginners rely on controlled processing, which consumes limited cognitive resources. Under high time pressure, they are likely to run out of resources. Flow states increase cognitive resources, providing greater benefit to beginners. This study has limitations. The correlational design cannot determine causality. There is also potential circularity: immersion was defined partly by secondary task performance, then shown to predict Tetris performance. Despite limitations, this study contributed by measuring time pressure from board features and controlling for it statistically, and by directly examining whether flow-related states co-occur with better performance.

Conclusion

This study examined whether flow-related mental states co-occur with better performance in Tetris. The main effect of immersion was significant after controlling for time pressure and skill. The three-way interaction showed that beginners benefit more from flow states, possibly because they are more likely to run out of resources under time pressure. These findings provide evidence for the functional link between flow experience and performance in real-time cognitive tasks.