Research on the correlation between physiological and psychological states of intangible cultural heritage puppet games based on flow theory

Yiming Ma [1, a], Xiaotong Mou [2, b,*], Xinran Zhang [1, c], Jing Zhao [1, d], and Zixi Wang [1, e]

[1] School of Art and Design, Beijing University Of Technology, Beijing, China.

[2] School of Architecture and Urban Planning, Beijing University Of Technology, Beijing, China.

[a] 18611420787@163.com, [b] Anna_mu@126.com, [c] 2257898633@qq.com ,

[d] zhaojing_milan@163.com, [e] 2651908648@qq.com

Abstract. This study is based on flow theory and explores the impact of skill challenge balance in intangible cultural heritage puppet games on users' physiological (heart rate variability) and psychological states (anxiety, fatigue, flow), providing a basis for optimizing game design and digital dissemination of intangible cultural heritage. 35 participants aged 18-30 were recruited for the experiment, and through LeapMotion's finger interaction method, they completed three types of tasks: high challenge low skill, low challenge high skill, and skill challenge balance. Subjective questionnaires (heart flow scale FSS) and physiological data (HRV), use one-way ANOVA and correlation test for data analysis. The low-frequency HRV showed a U-shaped relationship with flow, indicating that the coordinated activation of sympathetic and parasympathetic nerves is a necessary condition for flow. The balance between skills and challenges can effectively stimulate the flow experience through natural interaction methods such as gestures. The design of intangible cultural heritage games should take into account cultural connotations and dynamic difficulty adjustment. The study provides empirical support for the physiological mechanisms of flow theory and proposes a new path for optimizing the digital experience of intangible cultural heritage.

Keywords: Flow Theory，Gesture Interaction，Heart Rate Variability，Intangible Cultural Heritage Digitization.

1. Introduction

1.1 Research Background

The Flow Theory was proposed by psychologist Csikszentmihalyi in 1975 to describe the psychological state of an individual when they are highly focused and fully engaged in an activity. The flow experience is believed to be closely related to pleasure, efficiency, and creativity, with its core condition being a balance between task challenges and individual skill levels. With the rapid development of digital technology, flow theory has been widely applied in fields such as education, game design, and mental health.

However, existing research has mostly focused on the description of subjective psychological states, and the exploration of the correlation between flow experience and physiological states such as heart rate variability is still insufficient. Therefore, in the experience of intangible cultural heritage game scenes, how to quantify the flow state through physiological data and optimize the level and interaction design of intangible cultural heritage games is still a key issue that needs to be addressed.

1.2 Research significance

This study aims to reveal the correlation between psychological characteristics and physiological indicators of flow status by comparing subjective questionnaire data with physiological data, providing scientific data support for game design, dissemination and development of intangible cultural heritage, and other related content. This study quantitatively analyzes the impact of the skill challenge balance, which is the condition for flow generation, on users' physiological data responses. This not only deepens the empirical basis of flow theory, but also provides data support for the dynamic difficulty adjustment of human-computer interaction systems, helping to optimize user experience.

2. Related research

Flow theory has been widely applied in interaction design and user experience optimization. Yang et al. [1] integrated flow theory into automotive interaction interfaces, enhancing immersion through optimized operational logic. Li et al. [2] improved user flow in cultural product design by balancing multisensory interaction and skill-challenge dynamics, contributing to the digital transformation of cultural elements.

For cultural heritage dissemination, Ali [13] used VR serious games to enhance young users' engagement with Saudi heritage, demonstrating that immersive experiences foster cultural identity. Chen et al. [14] developed Thirteen Floods of Guangzhou, a VR game combining commercial history with task-solving, highlighting the value of "active participatory learning." However, both studies lack in-depth exploration of the interaction-flow relationship.

In gamification design, Chang et al. [12] found that goal-oriented players prefer relaxed flow states, offering insights for intangible cultural heritage (ICH) puppet game narratives. However, digital interactions with traditional crafts must balance cultural depth with operational feedback.

Despite progress in flow theory applications and heritage digitalization, gaps remain. Interaction design largely focuses on modern product scenarios, lacking research on ICH techniques' physical feedback, such as puppet manipulation. Additionally, cultural games prioritize visual immersion while overlooking the link between flow state and operational complexity.

3. Research Architecture

3.1 Flow Theory

Flow theory, proposed by Csikszentmihalyi in 1975, describes a psychological state where cognition, physiology, and emotion integrate, leading to deep focus, immersion, and satisfaction. Clear goals, timely feedback, and a balance between skills and challenges are key to inducing flow. Task difficulty and individual skill levels shape this process: high challenge with low skill causes anxiety, while high skill with low challenge leads to boredom. Flow occurs only when skills and challenges are balanced (Figure 1).

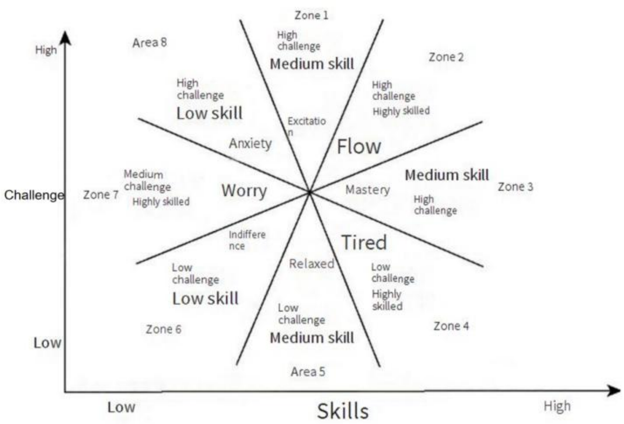

Figure 1 Flow Model

3.2 Research Theoretical System

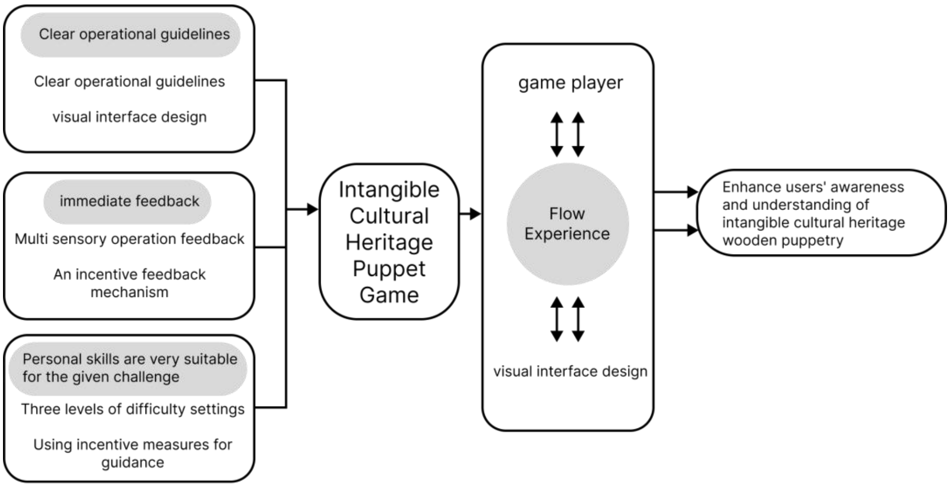

Figure 2 Process of Flow Experience Generation

This experiment designed interaction methods with different levels of difficulty, as shown in Figure 2. The relationship between flow experience and intangible cultural heritage games lies in the use of appropriate game design to help players immerse themselves in the flow experience of intangible culture and gain a deeper understanding of the cultural characteristics of puppetry. This study provides players with a higher gaming challenge experience by developing gameplay that combines Leapmotion fingers. At the same time, experienced game players and users with higher game skills will be selected to participate in this experiment.

4. Research content

4.1 Research Methods

This study focuses on the core condition of flow theory - the balance between skills and challenges, exploring the correlation and differences between different psychological states (anxiety, boredom, flow) and physiological states (skin electrical activity, heart rate variability) triggered by it in game tasks. The specific research content is as follows:

From January 2024 to January 2025, a total of 35 volunteers participated in the experiment. The participants were all 35 subjects aged 18 to 30, with 15 males and 20 females (mean age=24.04, variance=2.53). The participants are undergraduate and graduate students from Beijing University of Technology, majoring in electrical engineering, computer science, industrial design, and more.

All participants had experience playing computer games (average frequency=3.79, variance=3.82). Among them, 87.5% of people play computer games more than once a week. The attitude questions on the questionnaire were rated from 1 (strongly disagree) to 5 (strongly agree). Participants showed a positive attitude towards using multimodal interaction methods in the game (average=4.40, variance=0.67). In terms of understanding intangible cultural heritage, 9 participants had knowledge of puppetry, while 26 participants had no knowledge of it. Overall, most participants were almost unfamiliar with the content related to intangible cultural heritage puppetry (average=1.26, variance=0.23).

4.2 Experimental Design

This study adopted a one-way analysis of variance (ANOVA) design, in which participants will experience three task levels in sequence, and physiological data experienced in each level will be measured and recorded. In order to reduce sequential effects, a randomized design was adopted for the experimental sequence.

4.2.1 Stimulating Material Game Design

Based on the "skill challenge balance" model in flow theory, combined with the "three line control puppet" skill characteristics of Quanzhou puppetry, the three levels are strictly matched into the following three design categories:

1.High Challenge, Low Skill (Anxious State): In Level 1, players use pinching gestures to control a fan and manage three sets of wires to match the puppet's Drinking posture. A 10-second time limit and frequent obstacles exceed novice abilities, triggering the Puppet Injury animation and negative sound effects, inducing frustration and anxiety.

2.Low Challenge, High Skill (Bored State): In Level 2, players evade darts with simple finger waves, controlling the puppet's head with a single vertical gesture. Fixed dart paths, unlimited attempts, and low precision requirements make the task too easy, leading to boredom, especially for experienced players.

3.Skill-Challenge Balance (Flow State): In Level 3, players simulate puppet "kicking" with left-right finger movements. A dynamic adaptation mechanism adjusts the wine jar's frequency and position based on performance, ensuring a balanced challenge. Successfully kicking the jar triggers the Li Bai Writes Poetry animation, enhancing cultural immersion. This adaptive difficulty maintains skill-challenge balance, keeping players in the flow state.

Figure 3 Game Introduction

4.2.2 Experimental steps

The pre experimental stage divides user skill levels (high/medium/low) through operational testing (such as handle accuracy calibration tasks). During the formal experiment, each user completes three types of tasks (anxiety, boredom, and flow) in sequence, with each task lasting 10 minutes and an interval of 5 minutes to eliminate residual physiological data effects.

5. Experimental conclusion

5.1 Subjective questionnaire analysis

The subjective questionnaire is measured using the Flow Scale (FSS) and Task Perception Questionnaire. The Simple Flow Scale is used to measure the flow experience of participants after each experimental task, and the measurement results are mainly used to provide evidence for physiological indicators. This scale has been extensively researched and proven to have good reliability and validity. The questionnaire consists of 10 questions and is scored on a 7-point scale, ranging from 1 (completely agree) to 7 (completely disagree).

A t-test was conducted on the questionnaire data, and it was found that the way users experience gestures can enhance their flow experience. The subjective questionnaire analysis results show that in terms of cultural identity and cultural understanding dimensions, the gesture interaction group showed a statistically significant difference compared to the non interaction group ($t(38)=11.393$, $p<.001$), indicating that gesture interaction can significantly improve participants' subjective identity and understanding of cultural content; In terms of emotional involvement and immersion, there was a significant difference between the two groups ($t(38)=8.285$, $p<.001$), confirming that gesture interaction effectively enhanced participants' emotional engagement and immersion experience.

5.2 Physiological data analysis

The autonomic nervous system (ANS) consists of the sympathetic nervous system and the parasympathetic nervous system, and is believed to be associated with basic emotions. This study used the method of ANOVA to compare the inter group differences in HRV indicators among three types of tasks. Analyze the correlation between HRV low-frequency power (stress index) and task challenge, and reveal the specific impact of high challenge tasks on the autonomic nervous system.

Cardiovascular activity is a key indicator of flow experience in gaming. Heart rate (HR) increases with sympathetic activation and decreases with parasympathetic activity, while the interbeat interval (IBI) follows the opposite pattern. Heart rate variability (HRV) measures fluctuations in IBI, reflecting adaptability to environmental demands. HRV distinguishes sympathetic and parasympathetic influences through frequency components: low-frequency (LF: 0.14 – 0.15Hz), high-frequency (HF: 0.15 – 0.4Hz), and the LF/HF ratio.

The flow experience is related to cardiovascular activity. The activation of sympathetic nerve bundles in the autonomic nervous system may be related to flow status. Correspondingly, an increase in HR and an increase in LF/HF ratio may both occur with flow status. On the other hand, heart rate variability is also an indicator of psychological effort, which refers to the degree of effort to allocate cognitive resources to the current task. Higher psychological effort is correlated with lower heart rate variability

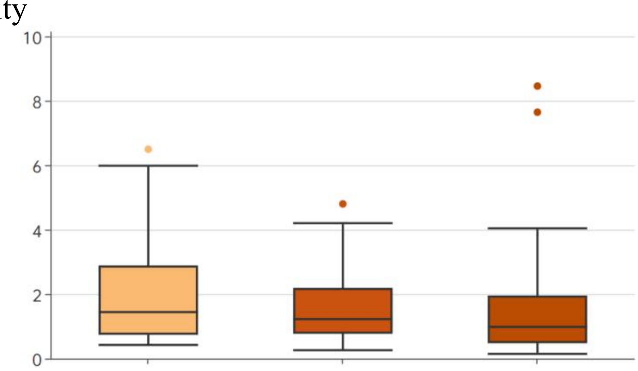

Figure 4: LF/HF data of HRV in three levels

The relationship between HRV and heart flow follows a U-shaped curve, showing that coordinated activation of sympathetic and parasympathetic nerves is essential for heart flow. In Figure 4, the LF/HF ratio of HRV across three levels reflects this: the first level (low challenge, high skill) has the highest LF/HF ratio, indicating dominance of sympathetic activity and player boredom; the second level (skill-challenge balance) has the lowest ratio, signifying balanced sympathetic and parasympathetic activation, aligning with flow; and the third level (high challenge, low skill) shows an increased ratio, indicating sympathetic overactivation and anxiety due to task overload. This U-shape suggests that heart flow requires balanced autonomic nervous system activity, with extreme activation of one system disrupting flow.

6. Conclusion and Prospect

6.1 Relationship between flow and task difficulty

This study designed experimental conditions of different difficulty levels through puppetry experience, which created a good experimental premise for inducing different flow experiences. For flow experience, LF can serve as an effective predictor. Previous studies have shown that higher flow experiences are accompanied by a decrease in LF. However, LF is associated with increased sympathetic activity in the autonomic nervous system, making it a necessary condition for flow experience to occur. However, there is a U-shaped relationship between task difficulty and flow experience, so simply taking the low frequency corresponding to the difficulty on the left or right side of the curve cannot be explained by sympathetic nervous activity. In addition, high flow experience is associated with moderate high frequency, which is a significant predictor of parasympathetic nervous system activity. However, the relationship between high frequency and flow experience is not linear, and excessive or insufficient parasympathetic activity cannot produce a higher flow experience. The overall flow experience is not solely generated by sympathetic or parasympathetic nervous system activity, but rather the result of their synergistic activity.

6.2 Future Outlook

This study is based on flow theory and verifies the important role of "skill challenge balance" in enhancing user immersion experience. Through Leap Motion finger interaction, users can activate their sensory and cognitive systems with natural and precise movements, entering a smooth psychological state, thereby enhancing emotional engagement and cultural experience. This result provides scientific data support for game designers and innovative design ideas for the digital dissemination of intangible cultural heritage.

However, there is still much room for exploration in future research. Firstly, different cultural elements may require varied flow experiences, so future studies could focus on designing adaptive interaction methods based on these cultural characteristics. Secondly, as physiological measurement technology advances, incorporating indicators like electroencephalography and skin temperature could provide a more comprehensive analysis of heart flow mechanisms. Additionally, skill levels and cultural backgrounds may influence flow experiences, suggesting the need for broader samples to improve the generalizability of research.

References

[1] Yang Aoran, Zhang Yong, Jia Xinhong, etc Research on Automotive Interaction Interface Design Based on Flow Theory [J]. Packaging Engineering, 2023, 44 (S1): 334339.1.19554/j.cnki.10013563.2023.S1.050

[2] Li Jiangyong, Tan Qiqian, Qiu Pan, etc Research on Interactive Design of Cultural and Creative Products Based on Flow Theory [J]. Packaging Engineering, 2020, 41 (18): 287293.10.19554/j.cnki. 10013563.2020.18.037

[3] Zhang Peng, Zhang Yuyang, Wang Fei, etc Evaluation Model of Pediatric Dental Fear and Anxiety Based on Physiological Indicators [J]. Basic Medicine and Clinical, 2024, (05): 705708

[4] Guan Qian Research on Evaluation and Optimization Design of Indoor Public Spaces in Elderly Care Institutions Based on Emotion Measurement [D]. Qingdao University of Technology. 2023

[5] Y. Li, A. S. Elmaghraby, A. ElBaz and E. M. Sokhadze, "Using physiological signal analysis to design affective VR games," 2015 IEEE International Symposium on Signal Processing and Information Technology (ISSPIT), Abu Dhabi, United Arab Emirates, 2015, pp. 5762, doi: 10.1109/ISSPIT.2015.7394401.

[6] K. Soman, V. Alex and C. Srinivas, "Analysis of physiological signals in response to stress using ECG and respiratory signals of automobile drivers," 2013 International MutliConference on Automation, Computing, Communication, Control and Compressed Sensing (iMac4s), Kottayam, India, 2013, pp. 574579, doi: 10.1109/iMac4s.2013.6526476.

[7] Hsieh, P.Y., & Chin, C.L. (2011). The emotion recognition system with heart rate variability and facial image features. IEEE International Conference on Fuzzy Systems (FUZZ), 19331940.

[8] McCraty, R., Atkinson, M., Tiller, W.A., Rein, G., & Watkins, A.D. (1995). The effects of emotions on shortterm power spectrum analysis of heart rate variability. The American Journal of Cardiology, 76(14), 10891093.

[9] Minsanghyun, Park, S., Lee, W., 2016. The comparison of immersion between automatic and manual movement method in FPS VR game. Journal of The Korean Society for Computer Game 29, 141–148. https://doi.org/10.22819/kscg.2016.29.4.017

[10] Chang, S.C., Chiu, Y.P., Hwang, J.C., 2020. Determining Satisfaction from Gameplay by Discussing Flow States Related to Relaxation and Excitement. Comput Game J 9, 369–382. https://doi.org/10.1007/s40869020001135

[11] Ali, M., 2024. Fostering cultural heritage awareness through VR serious gaming: A study on promoting Saudi heritage among the younger generation. J. Infrastruct. Policy Dev. 8, 3084. https://doi.org/10.24294/jipd.v8i3.3084