CHAPTER IV

RESULTS

4.1 Introduction

The analysis in this research focuses on evaluating the effectiveness of the SuraSole maze game, developed to improve balance through the application of Reinforcement learning (RL). The aim is to assess changes in balance-related parameters, such as RMS amplitude, RMS velocity, and COP velocity, in both the medio-lateral and anterior-posterior directions. These parameters reflect the participants' ability to control COP movement and overall stability.

The results include a comparison of the Balance score before and after gameplay to evaluate whether the game levels and difficulty adjustments, based on players' COP states, effectively enhance physical balance. Additionally, the Average reward data was utilized to measure the effectiveness of the RL system in adapting the game difficulty to match the players' abilities.

The analysis of participants' feedback was designed to assess levels of satisfaction, safety, and motivation for balance rehabilitation. This feedback provides insights into the game's ability to promote motivation and encourage patients to engage in rehabilitation activities consistently.

Therefore, the experiments conducted in this study not only emphasizes quantitative evaluations through physical parameters but also incorporates qualitative assessments based on participants' feedback and experiences. This combined approach provides crucial information for further development and improvement of the game to suit target groups with diverse characteristics.

4.2 Individual balance metrics

Based on the analysis of the parameters used to evaluate balance, it was found that after playing the game, the COP velocity, RMS amplitude, and RMS velocity in both directions showed certain trends of improvement. These trends indicate an enhancement in the ability to control movement and maintain balance of the COP, with the following details.

1. RMS amplitude (rms_amp_x): Decreased from 0.12 ± 0.07 to 0.08 ± 0.06 m, indicating a reduction in COP displacement in the medio-lateral direction, reflecting improved control of lateral balance, with p = 0.0698 (not statistically significant) from the paired t-test.

2. RMS Amplitude (rms_amp_y): Slightly decreased from 0.070 ± 0.036 to 0.068 ± 0.036 m, indicating increased stability in the anterior-posterior direction. Although the change was not pronounced, it still suggested a slight improvement trend, with p = 0.4190 (not statistically significant) from the paired t-test.

3. RMS velocity (rms_vel_x): Decreased from 0.043 ± 0.046 to 0.020 ± 0.010 m/s, indicating a reduction in COP velocity in the medio-lateral direction, suggesting improved control over lateral movement, with p = 0.0252 (statistically significant) from the paired t-test.

4. RMS velocity (rms_vel_y): Decreased from 0.013 ± 0.010 to 0.010 ± 0.003 m/s, indicating a reduction in COP velocity in the anterior-posterior direction, which reflects better control over forward-backward balance, with p = 0.1191 (not statistically significant) from the paired t-test.

5. COP velocity (velocity): Decreased from 0.0013 ± 0.0011 to 0.0007 ± 0.0003 m/s, indicating a reduction in the overall variability of COP, which is a sign of improved balance stability, with p = 0.0471 (statistically significant) from the paired t-test.

It should be noted that the experiment so far has been carried out on healthy volunteers with no balance impairment. Additional experiments with participants who have balance limitations are recommended to obtain more comprehensive data and to demonstrate the game's potential in effectively enhancing balance control skills.

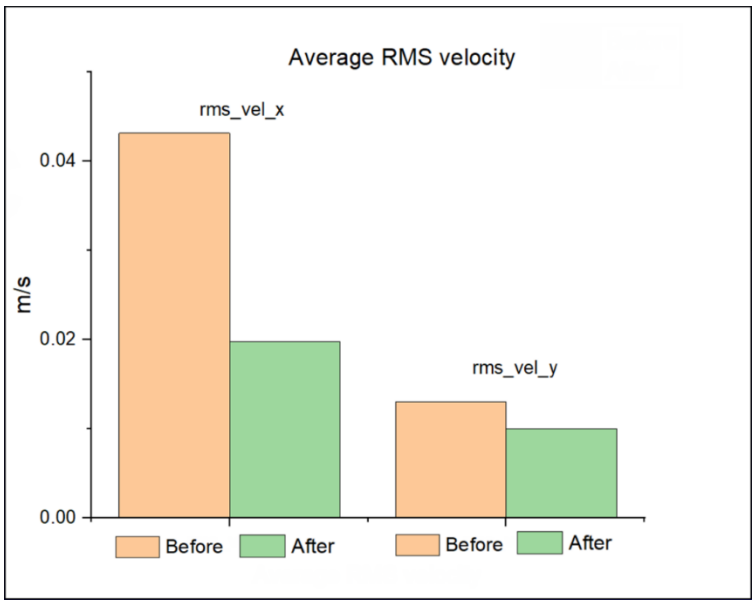

Figure 4.2.1 Average RMS velocity in the X and Y axes before and after gameplay

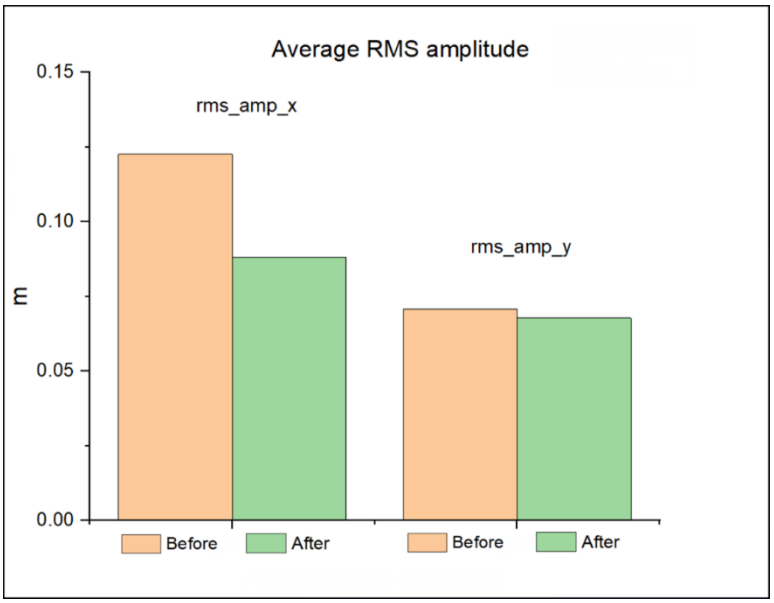

Figure 4.2.2 Average RMS amplitude in the X and Y axes before and after gameplay

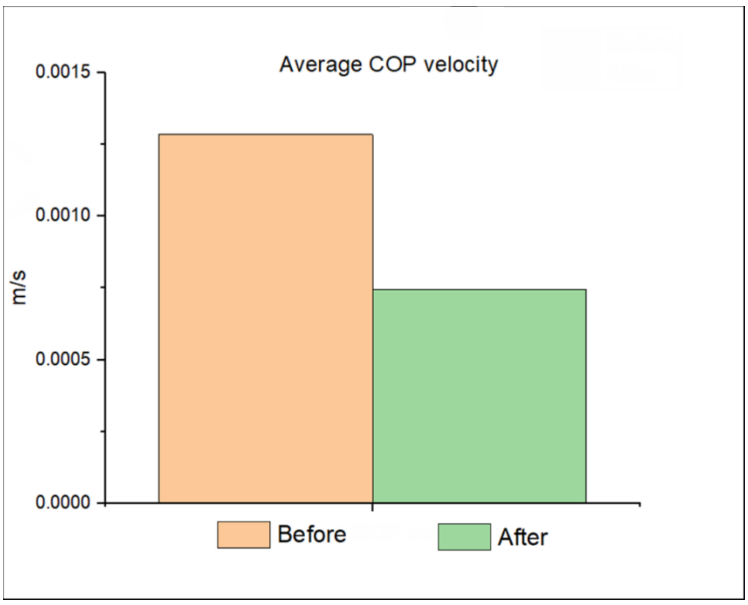

Figure 4.2.3 Average COP velocity before and after gameplay

4.3 Balance score

This section describes the details of the assessment conducted with the participants, including a summary of the findings from the balance ability evaluation to reflect the suitability of the game used for testing. It also analyzes whether the scores obtained from the experiment adequately reflect balance improvement. Additionally, a comparison of Balance scores in equation (2.11) between participants before and after gameplay is included to verify whether the designed game can help improve balance.

To validate the comparison results, a Paired t-test was performed to calculate the significance level (p-value), which indicates whether the difference between pre- and post-experiment scores is statistically significant (Datatab, 2024). A significance level of $p<0.05$ was set as the criterion. If the p-value obtained is less than or equal to 0.05, the difference between the pre- and post-experiment scores is considered significant. This suggests that the designed game can effectively improve balance ability with statistical significance.

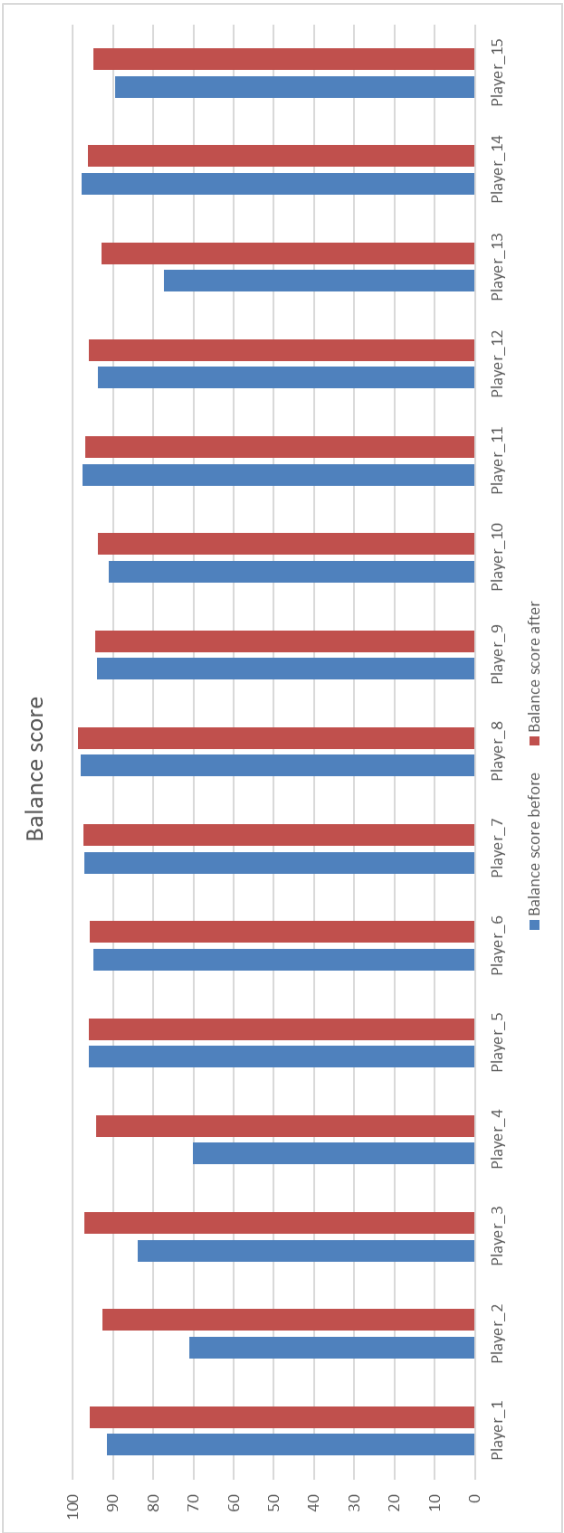

Figure 4.3.1 Balance score of the participants

The graph shows that most participants exhibited some improvement in their Balance score after playing the game compared to before the experiment (blue bars).

This reflects the game's potential to effectively enhance participants' balance ability. Notably, Player 3 and Player 13 demonstrated a significant improvement in their scores, increasing from 83.86 to 97.13 and 77.34 to 92.87, respectively. Additionally, Player 2 and Player 4, who had low initial scores, showed more progress, improving from 70.94 to 92.67 and 70.14 to 94.14, respectively. This indicates that the game may help develop balance control skills even in individuals with initially lower balance abilities.

Meanwhile, some participants, such as Player 7, Player 8, and Player 11, showed no significant difference in their scores before and after the experiment. This could be attributed to their already stable balance abilities or other factors, such as the game's challenge level not being appropriate for these participants. External factors, such as familiarity with the equipment or a lack of challenge during gameplay, may have also influenced their performance.

Overall, the average Balance score for all participants improved from 89.6 ± 9.23 before the experiment to 95.5 ± 1.6 after playing the game. Using the paired t-test using the significance level of 5% resulted in a p-value of 0.0161, there is a significant in the improvement of the average Balance score of the playing the game.

It is important to note that the participants in this study were healthy individuals with normal balance abilities, which might have limited the observed improvements compared to individuals with balance impairments. Therefore, further studies should be conducted with participants who have balance limitations to comprehensively evaluate the game's effectiveness. Additionally, adjusting the game's difficulty level to better match the capabilities of different groups of players, along with considering factors such as familiarity with the equipment and player engagement during the experiment, could further enhance the game's design. These improvements would ensure that the game effectively meets the needs of its target groups and maximizes its potential for use in balance rehabilitation.

4.4 Average reward

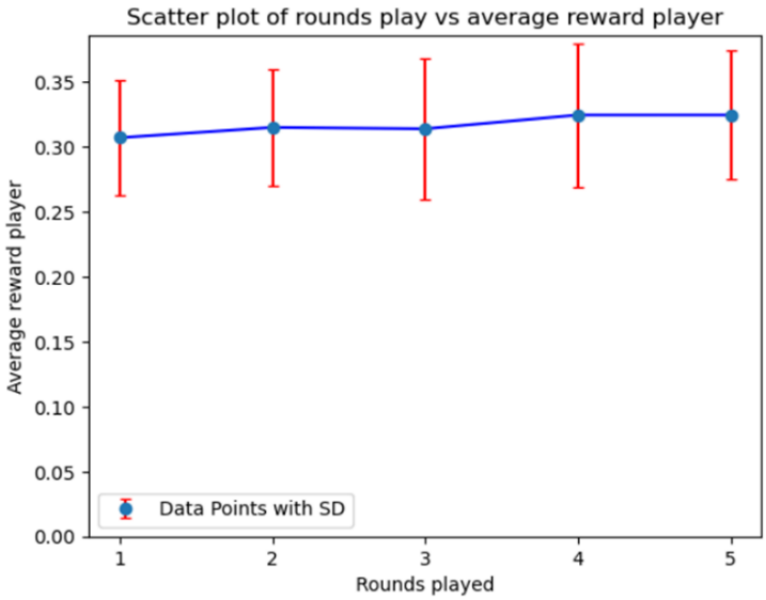

Figure 4.4.1 Relationship between the number of game play rounds and the average reward of participants

From Figure 4.4.1, it is evident that the Average reward tends to increase as the number of gameplay rounds increases. This indicates that the RL model helps players move the COP closer to the center over time, reducing the COP distance from the center and thereby increasing the Average reward, where by the immediate reward is given by equation (A.4.1). This trend reflects the Q-learning model's ability to learn and adapt to improve player performance as the number of gameplay rounds increases.

Using the Average reward from all participants provides an overall perspective on the RL model's effectiveness in helping players improve COP control. However, the variability in the reward values suggests differences in individual player abilities. Adjusting the model's parameters, such as learning rate or exploration rate, could further enhance performance at both the individual and overall levels.

Additionally, it should be noted that the participants in this experiment were general individuals with normal COP, who already had a good foundation in balance. This may have contributed to the model's consistent learning and performance improvements. However, familiarity with the game mechanics over multiple rounds may also have been a factor in players' improved COP control, resulting in reduced

COP distance and increased rewards. Therefore, separating the effects of RL from the familiarity with the game should be considered in future experiments.

The results of this experiment also indicate that while the RL model can improve COP control overall, reducing the variability in reward values may require fine-tuning parameters such as the learning rate or exploration rate. This would allow the model to learn more consistently and respond more effectively to players with varying abilities.

4.5 Player Satisfaction

After playing the game, participants completed a satisfaction assessment questionnaire to collect information about their experiences and opinions regarding the developed game. The purpose of this assessment was to measure the level of satisfaction, enjoyment, game safety, and the game's ability to promote balance rehabilitation. Analyzing the data from this assessment helps to understand the participants' responses to the game format and difficulty, as well as to evaluate whether the game design can create appropriate motivation and challenge for training. The questionnaire can be found in Appendix C.

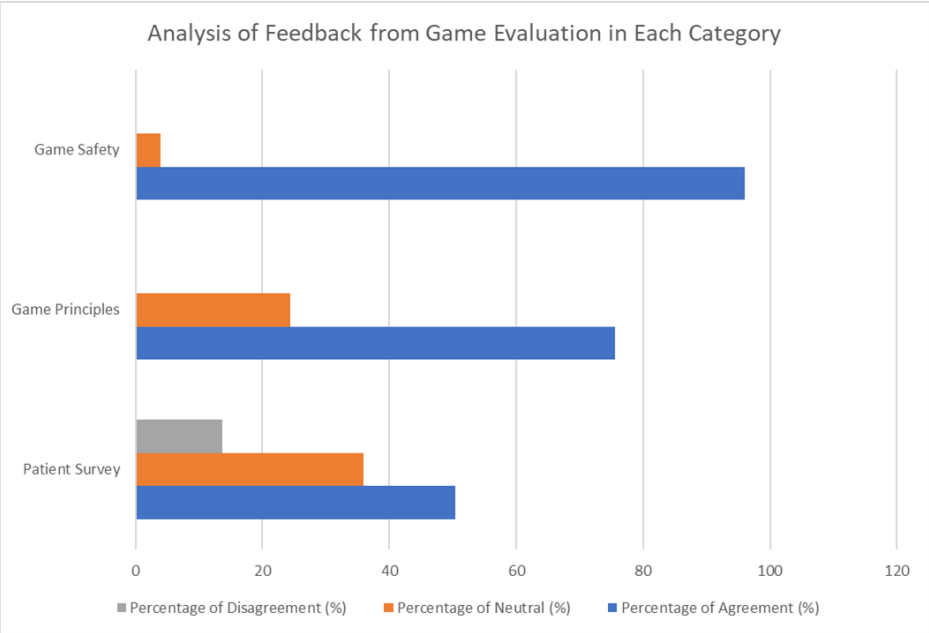

Figure 4.5.1 Analysis of feedback from game assessment in each category

From Figure 4.5.1, the evaluation is categorized into three aspects, patient survey, game safety, and game principles. The analysis of the results is as follows.

4.5.1 Patient survey

This category shows that 50.43% of participants expressed "agreement," indicating a generally positive reception from more than half of the participants. However, 35.9% responded "neutral," suggesting that a considerable number of participants did not perceive a significant difference in outcomes. Additionally, 13.68% responded with "disagreement," highlighting areas that may require improvement to enhance patient satisfaction in the future.

4.5.2 Game principles

The feedback for this category was positive, with 75.56% of participants expressing agreement. This result highlights that the maze levels were appropriately designed to match the patients' skill levels and demonstrates the game's effectiveness in terms of usability and technical principles. However, 24.44% of participants responded neutral, suggesting areas where the design may not have fully met expectations. There were no disagreement responses, indicating strong alignment between the maze design and user needs overall.

4.5.3 Game safety

The feedback for the Game Safety category was strongly positive, with 96% of participants expressing agreement. This indicates that participants perceived the game as safe for use, particularly in reducing risks related to physical fatigue, technical errors, or other safety-related concerns. The high level of agreement reflects the robustness of the game’s design in prioritizing user safety, which is a critical factor for therapeutic and rehabilitative applications.

On the other hand, 4% of participants responded neutrally, which may stem from uncertainty or a lack of clarity regarding certain aspects of safety. Nevertheless, the overall positive feedback reinforces the game's reliability and its ability to provide a safe environment for participants.

4.6 Summary

Chapter 4 summarizes the analysis related to the potential of the SuraSole maze game, which was developed to promote improvements in balance ability. The focus was on measuring key parameters such as RMS amplitude, RMS velocity, and COP velocity, which indicate trends toward improvement in the overall balance score of participants. The results showed a significant improvement in the Balance score, with $p = 0.0161$. which may reflect the potential of the game in supporting the development of participants' overall movement control skills. Furthermore, the increase in Average reward per round indicates the trend of the RL model in adjusting the game's difficulty levels to match the COP status of the players, potentially supporting the continuous improvement of participants' abilities.

However, it should be noted that this experiment was conducted with a group of volunteers who had normal balance and good baseline stability, which may mean the results do not fully reflect the game's effectiveness for individuals with balance impairments. Additionally, all experiments were conducted in a controlled laboratory environment, which may not fully align with real-world conditions where various environmental factors are present.

Feedback from participants also indicated positive satisfaction regarding the game's safety, usability design, and its ability to motivate rehabilitation engagement. The data from both quantitative and qualitative evaluations suggest that the SuraSole maze game holds potential for use in rehabilitation processes. Nevertheless, further studies are needed with sample groups experiencing balance issues and experiments conducted in environments that more closely resemble real-world settings to comprehensively assess the game's potential.