CHAPTER III

RESEARCH METHODOLOGY

3.1 Introduction

To achieve the objectives of this research, the development of a system capable of automatically adjusting the difficulty levels of a balance rehabilitation game and evaluating its effectiveness requires a clear and appropriate research methodology. This study divides the process into three key phases: the development of the Reinforcement learning (RL) model, the design and development of the SuraSole maze game, and the evaluation of the system through experiments with participants.

In the first phase, the research focuses on developing the RL model to adjust the game's difficulty levels based on balance metrics, such as COP (Center of Pressure), measured using SuraSole insoles. This phase includes the training and testing of the RL model to enable the system to select levels that align with the player's state.

In the second phase, the design of the SuraSole maze game emphasizes creating levels that correspond to the player's COP state in each quadrant. Input from experts, such as physiotherapists, is incorporated into the game design to ensure it suits players with specific characteristics.

In the final phase, experiments with participants are conducted to evaluate the game's effectiveness both quantitatively and qualitatively. Data is collected on balance metrics, and participant feedback is surveyed regarding their satisfaction, safety, and motivation to engage in the game.

Thus, the Research Methodology chapter outlines the detailed process, from RL model development to game design and evaluation.

3.2 Research design

This study is an experimental research with the objective of developing a balance rehabilitation game that automatically adjusts difficulty levels based on players' abilities using RL. The study also aims to analyze the impact of the game on participants' balance and assess its effectiveness in improving balance and enhancing motivation for participating in balance rehabilitation.

3.3 Participants

The study involved 15 participants aged between 21-44 years (mean age 26 .7 3 ±6.65 years 12 males and 3 females). Participants were voluntarily recruited in the laboratory and were required to have no physical balance limitations or injuries that could affect their movement.

3.4 Research tools

a) **SuraSole maze game:** A game developed using RL that can adjust difficulty levels based on players' COP data. The game consists of levels designed to assess and improve players' balance.

b) **SuraSole insoles:** Wireless sensor-equipped insoles used to collect COP data.

c) **Post-Game evaluation questionnaire:** A survey designed to measure participants' satisfaction, including their opinions on the game's safety, difficulty, and engagement.

3.5 Experimental procedures

The research methodology was conducted in two phases: Phase 1 involved developing the RL-based game adjustment system and focused on designing the conceptual framework of the game, Phase 2 evaluated the game with participants.

3.5.1 Phase 1: Development of RL-based game adjustment

In this phase, a RL model was developed to adjust the game's difficulty levels using simulated data. The RL model was designed to learn decision-making for

selecting game levels based on COP parameters. Details of the RL model training process and results are provided in Appendix B.

3.5.2 Phase 1: Game concept development

The game concept was inspired by (Riedmann, 2022; Baranyi, 2013), where players guide a ball through a maze by practicing weight shifting on SuraSole insoles. The game levels were designed to cover the COP states of players in five quadrants based on their balance capabilities.

Quadrants 1-4: Each quadrant contains nine game levels designed to improve players' balance at different states. From Figure 3.5.1 the difficulty of each level is ordered alphabetically (A-I), where "A" represents the easiest level and "I" represents the most difficult. The alphabet after the quadrant indicator (e.g., "A-I") specifies which quadrant the level belongs to.

Quadrant 5: This quadrant contains four game levels, as players in this state already have good balance. The focus here is on maintaining balance and evaluating the RL model's ability to guide players to this optimal state.

The level designs for Quadrants 1-4 were adapted from (Baranyi et al., 2013) and refined based on feedback from physiotherapists to ensure they meet players' needs and effectively improve balance. The RL framework for the SuraSole maze game are presented and the experiment results detailed in Appendix B.

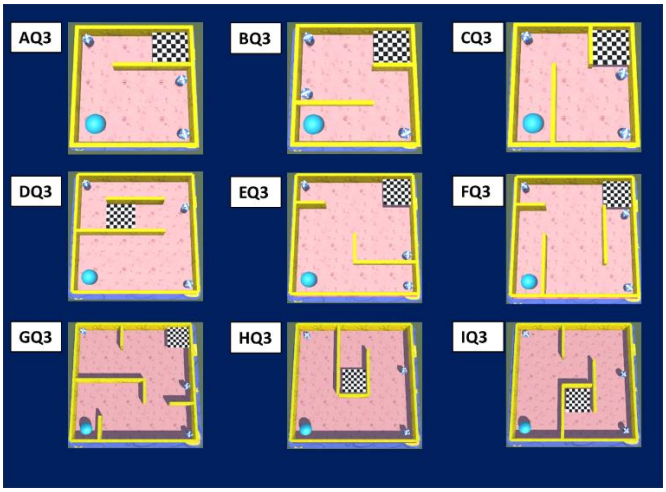

Figure 3.5.1 The 9 maze levels of COP in Quadrant 3

3.5.3 Phase 2: Experimental evaluation with participants

Once the RL model and the game were developed, the model was integrated into the SuraSole maze game for experimental evaluation with participants in a laboratory setting. The details of the procedure are as follows.

a) Preparation of participants

Participants underwent a training session to familiarize with the maze game developed to improve balance abilities. During the game, participants wore researcher-provided shoes equipped with SuraSole insoles, which were customized to fit their foot size. The game was connected via Bluetooth to the SuraSole insoles in each shoe. Participants were first trained to play the game to familiarize themselves with the game mechanics, including controlling the ball's movement and learning how to navigate through the levels. The training game is shown in Figure 3.5.2.

Figure 3.5.2 Training maze game

b) Assessment of game level for balance impairments

All participants played all levels, each designed for individuals with balance impairments, one round per level. These levels were evaluated for safety and to ensure they did not pose risks to players. Participants with normal balance were used to assess whether these levels were appropriate for individuals who may have balance limitations. In this part of the experiment, the RL model was not applied, as the participants already had normal balance. A post-game evaluation was then carried out using filled-in questionnaires. Results can be found in section 4.5.

c) Assessment of game level for normal balance

Participants were tested on levels designed for individuals with normal balance. They played five rounds in total. For each round, the Q-learning model selected the most suitable level for the player based on their COP data, measured before starting the game and again before starting a new level. This part of the experiment aimed to evaluate whether the model could accurately process players' COP status and select levels that provided appropriate challenges for each individual. A pre-and post-game COP-related measurements were evaluated. The results are presented in section 4.2-4.4.

Figure 3.5.3 illustrates the learning process of the RL model during gameplay. The process begins with measuring the player's COP to determine the current state. The measured COP data is then fed into the RL model, which evaluates and selects the most appropriate maze level for the player at that moment (Action).

After the player completes the selected level, the COP is measured again to assess how well the player can control the COP to stay near the center point. This COP data is used to calculate the reward based on the equation (B.1.1) presented in APPENDIX B. The closer the COP is to the center point, the higher the reward the player receives.

The obtained reward is then used to update the Q-value for the specific state and action using the Q-update equation (A.1.1) in APPENDIX A, enabling the model to learn how effective that particular action is for the given state.

Subsequently, a new state S' is generated from the COP measurement after gameplay, and the RL model selects a new level accordingly. This cycle repeats continuously, allowing the model to learn and improve its decision-making efficiency over time, ensuring that the level selection remains appropriate to the player's ability and progress at each stage.

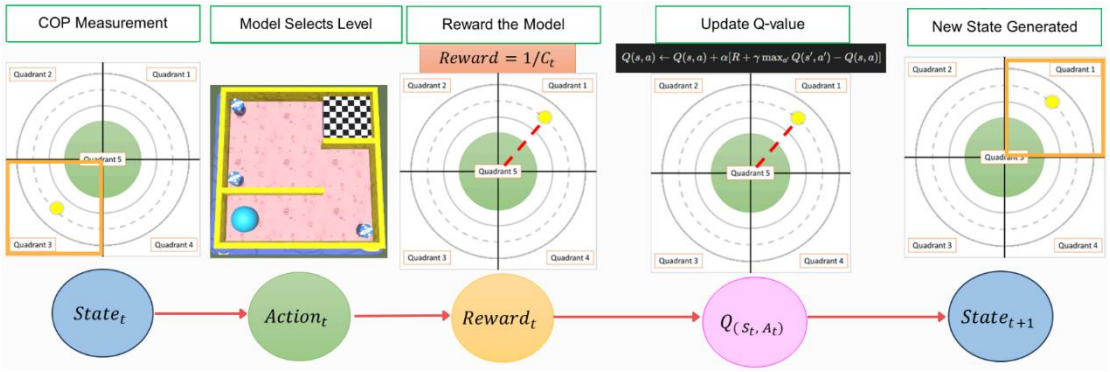

Figure 3.5.3 RL process for game level selection based on COP data

d) Evaluation of motivation for rehabilitation

After completing the designated levels, participants completed a questionnaire to assess whether these levels could enhance their motivation to engage in rehabilitation. This evaluation provided insights into whether the game could positively influence patients' behaviors and encourage participation in physical therapy. Evaluation results are given in section 4.5.

Figure 3.5.4 Game testing with participants wearing SuraSole insoles

3.6 Data analysis

a) Analysis of balance metrics

a.1 Compare the Balance score in equation (2.11) before and after gameplay to evaluate the effectiveness of the game in improving participants' balance.

a.2 Analyze RMS amplitude, RMS velocity, and COP velocity parameters in equation (2.5-2.9) to assess changes indicating improvements in balance in each direction (medio-lateral and anterior-posterior).

b) Analysis of game level adjustment through RL

b.1 Examine the Average reward in equation (A.4.1) obtained by participants in each round to evaluate whether the RL system could adjust game difficulty appropriately to match players' abilities.

c) Analysis of participants' feedback

c.1 Use a questionnaire to measure participants' levels of Satisfaction and Safety with the game.

c.2 Analyze responses to questionnaire items related to Motivation for Rehabilitation, such as enjoyment, challenge, and willingness to play again.

3.7 Summary

Chapter 3 presented the research methodology for the development and evaluation of the SuraSole maze game. This began with the development of a RL model to dynamically adjust the game's difficulty based on the COP state of the players and the design of maze levels based on recommendations from physical therapists to ensure suitability for the participants. Additionally, quantitative data collection and participant feedback were conducted to evaluate the game's effectiveness in terms of safety, improving balance ability, and motivating engagement in the rehabilitation process.